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Report on the Science-driven Evaluation of Large-scale Research Infrastructure Projects for Inclusion in an National Roadmap

Contents

Preamble

The National Roadmap Process was established in Germany as a strategic instrument for the prioritisation of future investments in terms of research policy by the federal government in the area of large-scale research infrastructures (RI). The far-reaching importance of research infrastructures to the science and research system, their growing need for resources and their increasing complexity call for strategic investment planning in this field which is significant to research, teaching, early career support and transfer. Against this background and following the successful implementation of a pilot phase in 2011–2013, the Federal Ministry of Education and Research (BMBF, *Bundesministerium für Bildung und Forschung*) asked the German Council of Science and Humanities (the Council) to conduct another science-driven evaluation, this time of twelve research infrastructure proposals.

At the beginning of 2015 the German Council of Science and Humanities established a mandated committee, 'Evaluation of Large-scale Research Infrastructures for Inclusion in a National Roadmap', which carried out the science-driven evaluation on the basis of a process trialled in the pilot phase and the lessons learnt from it. In contrast to the majority of national roadmaps for research infrastructures in other European states, the BMBF links inclusion in the roadmap with a basic funding intention. Consequently, in addition to scientific quality, economically viable planning plays an important role, with the result that all proposals are subject to an economic evaluation as well as a science-driven evaluation. On the basis of the science-driven and economic evaluations and with due consideration of the societal importance of the proposed research infrastructures, the BMBF will decide whether to include the project in the roadmap.

A large number of experts – including experts from other countries – who are not members of the German Council of Science and Humanities formed part of the committee. The Council owes them an extraordinary debt of gratitude. Special thanks are also due to the numerous reviewers who participated in the differentiated individual assessments of the projects.

This evaluation report is primarily intended for the BMBF, with concrete recommendations on the further development of the proposals also for the responsible institutions for the research infrastructure projects, the majority of which are funded jointly by the federal and state governments on the basis of Article 91 b of the Basic Law. It is also addressed to the scientific communities, research organisations and political actors at national, European and international level.

The committee approved the evaluation report on 14 June 2017 and presented it to the German Council of Science and Humanities at its meeting between 12 July 2017 and 14 July 2017.

A. The National Roadmap Process for Research Infrastructures

Following the successful implementation of a pilot phase in 2011–2013, at the beginning of 2015 the Federal Ministry of Education and Research (BMBF) launched another National Roadmap Process and asked the German Council of Science and Humanities, as a key actor, to carry out another science-driven evaluation under its own responsibility. |[1] In the section that follows, firstly the requirements relating to research infrastructures in the Roadmap Process are described and then sections A.II to A.V describe the Roadmap Process and the process of science-driven evaluation by the German Council of Science and Humanities.

A.I RESEARCH INFRASTRUCTURES WITHIN THE ROADMAP PROCESS

Research infrastructures have become indispensable in all disciplines. It is this development which, over the last 15–20 years, has given rise to the generic term 'research infrastructure', which has replaced the term 'major instrumentation'. At European level, this development has primarily been driven by the European Strategy Forum on Research Infrastructures (ESFRI). In the first ESFRI Roadmap published in 2006, research infrastructures were described as unique facilities, resources and services |[2] which enable and facilitate research

| 1 Federal Ministry of Education and Research: The National Roadmap Process for Research Infrastructures. Investing in the Future of Research. January 2016, p. 3. https://www.bmbf.de/pub/The_National_Roadmap_Process_for_Research_Infrastructures.pdf, last accessed on 09/02/2017.

| 2 ESFRI: European Roadmap for Research Infrastructures, Report 2006, Luxembourg 2006, p. 16. Similarly broad definitions of research infrastructures continue to be used today in various national and European contexts. See German Council of Science and Humanities: Report on the Science-driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase), Cologne 2013, p. 11; https://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 09/02/2017. See also Council for Scientific Information Infrastructures: Performance through Diversity 2016, A-14; ESFRI: Public Roadmap 2018 Guide, p. 6. In addition to the BMBF pilot project for the National Roadmap in Germany (BMBF (ed.): Roadmap for research infrastructures. A pilot project of the BMBF, Bonn 2013, p. 2), other examples include France (*Ministère de L'Éducation nationale, de L'Enseignement superieur et de la Re-*

by entire scientific communities in Europe. The German Council of Science and Humanities first adopted this broad ESFRI definition with regard to the natural sciences |[3] and then developed the concept considerably. Accordingly, research infrastructures provide facilities, resources and services "which are specifically established for scientific purposes and are made available on a medium-term to semi-permanent basis. Their proper establishment, operation and utilisation usually require specific, specialised scientific or interdisciplinary (methodological) competence. Their function is to enable or facilitate research, teaching and the training of early career researchers. They may be geographically fixed, distributed over multiple locations or provided exclusively in a virtual format without a defined physical location. They are not used exclusively by specific individuals or groups but, in principle, are open to the international specialist community or multiple specialist communities." |[4]

On this basis, the German Council of Science and Humanities distinguished four ideal types of research infrastructures. To take account of the interests of the humanities and cultural studies, in particular, the Council both broadened the view to include information infrastructures and defined the social research infrastructure type, which had not previously been introduced in a European context. The following ideal types are identified:

_ **Instruments** and large-scale facilities, which may be at one location or distributed across multiple locations, e. g. particle accelerators, telescopes or distributed imaging instruments;

_ **Resources** in the sense of information infrastructures, e. g. collections, archives, data surveys and collections in the social sciences (surveys and panel studies), material collections and databases;

_ **Information technology infrastructures** (e-infrastructures), e. g. high-performance computers, supercomputers or Grids and

_ **Social research infrastructures** (e. g. social encounter centres and research centres, Institutes for Advanced Studies). |[5]

cherche (ed.): *Stratégie Nationale des Infrastructures de Recherche*, 2016, p. 7), Malta (Ministry for Education and Employment (ed.): National Research and Innovation Strategy 2020, 2014, p. 19), Greece (GSRT (ed.): National Roadmap for Research Infrastructures, 2014, p. 11), Denmark (Danish Agency for Science, Technology and Innovation (ed.): Danish Roadmap for Research Infrastructures 2011).

|[3] German Council of Science and Humanities: *Stellungnahme zu zwei Großgeräten der naturwissenschaftlichen Grundlagenforschung. Freie-Elektronen-Laser für weiche Röntgenstrahlung* (BESSY FEL) *und eisbrechendes Forschungsbohrschiff* (AURORA BOREALIS), in German Council of Science and Humanities: *Empfehlungen und Stellungnahmen* 2006, vol. III, Cologne 2007, p. 89-247.

|[4] German Council of Science and Humanities: *Übergreifende Empfehlungen zu Informationsinfrastrukturen*, Cologne 2011, p. 17.

|[5] German Council of Science and Humanities: Recommendations on Research Infrastructures in Humanities and Social Sciences, in German Council of Science and Humanities: Recommendations on Research Infrastructures, Cologne 2011; see also German Council of Science and Humanities: Report on the Science-

The current Roadmap Process draws on this understanding of research infrastructures. However, in addition to the general concept of a research infrastructure, projects must also satisfy the following criteria |[6]:

_ They are significant in terms of national research policy.

_ They have a long service life – normally at least ten years.

_ Access to them is generally open and their use is regulated on the basis of scientific quality standards.

_ The costs of their establishment and construction are so high that they require substantial national and public funds and therefore justify an extensive national decision-making process. In the current Roadmap Process, the entry threshold is EUR 50 million for projects in the natural sciences and EUR 20 million for projects in the humanities and social sciences.

_ They have overarching governance adequate to the tasks they perform. Where multiple locations with complementary tasks are involved, these must form a functionally integrated research infrastructure and therefore have to be assessed as a single unit with common standards.

High-performance computers and supercomputers as a form of information technology infrastructures are not included in this process as a separate funding programme exists or is being prepared for these. |[7]

A.II ESTABLISHMENT OF THE ROADMAP PROCESS

The National Roadmap Process is a strategic instrument for the prioritisation of investments in large-scale research infrastructures, as described previously (see A.I), and builds on a pilot process which was developed and implemented between 2011 and 2013. At the request of the BMBF, the German Council of Science and Humanities designed a process for the comparative science-driven evaluation of large-scale research infrastructure projects and trialled it with nine projects. |[8] On this basis, and building on the results of a cost analysis

driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase), p. 86. http://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 16/02/2017.

|6 Federal Ministry of Education and Research: The National Roadmap Process for Research Infrastructures. Investing in the Future of Research. January 2016, p. 5. https://www.bmbf.de/pub/The_National_Roadmap_Process_for_Research_Infrastructures.pdf, last accessed on 09/02/2017.

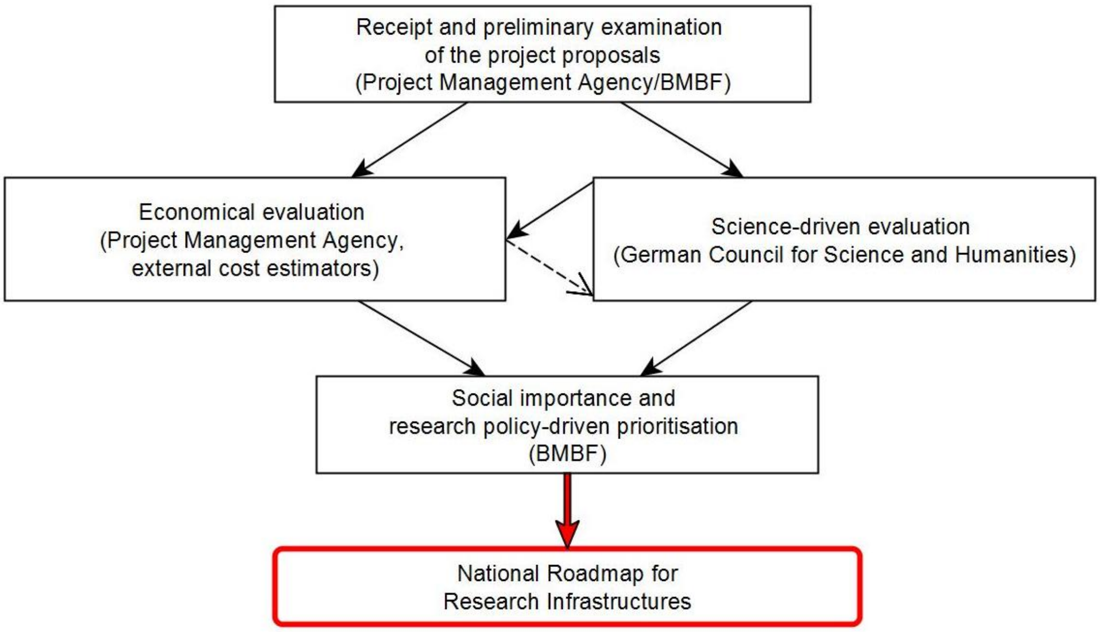
|7 German Council of Science and Humanities: *Empfehlungen zur Finanzierung des Nationalen Hoch- und Höchstleistungsrechnens in Deutschland*, Stuttgart 2015. http://www.wissenschaftsrat.de/download/archiv/4488-15.pdf, last accessed on 20/02/2017.

|8 German Council of Science and Humanities: Report on the Science-driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase). http://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 16/02/2017.

conducted in parallel, the BMBF published the first National Roadmap for Germany, thus successfully completing the pilot process in April 2013. |[9] With the commencement of the new round in 2015, the process can be considered established.

The experience gained during the pilot phase was used to further develop the current Roadmap Process. Figure 1 provides a schematic representation of the relationship between the BMBF, the German Council of Science and Humanities and the project management agency.

Figure 1: Relationship between involved parties in the National Roadmap Process



In contrast to the pilot phase, in which the BMBF asked the responsible institutions of known projects to submit a concept proposal, access to the current National Roadmap Process was given to all interested universities and non-university research institutions.

The submitted proposals were subjected to a formal initial examination by the BMBF and/or the project management agency in order to verify that the documents were complete (e. g. declaration on bearing operating costs) and a cursory technical check with reference to the BMBF's criteria pertaining to a research infrastructure (see A.I).

The committee of the German Council of Science and Humanities designed a comparative evaluation of the submitted research infrastructure proposals

|[9] Federal Ministry of Education and Research: Roadmap for research infrastructures. April 2013. https://www.bmbf.de/pub/Roadmap_Forschungsinfrastrukturen.pdf, last accessed on 16/02/2017.

based on a review by external reviewers (see A.V). In parallel to this science-driven evaluation, an economic evaluation organised by the project management agency was carried out, the core of which was an external cost estimate of the submitted proposals on the part of experts. The process has been further developed with the interlinking of these evaluation processes carried out in parallel. In the current science-driven evaluation process, one member of the committee was nominated as a rapporteur for each proposal. The rapporteurs also participated as guests in the economic evaluation, where they were able to contribute relevant input from the science-driven evaluation. Conversely, unresolved issues as well as economic and technological risks were then fed back into the science-driven evaluation process.

On the basis of the results from the evaluation processes and taking into account the societal importance of the proposed research infrastructures, the BMBF will then prioritise the proposals in terms of research policy and draw up the National Roadmap.

A.III ADMISSION INTO THE CURRENT ROADMAP PROCESS

The current round of the Roadmap Process was announced by the BMBF in August 2015. The complete documents had to be submitted by January 2016. |[10] The proposals were to be prepared in line with guidelines drawn up jointly by the BMBF and the German Council of Science and Humanities, which were published at the same time as the announcement of the Roadmap Process. |[11]

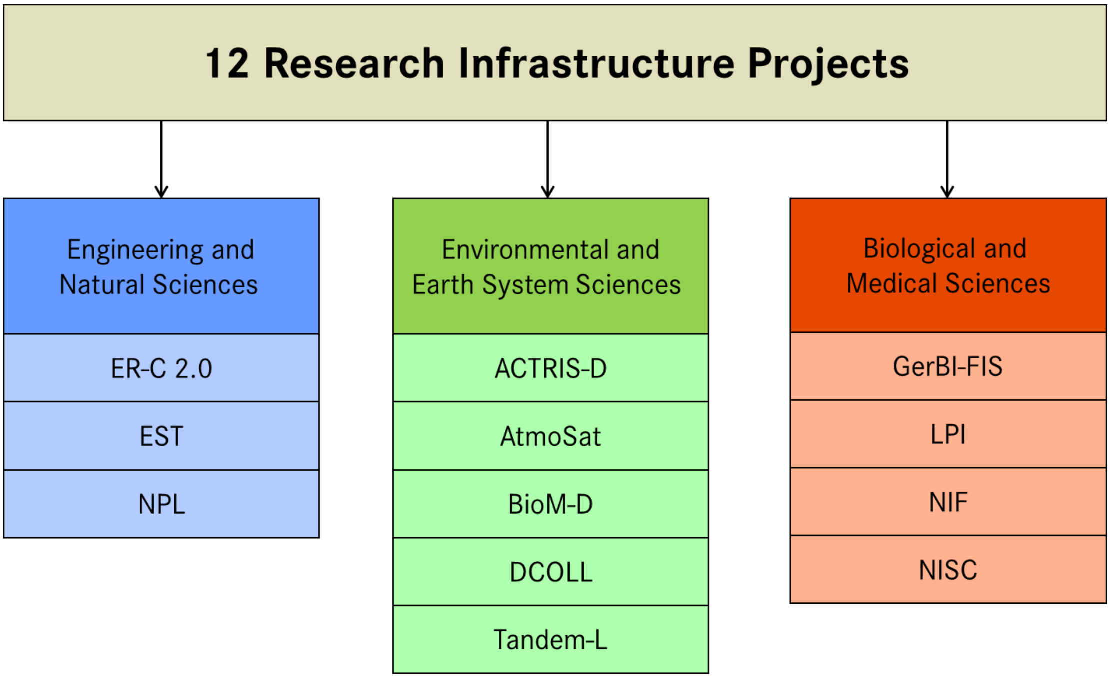
Twelve of the submitted proposals successfully passed the formal initial examination carried out by the BMBF and the project management agency, and were accepted in spring 2016 by the mandated committee of the German Council of Science and Humanities for the science-driven evaluation. The proposals were assigned to one of the following three research areas: Engineering and Natural Sciences, Environmental and Earth System Sciences, or Biological and Medical Sciences. The assignment of the submitted proposals to specified areas of research allows the research infrastructure projects to be scientifically/thematically positioned and permits the later framing of the evaluation results.

| 10 Federal Ministry of Education and Research: *Bekanntgabe*. https://www.bmbf.de/foerderungen/bekanntmachung-1088.html, last accessed on 09/02/2017.

| 11 BMBF: Guidelines for outlining proposals for the National Roadmap for Research Infrastructures, issued by the BMBF, 2015. http://www.wissenschaftsrat.de/download/archiv/FIS_Leitfaden_Veroeffentlichung.pdf, last accessed on 09/02/2017.

The diagram below provides an overview of the projects and their assignment to the research areas (see Figure 2). The projects and their positioning in the research areas are then briefly presented (see A.IV).

Figure 2: Assignment of the projects to research areas



A.IV PROPOSALS IN THE CONTEXT OF THEIR RESEARCH AREAS

The three research areas to which the proposals are assigned, each cover very large areas of science and encompass different disciplines. The delineation of the research areas was based on functional requirements in light of the proposals received, experience gained during the pilot phase of the Roadmap Process and on the basis of distinctions made in the ESFRI process. This is especially true in the case of Engineering and Natural Sciences.

IV.1 Engineering and Natural Sciences

This area of research is very heterogeneous, encompassing a wide variety of fields and disciplines, such as physics, astronomy, chemistry, biology and engineering sciences. The objects of research are equally varied, ranging from the smallest building blocks of matter to the largest structures in the universe and fundamental interactions. The research infrastructure proposals come from materials research, astrophysics and photonics.

Materials research is concerned with the structure, synthesis, processing and properties of materials. In this area there is a proposal to establish the **Ernst Ruska Centre 2.0** as the **National Research Infrastructure for Ultra-High-Resolution Electron Microscopy** (ER-C 2.0). The intention is to study structures at atomic and molecular level with the aid of next-generation electron microscopes. In addition to a focus on hard matter and material physics, the purpose of ER-C 2.0 is to enable the analysis of soft matter and its application in the life sciences.

Another project, the **European Solar Telescope** (EST), comes within the field of **astrophysics**, which is concerned with the formation, properties and evolution of the universe and its components. With its four-metre-wide aperture, the proposed telescope would be the largest solar telescope ever built in Europe. The planned investigation of interactions between plasma, magnetic field and radiation in the solar atmosphere would benefit the whole field of astrophysics, especially imaging in solar physics and plasma physics. EST has been included in the ESFRI Roadmap since 2016.

The planned **National Photonics Labs** (NPL) should provide a research and development platform for **photonics** and photonic technologies. Photonics is concerned with the creation, modulation and detection of light and its constituent particles, known as photons. NPL should study light and its applications so that this knowledge can be applied to produce new types of optical components and systems.

IV.2 Environmental and Earth System Sciences

The Environmental and Earth System Sciences encompass a wide spectrum of scientific disciplines, such as geosciences, physics, chemistry, biology, and also the social and engineering sciences that contribute to research in this area. At the core of environmental and earth systems research is the acquisition of knowledge about reciprocal processes in and between the Earth's spheres (biosphere, geosphere, atmosphere and hydrosphere) and the anthroposphere. Physical, chemical and biological topics as well as socio-economic and socio-cultural topics are equally addressed.

The five proposals to be evaluated in this research area are associated with a wide range of components in the Earth system and environmental issues. However, they can more or less be categorised as they analyse a specific Earth sphere.

The proposals **Aerosol, Clouds and Trace gases Research InfraStructure – German Contribution** (ACTRIS-D) and **AtmoSat** are aimed at the study of the Earth's atmosphere. ACTRIS-D draws on the European project ACTRIS in the ESFRI Roadmap and is designed to study the composition and interactions of atmospheric aerosols, trace gases and clouds. The planned satellite mission AtmoSat is designed to investigate the influence of chemical and physical processes in the middle atmosphere (approximately 5 to 100 km of altitude) on global and regional climates.

While these two projects focus on the atmosphere, the proposals **German Natural Science Collections Infrastructure** (DCOLL, *Deutsche Naturwissenschaftliche Sammlungen als integrierte Forschungsinfrastruktur*) and **German Center for Biodiversity Monitoring** (BioM-D, *Deutsches Zentrum für Biodiversitätsmonitoring*) are more concerned with the study of the biosphere and geosphere, and to a lesser extent the hydrosphere. DCOLL is an infrastructure for the digitisation of scientific collections and BioM-D is a biodiversity monitoring project.

Tandem-L, the fifth proposal in this area, equally addresses the study of the geosphere, hydrosphere, cryosphere and biosphere. Two satellites, equipped with Synthetic Aperture Radar (SAR) technology and synchronised orbits, are to map dynamic processes on the Earth's surface with maximum quality and resolution.

IV.3 Biological and Medical Sciences

Biological and Medical Sciences are concerned with living organisms and their structure, functions as well as relations with their environment. A wide range of scientific disciplines, such as physics, chemistry and biology contribute to this area. The focus of the research infrastructure proposals positioned in this area in the current Roadmap Process is on imaging and optical procedures in biomedicine. This involves techniques to make the structures and functions of cells, tissues and organs visible and therefore accessible for scientific study, clinical analysis and medical intervention.

In the current Roadmap Process, four research infrastructure proposals from this research area are being evaluated. The **German BioImaging Research Infrastructure** (GerBI-RI) is conceived as a distributed research infrastructure with five nodes, providing access to state-of-the-art imaging technologies at light microscopic level before these technologies become commercially available. GerBI-RI is therefore intended to serve as a national resource for research in the Biological and Medical Sciences.

The **Leibniz Center for Photonics in Infection Research** (LPI) is intended to establish a photonics centre open to a broad user base in which new methods are developed for the diagnosis, monitoring and treatment of infections. These new methods would then be developed to the clinical application stage, thus covering the complete innovation chain.

The **National Biomedical Imaging Facility** (NIF) intends to provide various diagnostic imaging techniques such as magnetic resonance imaging (MRI), positron emission tomography (PET), magnetoencephalography (MEG), electroencephalography (EEG), hybrid imaging processes (hybrid MR-PET) and multimodal, multidimensional imaging processes (MR-PET-EEG). The proposal also includes the development and construction of the first 14 Tesla (T) scanners for human application.

Another imaging research infrastructure, the **National Imaging Science Center** (NISC), will bring together microscopic technologies and macroscopic imaging modalities with other medical measuring techniques under the same roof. This will allow these complementary fields of research to be linked and thus enable new developments in medical imaging.

A.V SCIENCE-DRIVEN EVALUATION BY THE GERMAN COUNCIL OF SCIENCE AND HUMANITIES

The science-driven evaluation of the individual proposals, for which the German Council of Science and Humanities is responsible, takes place in two phases: evaluation and assessment. Both phases are oriented towards the four dimensions developed in the pilot phase |[12]:

1 – The dimension of **scientific potential** refers to the importance of the project to the development of new or existing fields of research. In the assessment of the scientific demand, projects are considered both in themselves and in relation to competing and complementary research infrastructures.

2 – In the dimension of **utilisation**, the size and origin of the user groups and the rules governing access to the proposed research infrastructure are examined. The data concept, measures for the quality assurance of utilisation as well as standards of good scientific practice in the handling of research data and publications are also appraised.

3 – The dimension of **feasibility** takes into account the technical, personnel and institutional requirements of the responsible institution (including the governance concept) and associated risks. The implementation status also plays a role.

4 – In the dimension of **relevance to Germany as a location of science and research**, the relevance of the project to Germany's role and interests as well as the impacts on the visibility and attractiveness of German research are assessed.

Three reviewers with expertise in the area of research of the respective project – mostly from other countries – are recruited for each proposal. In the first phase, expert reviewers initially prepare, independently of one another, written reviews of the research infrastructure proposals. As the process continues, the researchers responsible for preparing the proposal are given the chance to respond to open questions about the project and discuss the proposal with the

| 12 German Council of Science and Humanities: Report on the Science-driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase), p. 86. http://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 16/02/2017.

reviewers and the committee. This interactive process deepens the reviewers' understanding of the project and also that of the committee members involved in these discussions. The result of this first phase of the science-driven evaluation is joint reviews, which are drawn up by the reviewers of each proposal with the assistance of the relevant rapporteur on the basis of the individual written reviews and the discussions with the proposers. Here, too, interactive agreement in situ is essential to reaching a common assessment.

The aim of the second phase is to produce a comparative evaluation of all proposals. To this end, the committee prepares, on the basis of the joint reviews, the individual assessments, which may also contain recommendations on the further development of the proposals. These individual assessments of the proposals are published in Appendix D.

The individual assessments form the basis of the comparative evaluation (see B.I). The committee assesses the projects comparatively across all research areas and separately for each dimension. The comparative evaluation of the proposals takes place as part of a discursive process, which allows the strengths as well as the weaknesses of individual proposals in a given dimension to be clearly identified. Differences in assessment standards, which become evident in a comparison of the individual assessments across the various research areas, can be taken into account in a calibration process. The outcome of the dimension-based comparative evaluation is a table providing an overview of all assessments (see Table 1 in section B.I); it also provides the basis for the summary assessment of the proposals (see B.II to B.IV).

The comparative evaluation together with the individual assessments (see Appendix D) form the result of the science-driven evaluation process. As all proposals are subjected to a science-driven, economic and socio-political evaluation within the Roadmap Process, good performance in the science-driven evaluation is not sufficient on its own for inclusion in the National Roadmap and therefore a basic promise of funding.

B. Results of the comparative science-driven evaluation

In this section, the results of the comparative evaluation of the research infrastructure projects are firstly presented in tabular form (see B.I). By way of a compact overview, basic information and the summary assessments of the eleven proposals are then presented as an additional result of the comparative evaluation (see B.II to B.IV). Detailed descriptions of all proposals and their individual assessments – broken down into the four dimensions of evaluation – can be found in Appendix D.

B.I RESULTS OF THE DIMENSION-BASED COMPARATIVE EVALUATION

As a matter of principle, projects had to demonstrate sufficient scientific potential in order to be included in the comparative evaluation. All projects satisfied this requirement.

However, one research infrastructure project could not be included in the further comparative science-driven evaluation. The individual assessment of the BioM-D proposal revealed that, in the proposed form, the ambitious proposal involved a very large amount of research and development work and is therefore not yet sufficiently mature for the comparative evaluation. The German Council of Science and Humanities therefore recommends that the proposal should be further elaborated to allow it to be submitted again at a future date. The individual assessment (see Appendix D.II.4) contains guidance on further developing the project, with the result that the scientific potential evident so far will be more clearly elaborated in the context of the subsequently more mature technologies. Only then, an appropriate comparative evaluation can be carried out, also in order to assess, among other things, the feasibility of the proposal.

For the comparative evaluation of the remaining eleven projects, a process and an evaluation scale developed during the pilot process were used. | [13] The projects were compared in pairs in each dimension and then ranked, in order to then form ‘classes’. Each class was assigned a number of stars as a mark of its quality. The committee used a five-grade ordinal evaluation scale to allow for clear differentiation within the evaluation. The evaluation scale ranges from one star (sufficient quality) to five stars (outstanding quality). It should be emphasised that it was not necessary for the whole scope of stars (meaning the evaluation scale) to be covered within the evaluation of each dimension. The project that received the best evaluation in comparison did not therefore necessarily have five stars and the one that received the poorest evaluation one star.

Gradations in the awarding of stars mean that the projects differ and/or still have potential for improvement with respect to certain evaluated aspects within a dimension, for example access management or technical requirements and risks. Suggestions as to possible ways of improving or further developing the proposal can be found in the individual assessments of the projects (see Appendix D).

Due to the larger number of projects to be evaluated (compared to the pilot phase), the projects of one research area were first comparatively evaluated in pairs within one dimension, before the rankings were consolidated across all research areas, independently for each dimension.

Table 1 on the following page summarises the results of the comparative evaluation.

| [13] German Council of Science and Humanities: Report on the Science-driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase), p. 83–86. http://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 16/02/2017.

Table 1: Results of the dimension-based comparative evaluation

Proposal	Scientific Potential	Utilisation	Feasibility	Relevance to Germany as a location of science and research
ACTRIS-D	★★★★	★★★★	★★★★★	★★★★
AtmoSat	★★★★★	★★★★	★★★★	★★★★★
DCOLL	★★★	★★★★★	★★★★	★★★
ER-C 2.0	★★★★	★★★★	★★★★	★★★★★
EST	★★★	★★★★★	★★★★	★★★★
GerBI-RI	★★★	★★★★	★★★★★	★★★★
LPI	★★★★	★★★★	★★★★	★★★★★
NIF	★★★★★	★★★★★	★★★★	★★★★★
NISC	★★	★★★	★★★	★★★
NPL	★★★	★★★	★★★	★★★★★
Tandem-L	★★★	★★★★	★★★★	★★★★★

With regard to the overview provided in this table, one has to take into consideration, firstly, that the ranking in each dimension is ordinal, i. e. a project with four stars performed better in the evaluation than a project with three stars. The magnitude of the difference is not quantifiable. Secondly, the evaluation was independent for each dimension. A ranking based on adding up totals or calculating the average across all dimensions is therefore not permissible. For the policy prioritisation a differentiated consideration of the comparative evaluation and the individual assessment is thus required.

B.II SUMMARY ASSESSMENTS IN THE FIELD OF ENGINEERING AND NATURAL SCIENCES

II.1 Ernst Ruska-Centre 2.0 (ER-C 2.0)

II.1.a Basic information

Ernst Ruska-Centre 2.0 – National Research Infrastructure for Ultra-High-Resolution Electron Microscopy (ER-C 2.0) is a proposal for the establishment of a new national infrastructure for the ultra-high-spatial-resolution characterisation of atomic and molecular structures using next generation electron microscopes. The proposed infrastructure is based on the existing Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons (ER-C) at *Forschungszentrum Jülich* (FZJ). The aim is to expand the present ER-C into a national research infrastructure. ER-C 2.0 will offer new opportunities for characterising soft and biological materials, in addition to further developments in the existing focus of ER-C on inorganic materials.

ER-C 2.0 will be operated jointly by FZJ, RWTH Aachen University |[14] and the University of Düsseldorf on the basis of a cooperation agreement. It will also be supported by four associated partners and will be open to the addition of further partners in the future.

The implementation phase is planned for the years 2018 to 2022. The operation phase will then start in 2022 and last at least 15 years.

The investment costs amount to approx. EUR 98 million. The operating costs amount to approx. EUR 8.8 million per year, in addition to the current operating costs of ER-C. |[15]

| 14 *Rheinisch-Westfälische Technische Hochschule Aachen.*

| 15 According to the proposal, inflation has been taken into account.

Scientific Potential: ER-C 2.0 will significantly expand opportunities to analyse inorganic and biological matter by providing and interlinking next-generation ultra-high-resolution electron microscopes. With its combination of instruments, this research infrastructure will develop scientifically highly innovative capacity and is expected to enable a substantial technology leap. The expected contributions are of very high value for materials and life sciences.

Utilisation: ER-C 2.0 supports a very broad and interdisciplinary user community recruited from materials and life sciences. A high added value is expected from the joint research of these communities at the research infrastructure. User access is open and free of charge. Three quarters of the instrumental measurement time are available for external use. ER-C 2.0 presents an open data strategy that is tailored to the different user communities.

Feasibility: For the development und utilisation of electron microscopes as well as tomographic methods, ER-C 2.0 can build on the established structures and high expertise of the existing Ernst Ruska-Centre. Only the development of some components presents a technical risk. The interaction of different communities in the material and life sciences promises a high added value for the respective scientific fields. Therefore, the success of the research infrastructure depends largely on the acquisition of additional scientific expertise in the life sciences.

Relevance to Germany as a location of science and research: ER-C 2.0 will continue to significantly expand the leading position of its responsible institutions in the field of electron microscopy and will develop into a unique infrastructure that attracts researchers from around the world. With ER-C 2.0 technology development at the highest level is pursued, boosting the international visibility and attractiveness of Germany as a location of science and research.

II.2 European Solar Telescope (EST)

II.2.a Basic information

The European Solar Telescope aims at both providing insight into the generation of magnetic fields in stars and at identifying and characterising the mechanisms of their organisation into larger structures as well as their dissipation into space and the near Earth environment. With the telescope‘s aperture of 4 m, it is supposed to be able to attain high spatial and temporal resolution in combination with high sensitivity for measuring the magnetic field in the solar atmosphere. The key scientific questions include the search for the source of solar variability and the impact of solar activity on life on Earth and on modern civilization.

The development of EST is organised by the European Association for Solar Telescopes (EAST), a consortium of solar research centres in 15 European countries. |[16] The construction and operation of EST will be jointly led by Spain and Germany. The leading responsible institution in Germany is the Kiepenheuer Institute for Solar Physics in Freiburg accompanied by the Max Planck Institute for Solar System Research in Göttingen and the Leibniz Institute for Astrophysics Potsdam (AIP) as additional responsible institutions. The leading Spanish partner is the *Instituto de Astrofísica de Canarias* in Tenerife.

The telescope will be constructed at one of the two international observatory sites in the Canary Islands (*Observatorio del Roque de los Muchachos* in La Palma or *Observatorio del Teide* in Tenerife). A Telescope Operation and Science Centre (TOSC) will be established at sea level of the respective island. Furthermore a Science Data Center (SDC) will be installed in Germany providing data access and online services to the research community.

The construction of EST is foreseen to be starting at around 2019/2020, with an estimated construction phase of six years including the commissioning phase (first light). The expected scientific lifetime amounts to 30 years in total with an estimated operation phase of 25 years, followed by the decommissioning phase in about 2055.

The German share of the investment costs of EST will amount to EUR 50 million, the share for the operating costs are estimated to EUR 2 million per year. |[17]

|[16] Austria, Croatia, Czech Republic, France, Germany, Great Britain, Hungary, Italy, Netherlands, Norway, Poland, Slovakia, Spain, Sweden and Switzerland.

|[17] According to the proposal, inflation has been taken into account. With regard to the overall costs, the German share will amount to 25 %.

Scientific Potential: EST comprises a 4-metre telescope with multi-conjugated adaptive optics. The combination of these technologies permits a high spatial and temporal resolution of solar observations, which has not been accomplished yet. The research infrastructure will thus contribute significantly to the study of fundamental questions in solar physics, plasma physics and stellar astrophysics. EST is an advanced telescope development and, as such, a logical and promising continuation of existing forerunner projects, e. g. GREGOR. Together with the second equally-sized telescope on Hawaii, EST enables scientists to observe the sun over a 24 hours period.

Utilisation: Since EST will be the only and internationally competitive large telescope that is available to the entire European solar research community, one can expect a very high capacity utilisation. The access to EST as well as the allocation of the observation time are highly transparent and adequately organised for different user groups. The open data strategy is a further strength of the enterprise that also provides excellent reuse possibilities.

Feasibility: Overall, the EST proposal is very mature. There is still a technological risk with individual components, such as the heat trap. However, due to the extensive scientific and technical experiences of the responsible scientists in the consortium with former solar telescope projects, a successful implementation is to be expected.

Relevance to Germany as a location of science and research: EST is essential to safeguard the international top position of German solar physics research in the long term. Germany's leading role during the operation of EST and the combined privileged access make the institution highly attractive. The research findings will lead to a better understanding of how the sun affects the earth system. Furthermore, the intended technological developments can result in spin-off effects in numerous industrial applications.

II.3 National Photonics Labs (NPL)

II.3.a Basic information

The National Photonics Labs will be dedicated to the exploration of light and its applications as well as to the development of mission critical optical components and instruments for experiments in fundamental science, in particular for large scale scientific endeavours. Its scientific orientation is the result of an initial strategy process: The demands of various scientific communities (e. g. astronomy, extreme light, applied quantum optics or laser physics) for advanced optical components and instrumentation were mapped to different branches of photonics (e. g. optical coatings or optics design).

NPL would be the first research infrastructure to be implemented under the aegis of the Fraunhofer society. The leading responsible institution is the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF, *Institut für angewandte Optik und Feinmechanik*), Jena, with its partners, the Helmholtz Institute Jena, |[18] and the *Physikalisch-Technische Bundesanstalt* (PTB), Braunschweig/Berlin.

The implementation phase is planned for the years 2018 to 2023. The operation phase is supposed to start in 2024 and to last twelve years.

The investment costs will amount to approx. EUR 125 million. The operating costs will lie between EUR 8.0 million and EUR 9.4 million per year. |[19] They will be financed by own contributions, as well as, by the scientific community and the business sector via user fees, according to the Fraunhofer model.

The planned operator model admits NPL to build-up financial reserves to reset new investments, which address changing needs in science and technologic possibilities.

|[18] The Helmholtz Institute Jena is an outstation of the Helmholtz Centre for Heavy Ion Research GSI, Darmstadt and partner institution of the German Electron Synchrotron (DESY).

|[19] According to the proposal, inflation has been taken into account.

Scientific Potential: The main goal of NPL is to support excellent research in photonics, and at the same time to enable scientific breakthroughs in different fields of research, like gravitational wave astronomy and astrophotonics, by developing highly precise optical components. The focus on large and heavy free-form components is unique worldwide. The collaboration with relevant scientific communities is not properly established yet. Therefore it is not certain, whether the existing technological innovation potential can be exploited.

Utilisation: NPL addresses four scientific fields (gravitational wave astronomy, astrophotonics, extreme light sources, high-intensity laser systems) and therewith a potentially wide user group. NPL is still in an early planning phase with regard to interactions with future users and therefore the actual utilisation cannot be estimated yet. Especially in the field of astrophotonics, the success of NPL will be largely dependent on getting involved into the relevant international instrumentation projects.

Feasibility: The innovative approach of the project carries significant technical risks. However, a comprising risk analysis is presented. Regarding governance and project planning considerable challenges exist, i. e. in the collaboration of such diverse responsible institutions as well as the interaction with users, which are not properly addressed in the concept. The organisational embedding of NPL in the Fraunhofer Institute for Applied Optics and Precision Engineering as well as the local universities is a good foundation for the still required increase in personnel.

Relevance to Germany as a location of science and research: The primarily at the Jena site concentrated research for photonics will significantly contribute to the international visibility and attractiveness of Germany as a location of science and research. In addition, the excellent linking of science, technology development and industry will strengthen the role of Germany in photonics. With the large variety of photonics projects, NPL offers young researchers unique career development opportunities.

III.1 Aerosol, Clouds and Trace gases Research InfraStructure – German contribution (ACTRIS-D)

III.1.a Basic information

ACTRIS is a distributed European research infrastructure (RI) on the ESFRI-Roadmap, [20] which consists of central facilities (head office, data centre, calibration centres) and national facilities (simulation chambers, national observatories). ACTRIS focuses on atmospheric observations of near-surface chemical and physical aerosol properties as well as on concentrations of short-lived trace gases and vertical profiles of aerosol particles, short-lived trace gases, and clouds. Furthermore, simulation chamber studies will allow a better process understanding of atmospheric aerosols, clouds and reactive gases. ACTRIS-D will be the German contribution to ACTRIS, including a substantial upgrade of existing German ACTRIS components.

ACTRIS-D will be jointly operated based on a consortium agreement by the following institutions: Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Bremerhaven; Leibniz Institute for Tropospheric Research (TROPOS), Leipzig; Max Planck Institute for Chemistry (MPIC), Mainz; Max Planck Institute for Meteorology (MPIM), Hamburg; German Meteorological Service (DWD), Offenbach; Federal Environment Agency (UBA, *Umweltbundesamt*), Dessau-Roßlau; *Forschungszentrum Jülich* (FZJ); Karlsruhe Institute of Technology (KIT); and the Universities of Wuppertal, Frankfurt/Main, Munich, Bremen, and Cologne.

The life-time of ACTRIS-D will be eighteen years (2019–2036) and will be split in two main phases. The implementation phase will take place between 2019 and 2026 and comprises a substantial upgrade of existing German ACTRIS components. The first four years include necessary preparations and the realisation of the construction plan. The latter one focuses on the data stream (from data collection through the routine operations of the national facilities and data quality screening to their use in higher-level products). A goal of the construction plan is also to secure long-term access to high-level research platforms and to high-quality data, enhancing their use and facilitating research of a worldwide community of users. The operation phase will last for at least 10 years (2027–2036), but potentially for ca. 25 years as intended by ACTRIS on EU

[20] European Strategy Forum on Research Infrastructures (ed.): Strategy report on research infrastructures. Roadmap 2016, p.36. http://www.esfri.eu/sites/default/files/20160308_ROADMAP_single_page_LIGHT.pdf, last accessed on 03/08/2016.

level. There is no unitary closure phase. However, it is pointed out in the proposal that there might be the necessity to discharge individual components or to replace them step by step. Such individual discharges or replacements will not significantly influence the overall performance of ACTRIS-D.

The requested investment costs in the implementation phase will amount to EUR 86.5 Million. The total costs during the ten year operation phase will be approx. EUR 95.2 Million and will completely be borne by the responsible institutions. The total costs in the closure phase will also be contributed by the responsible institutions and are estimated at ca. 1.6 % of the requested funding for the development phase.

Scientific Potential: ACTRIS-D will substantially extend the investigation of atmospheric trace gases, aerosols and clouds in the troposphere and lower stratosphere, using ground-based measurements. The modularity and flexibility of the distributed infrastructure, including calibration centres and simulation chambers are worldwide unique. The long-term datasets allow analyses, which are highly relevant to understand climate processes. Moreover, the data will have a high value for studying the impact of air pollution on human health and environment.

Utilisation: ACTRIS-D offers an extensive service capacity for the large and interdisciplinary community in the area of atmospheric and climate research. Furthermore, it is expected that societal organisations and actors will greatly benefit from the data and their analyses. As a part of the European ACTRIS project, ACTRIS-D has a convincing data-concept, which includes free access to measurement data.

Feasibility: ACTRIS-D is based on existing structures on the national level and is further embedded in the European ACTRIS-Project, which provides outstanding institutional conditions and personnel. The technical risk is very low due to the fact that the envisaged instruments use already established technologies.

Relevance to Germany as a location of science and research: ACTRIS-D will essentially contribute to increase the visibility of German atmospheric research on the international level. Moreover, ACTRIS-D will boost the global attractiveness of the participating institutions for senior researchers as well as for young scientists. The data will also have a high potential for applications in other areas, e. g. in health sciences and for weather services.

III.2 AtmoSat

III.2.a Basic information

The AtmoSat infrastructure comprises an observation system (satellite and instruments) to generate unique atmospheric data and a data infrastructure to enable global freely accessible use of the measured data. AtmoSat will allow the first detailed investigation of the influence of the middle atmosphere (5-100 km) on global and regional climate and weather. The scientific goals of AtmoSat require three-dimensional, daily measurements of temperature and trace gas distributions with a high vertical resolution for the vertical range of the middle atmosphere to give a better understanding in particular of decadal climate variability and its regional patterns.

AtmoSat will be operated jointly by FZJ, Karlsruhe Institute of Technology (KIT) and Helmholtz Centre Potsdam (GFZ) on the basis of a cooperation agreement.

According to the proposal, the development and life-time of AtmoSat is planned over a period of 20 years, starting in 2018 and ending in 2037. This includes three partly overlapped phases. The implementation phase will concentrate on the development of the observation system and the data infrastructure. The data processors which transfer the raw data into higher data products will be realized between 2018 and 2022. The operation phase will take place between 2023 and 2032. The nominal observation in the first five years (2023–2027) coincides with the development of the data infrastructure. This is the period of data acquisition and processing for the user community. In parallel, a scientific data base will be build, which covers further optimized data products and additional trace gases. The closure phase, which ends with final archiving, is planned between 2032 and 2037.

The investment costs in the implementation phase will amount to EUR 110 million. The full costs in the operation and closure phases will be financed by these institutions and will amount to EUR 3.84 million.

Scientific Potential: AtmoSat will provide for the first time superior-quality data of the middle atmosphere in a hitherto impossible vertical resolution and will enable ground-breaking findings of the chemical and physical processes in the atmosphere. The newly developed device combination will supply simultaneously vertical profiles of multiple trace-gases. The produced data-sets have highest relevance for the research on fundamental dynamics of the atmosphere and global climate change.

Utilisation: Based on experiences with previous missions, the expected demand for AtmoSat data is very high. The primary addressees are scientists in the international fields of atmospheric and climate research. Moreover, governments and international organisations will benefit from the data and analyses based on them. AtmoSat has a solid plan for data management and the data products will be freely available via an online-portal.

Feasibility: With regard to the personnel and technical requirements, the participating institutions offer very good competences to realise AtmoSat. Overall, the implementation risk is low due to the fact that the used instruments already exist or the necessary developments have almost been completed. The test phase for the application of the instruments on a satellite will be starting in the near future.

Relevance to Germany as a location of science and research: The unique AtmoSat data-sets will be highly visible worldwide and will substantially strengthen the role of Germany in climate and atmospheric sciences. This applies with regard to Earth observation, data assimilation, and modelling. On the whole, a vast attractiveness is expected for both, senior and early-career scientists all over the world. With its focus on urgent questions in climate research, AtmoSat will also substantially strengthen the future oriented environmental policy strategy in Germany.

III.3 German Natural Science Collections Infrastructure (DCOLL)

III.3.a Basic information

The "German National Science Collections Infrastructure (DCOLL)" aims to unlock the potential of Germany's research museums, university collections, and other collection based institutions by building a consortium between the seven largest natural history collections of the Leibniz Association and certain federal states. The DCOLL members' collections encompass more than 120 million samples and voucher specimens. According to DCOLL this represents 75 % of the national collection inventory. The goal of this joint infrastructure is to coordinate the preservation and extension of natural history collections and to undertake large-scale digitisation of collections in order to enable broad and fast access to specimen information, and thereby improve and increase collection utilisation and research for various user groups, applications and disciplines.

The proposed research infrastructure will be decentralized, nationally coordinated, and internationally cross-linked. It is planned in nine technically-methodically oriented, temporally largely parallel modules/project strings. The leading responsible institution is the *Museum für Naturkunde* - Leibniz Institute for Evolution and Biodiversity Science (MfN), Berlin, along with a consortium of six cooperating institutions: Senckenberg Nature Research Society (SGN), Frankfurt/Main; Zoological Research Museum Alexander Koenig - Leibniz Institute for Animal Biodiversity (ZFMK), Bonn; Leibniz Institute – German Collections of Microorganisms and Cell Cultures (DSMZ), Braunschweig; Botanic Garden and Botanical Museum Berlin-Dahlem (BGBM), Free University of Berlin; Bavarian Natural History Collections (SNSB), Munich; and Stuttgart State Museum of Natural History (SMNS).

After a construction period of eight years for setting up all infrastructure required for DCOLL, the open ended utilization phase is supposed to begin in 2027. |[21] Investment costs without own contributions are estimated to a total of EUR 370 million. The annual operating costs are estimated to lie between EUR 0.87 million and EUR 16.6 million, |[22] supposed to be fully financed by the consortium member institutions.

|[21] For one part of the infrastructure, the research vessel, utilization will already begin in 2025.

|[22] The median (2025–2031) amounts to EUR 12.3 million per year.

Scientific Potential: DCOLL will significantly enlarge collection-based research by digitising natural history science specimens on a large scale. The core mission of the research infrastructure is the digitisation, acquisition and supply of complex and large data-sets as well as the establishment of international standards. As a service and information infrastructure, DCOLL is highly relevant for and innovative in the area of biodiversity research. Additional collection efforts, including infrastructures that are necessary for that purpose, are the primary task of the participating institutions.

Utilisation: The utilisation potential of DCOLL is outstanding. The research infrastructure addresses a large national and international scientific community of various disciplines as well as amateurs, educational institutions, political actors and government agencies. The data will be made available for a broad user group via an online-portal and will be free of charge. DCOLL has an excellent strategy for the production, long-term storage, and supply of data.

Feasibility: Since DCOLL utilises technologies that already exist, the risk is very low. The institutional integration of the project is very tight. It will be challenging, however, to find enough qualified personnel with expertise in digitisation and genomics, which is necessary to successfully implement DCOLL.

Relevance to Germany as a location of science and research: Providing a digital service and information infrastructure and connecting the involved natural history museums and biodiversity research institutions in Germany will have an enormous scientific and societal impact and increase the international visibility of the participating scientific institutions. This should have a very positive effect on international collaborations and will set standards for collection-based research – throughout Europe and worldwide. This is not the case, however, for the planned collection activities and the corresponding infrastructures.

III.4 Tandem-L (TDL)

III.4.a Basic information

Tandem-L is a research infrastructure, which will comprise two L-band SAR satellites, [23] an associated ground segment and a dedicated science and user segment. According to the proposal, Tandem-L will interferometrically image the entire landmass of the Earth up to twice weekly with unique quality and resolution. Central goals are to measure the global forest biomass and struc-

[23] The L band is defined as the 1-2 GHz range of the radio spectrum.

ture, and the variations of the near surface soil moisture, to monitor deformations of the Earth's surface systematically on a millimetre scale, to quantify glacier motion and melting processes in the polar regions, and to observe the dynamics of ocean surfaces and ice drift.

Tandem-L will be operated jointly by German Aerospace Center (DLR, *Deutsches Zentrum für Luft- und Raumfahrt*), Oberpfaffenhofen; AWI Bremerhaven, FZJ, Helmholtz Centre for Ocean Research (GEOMAR), Kiel, German Research Centre for Geosciences (GFZ), Potsdam, Helmholtz Centre Munich – German Research Centre for Environmental Health, and Helmholtz Centre for Environmental Research (UFZ), Leipzig, on the basis of a cooperation agreement.

The life-time of Tandem-L will be 16 to 18 years and includes an implementation and an operation phase. The implementation phase comprises the development of the satellites, the associated ground segment as well as of the dedicated science and user segment. It will take place between 2017 and 2025. This phase overlaps with the first part of the operation phase. This is the so-called basic operation phase E2 |[24]. E2 starts after the launch of the two satellites (planned for late 2022) and subsequent six-month commissioning phase E1 |[25] and lasts until 2025. During E2, the system delivers calibrated SAR image products and operationally provides them to the users. In parallel, the RI will be further developed to prepare Tandem-L for the extended operation phase E3, starting in 2026 and comprising the full production of higher-level information products.

The investment costs in the implementation phase will be approx. EUR 665 million. The costs in the operation phase will be borne by the participating institutes and will amount to approx. EUR 13.5 million per year during the basic operation. According to the business plan of the proposal, the operation costs can increase up to approx. EUR 30.8 million per year during the extended operation phase. The costs in the closure phase will amount to EUR 0.47 million for the controlled deorbiting of the two Tandem-L satellites.

| 24 First operational phase.

| 25 Commissioning phase.

Scientific Potential: Tandem-L provides unique high-resolution recordings of the Earth's surface in short intervals. The measurements in the geo-, bio-, cryo-, and hydrosphere contribute significantly to the investigation of the earth system and global change. The project is in particular innovative for measurements of the land biomass, as well as of the elevations of the land and ice surface. In addition, Tandem-L will contribute to other areas of the geosciences, e. g. soil moisture, permafrost, and ocean circulation.

Utilisation: Tandem-L addresses the entire interdisciplinary community of the geo- and biological sciences. A full utilisation of the instruments and data is expected. The concept includes a convincing data strategy including data storage and utilisation. The generated data will be freely available for scientific purposes via an online-portal.

Feasibility: The participating institutions have a long track record concerning challenging space missions. A careful risk analysis has been conducted and a substantial test-phase for the satellite-mission has been completed successfully. It can be expected that the challenges related to the development and application of novel technologies, as well as to the processing of high data volume, will be mastered.

Relevance to Germany as a location of science and research: Tandem-L will broaden the appeal of Germany as a place of scientific excellence. Furthermore, as a technological and innovative Earth observation platform it could attract scientists from a broad range of disciplines. The geoscientific data are highly relevant to the study of environmental change and hazards, i. e. volcanoes, or earthquakes. Moreover, the data are useful for applications to important societal issues, e. g. urban planning and land use and change.

B.IV SUMMARY ASSESSMENTS IN THE FIELD OF BIOLOGICAL AND MEDICAL SCIENCES

IV.1 German BioImaging Research Infrastructure (GerBI-RI)

IV.1.a Basic information

The German BioImaging Research Infrastructure (GerBI-RI) aims to be a new, distributed research infrastructure for biological imaging. It builds on German BioImaging [26], the national network for microscopy and image analysis funded by the German Research Council (DFG, *Deutsche Forschungsgemeinschaft*). The

[26] www.germanbioimaging.org.

fundamental idea of the RI is to bring together excellent developers of instrumentation and methods of biological imaging technologies with application-oriented scientists from the Biological and Medical Sciences and grant the latter access to unique equipment and expertise.

GerBI-RI will consist of five imaging nodes, a virtual software node and a central coordinating structure, the hub. The imaging nodes are supposed to provide access to the most advanced, experimental microscopes well before they become commercially available. By these means the RI will enable projects that otherwise would not be possible or would happen at a much later stage, the virtual node develops software tools for managing, processing and analysing the acquired extensive image data; the hub coordinates user access and the nodes' activities, ensures data storage, is responsible for the training of GerBI-RI users and staff in the newly planned Training and Technology transfer Center (TTC), and supports the transfer of knowledge and technology to the wider public and corporate business.

The leading responsible institution, operating the hub, will be the University of Konstanz.

The five imaging nodes will be formed by local alliances of several institutions. At each site researchers and developers of advanced imaging technologies will closely collaborate with local Advanced Light Microscopy – Core Facilities (ALM-CFs) and their users.

_ Berlin/Magdeburg (Max Delbrück Center for Molecular Medicine Berlin, Charité University Medicine Berlin, German Rheumatism Research Center Berlin, Technical University of Berlin, Leibniz Institute for Molecular Pharmacology Berlin, Zuse Institute Berlin, Leibniz Institute for Neurobiology Magdeburg): intravital / in vivo microscopy, functional imaging

_ Bonn (German Center for Neurodegenerative Diseases Bonn, Center of Advanced European Studies and Research caesar Bonn, University of Bonn): single molecule microscopy, brain imaging and behaviour

_ Dresden (Max-Planck Institute of Molecular Cell Biology and Genetics Dresden, Technical University of Dresden/BIOTEC |[27]): light sheet microscopy, imaging biophysics

_ Freiburg (University of Freiburg, Max Planck Institute of Immunobiology and Epigenetics Freiburg): photonic force microscopy, fast label-free imaging

| [27] Biotechnology Center TU Dresden.

_ Heidelberg (EMBL/ALMF [28] Heidelberg, Max Planck Institute for Medical Research, University of Heidelberg): superresolution microscopy, high-throughput advanced light microscopy

Furthermore, the nodes Berlin/Magdeburg and Heidelberg as well as the nodes Dresden and Freiburg will join forces in developing and offering across-scales correlative microscopy and intelligent automated microscopy, respectively.

Within the virtual node, scientists of the various GerBI-RI sites work together in developing new algorithms and software tools that are made available to the entire scientific community.

The structural, technical, and personnel capacities will be created during the implementation phase, which is planned to last for a period of five years and is divided into a set-up and a pilot phase. During the pilot phase, users are granted limited access to the newly developed instruments. The virtual node will keep developing algorithms for image data analysis throughout the whole process.

The investment costs will amount to EUR 96.9 million. [29] The operation phase is supposed to start in 2024 and GerBI-RI will be set up for an unlimited period of time. The operating costs, which will be fully financed by the responsible institutions, will amount to EUR 12.8 million per year. [30]

[28] European Molecular Biology Laboratory / Advanced Light Microscopy Facility.

[29] Without own contributions. According to the proposal, inflation has been taken into account.

[30] According to the proposal, inflation has been taken into account.

Scientific Potential: GerBI-RI promotes the development of new microscopy and imaging techniques and allows their widespread use before they are commercially available. Basis is the close collaboration of instrumentation and method developers with scientists from the life sciences. This collaboration is highly relevant to drive scientific progress in the life sciences and medicine as well as to promote technological innovation.

Utilisation: For the distributed research infrastructure a large user group from different fields of the biosciences and medicine as well as industry is expected. Service and access management are very well designed. A particular strength of the convincing data concept is a user-friendly online portal to analyse the acquired image data. It will be decisive for the success of the research infrastructure to keep user fees as low as possible and to support the scientific user groups in fund-raising.

Feasibility: The implementation of technologies at the planned research infrastructure carries a low risk, since all involved institutes have the necessary instruments, long-term experience in the development and application of new microscopy and imaging techniques as well as qualified personnel. The proven plan for governance is eminently suitable for the demands of a distributed infrastructure.

Relevance to Germany as a location of science and research: GerBI-RI will increase the visibility as well as competitiveness of Germany in the bio-imaging field and will enable the participation of Germany in the European research infrastructure Euro-BioImaging. By providing the access to the newest imaging methods, GerBI-RI increases the attractiveness of Germany as a location of research and science, especially for young scientists. In addition, GerBI-RI will push the industrial development in bioimaging by a rapid commercialization of new technologies.

IV.2 Leibniz Center for Photonics in Infection Research (LPI)

IV.2.a Basic information

The Leibniz Center for Photonics in Infection Research (LPI) aims at establishing a user-oriented open centre for photonics and optics for the development of fundamentally new solutions for the diagnosis, monitoring and experimental treatment of infections as well as at transferring these solutions into routine applications. According to the proposal, LPI's central approach is the pursuit of innovative photonics-based diagnostic and treatment methods to tackle infectious diseases. The applicant intends to implement novel diagnostic technology and treatment approaches along the entire innovation pipeline from the idea to the validated method in a single research infrastructure.

LPI will combine a wide range of photonic technologies, including new and globally-unique light-based methods, with methods borrowed from molecular biology and enabling technologies (e. g. microfluidics) in order to use these methods directly in multi-centre clinical applications. The researched and prototyped diagnostic and treatment approaches will then be clinically validated in established study platforms of the applicant and using flying study nurses integrating in the value chain. The LPI concept intends to offer an efficient translational approach to converge the potential photonic technologies with routine clinical processes. Therefore LPI will set up three research platforms: a spectroscopic and imaging platform, a diagnostic services pipeline and a therapeutic services pipeline.

LPI is based on the competencies of Jena University Hospital (JUH), University of Jena, the Leibniz Institute of Photonic Technology (IPHT e. V.) and the Leibniz Institute for Natural Product Research and Infection Biology, Hans Knöll Institute (HKI), which are all located in Jena.

The timeframe of LPI's introduction and implementation is planned in three stages: the preliminary phase from 2016 to 2018, the implementation phase from 2019 to 2023 and the operation phase from 2024 to 2033. The investment costs will amount to EUR 154 million |[31]. In the preliminary phase, the participating institutions provide personnel, such as experts for the development of LPI, and take over accumulated material costs. For the implementation phase, financing is primarily planned through LPI's own research infrastructure projects as well as third party-funded projects. During the operation phase the annual costs will vary between from EUR 9.3 million and EUR 11.6 million per year |[32].

| 31 Not including own contributions.

| 32 According to the proposal, inflation has been taken into account.

Scientific Potential: Due to the combination of photonic methods and infection research, LPI is of high strategic relevance to the precise and rapid diagnosis as well as targeted therapy of infectious diseases. The focus on photonic techniques in clinical application is unique. In addition, the intended further development of this technology is altogether very convincing, and it is likely that it will also be applied to the diagnosis of other diseases.

Utilisation: With its interdisciplinary approach LPI addresses a broad scientific user group. In addition to the realisation of internal initiatives, 'technology scouts' will monitor external developments in photonics and infection research and thereby acquire potentially interesting approaches and new users. Furthermore, there is a high interest on the part of industry. The access to the RI is open and will be regulated via a peer review process.

Feasibility: The successful use of photonic methods in infection research has, in principle, been proved. The implementation plan and the risk management concept are very convincing. The personnel and institutional requirements that are essential for a successful realisation of LPI are provided by the participating institutions.

Relevance to Germany as a location of science and research: LPI brings together highly renowned research institutions in the areas of photonics and infectiology in Jena. This will significantly increase the national and international visibility and appeal of the scientific location, in particular for young scientists. Due to its promise for clinical application, the transfer potential of LPI is high. This promises a strong economic impact for Germany.

IV.3 National Biomedical Imaging Facility (NIF)

IV.3.a Basic information

The National Biomedical Imaging Facility (NIF) aims to establish an open facility for research in, and application of, biomedical imaging with initial locations at the *Forschungszentrum Jülich* (FZJ) and the German Cancer Research Center (DKFZ, *Deutsches Krebsforschungszentrum*) in Heidelberg. The two founding Helmholtz partners will create the NIF infrastructure to advance basic research as well as technology development and clinical applications. For the implementation of NIF, new instruments will be purchased and installed. It is pointed out by the applicants that the equipment, its housing, the required staff, and the need to keep the infrastructure up-to-date represent significant expenses which cannot be borne by a single university or research centre. For this reason, a concerted, national effort is said to be needed. NIF will provide access to important diagnostic imaging technologies such as MRI, PET, MEG, EEG, hybrid MR-PET and multimodal, multi-dimensional imaging (MR-PET-EEG). NIF will facilitate the in vivo investigation of the entire body by focusing on technology and methodology for whole-body exams at extremely high magnetic fields. In the current stage, 14 T human MRI is targeted; the long-term aim of NIF is a 20 T human MRI.

The leading institutions FZJ and DKFZ are responsible for the development of the infrastructure and the data infrastructure as well as for the implementation phase and the operation phase. The operation phase will last ten years from 2018 to 2027. Starting in 2018 NIF will provide access to already established large-scale equipment such as the 9.4 T MR-PET hybrid scanner at FZJ and the 7 T MRI scanner at the DKFZ. According to the current planning status, the implementation phase also starts in 2018 and is supposed to be completed after circa five years. The total investment costs amount to approx. EUR 243 million of which EUR 130.7 million are allotted to the DKFZ and EUR 112.4 million to the FZJ. The operating costs will amount to approx. EUR 116.2 million for the complete operation phase; |[33] EUR 42.2 million will be borne by the DKFZ and EUR 74.1 million by the FZJ. |[34]

|[33] The annual operating costs lie between EUR 847 thousand (2018) and EUR 21.1 million (2027). The operational costs increase incrementally due to the successive commissioning of the large-scale equipment.

|[34] According to the proposal, inflation has been taken into account.

Scientific Potential: As NIF combines multimodal imaging technologies and develops a 14 T full-body MRI system, its scientific potential is outstanding. By doing so, NIF establishes a worldwide unique research infrastructure where ground-breaking advances can be achieved through a multimodal, highest-resolution characterisation of structures, functions and metabolic processes. A breakthrough in the diagnostics of cancer and nervous system diseases can be expected.

Utilisation: NIF addresses the documented needs of a large user group of various disciplines in both biomedical basic science and clinical research. The access to the research infrastructure is open, free and exclusively guided by criteria of scientific excellence. The data management concept and the application of discipline-specific standards are exemplary. The proposed quality assurance systems are adequate and functional.

Feasibility: The participating institutions are outstandingly qualified in the area of imaging technologies and have extensive experience with the organisation and operation of research infrastructures. With exception of the 14 T MRI, the individual imaging technologies are established. The novel combination of these technologies and the development of the 14 T MRI – especially for use on humans – are innovative and challenging at the same time. Although the development of the 14 T MRI for human application is high-risk, the respective risk management plan is convincing.

Relevance to Germany as a location of science and research: The technology development of NIF is of highest interest to science and industry. An additional major strength of the research infrastructure is its translational potential into clinical medicine. The implementation of NIF will help Germany become one of the most attractive locations for biomedical imaging worldwide. Scientists from all over the world will benefit from the research infrastructure and its training programmes. This is especially true for young academics.

IV.4 National Imaging Science Center (NISC)

IV.4.a Basic information

The National Imaging Science Center (NISC) aims to integrate processes for multi-parametric and multiscalar microscopic and macroscopic imaging with molecular multi-omics technologies in all essential areas, yielding complementary information with different time and spatial scales. According to the proposal, NISC will unite experts from different fields of imaging sciences and major adjacent disciplines, such as omics, pathology, pharmacy, bioinformatics and systems biology, establishing an interdisciplinary and comprehensive high-level RI under one roof at the University Campus Tübingen, Germany.

The leading responsible institutions will be the Universities of Tübingen and Stuttgart. The Max Planck Institutes for Developmental Biology, Biological Cybernetics and Intelligent Systems are named as close collaborating partners.

The spatial, technical, and personnel capacities will be created during the implementation phase, which is planned to last for a period of four and a half years.

The investment costs will amount to EUR 132.7 million. [35] The operation phase is planned to start in 2022, when all staff has moved into the new building. NISC will be set up for an unlimited period of time. The operating costs, which will be fully financed by the responsible institutions, will amount to EUR 7.65 million per year.

[35] Without own contributions. According to the proposal, inflation has been taken into account.

Scientific Potential: The scientific potential of NISC is high, due to the linkage of macro- and microscopic imaging techniques with information provided by other measurement techniques. The core objective and the scientific questions, however, are insufficiently specified. While the support of local research groups and the integration of industrial partners are convincing, further national and international scientific communities are not yet sufficiently considered.

Utilisation: There is a large potential user group in the area of biomedical basic science and clinical research. Access to NISC is open and the required management is appropriate. The needed training structures and services for external users, however, are inadequately described. Overall, the data concept is reasonably developed, but concerning data stewardship and the integration in other European data bases (e. g. BBMRI, EATRIS, ELIXIR) improvements could be made.

Feasibility: The technological risk of NISC is low, since established technologies will be combined and extended. The successful integration of macro- and microscopic methods with the omics-technologies is, however, a challenge. The research infrastructure is based on existing structures, and is very well integrated in the responsible institutions, both on the institutional as well as on the strategical level. The governance concept is adequate. The plans for personnel recruitment and training of young researchers are, however, not sufficiently developed.

Relevance to Germany as a location of science and research: In the area of PET-MRI-research, NISC can help Germany to gain a leading position worldwide. The research infrastructure can essentially contribute to the international visibility of bioimaging research in Germany and can develop a high attractiveness for young scientists. The high innovation potential of NISC cannot be fully exploited, however, since the interdisciplinary cross-linkage to research areas outside of biomedicine and the integration of other national and international infrastructures related to bioinformatics, biomarker-development, and data analysis, is not adequately pursued.

C. Conclusion and outlook

The publication of the BMBF's first National Roadmap for research infrastructures in 2013 signalled the successful completion of a pilot project in which a process was developed for the prioritisation of research infrastructures across all research areas. This has already given visibility to the German position in a European and international context. In August 2015, the BMBF launched the current Roadmap Process and thus established the process as a strategic instrument for research policy decision-making on future investments. At the same time, the process was modified and further developed on the basis of lessons learnt in the pilot phase. For example, access was offered for the first time through a public announcement, and the science-driven evaluation was more closely interlinked with the economic evaluation. With the raising of the threshold value for investment costs from EUR 15 million (total investment costs) to EUR 50 million (German share) or EUR 20 million for projects in the humanities and social sciences, the focus of the National Roadmap was concentrated on 'large-scale' research infrastructures.

The planned investment costs (German share) of the twelve evaluated proposals are between EUR 50 million and EUR 665 million. In total, the twelve evaluated proposals in the current Roadmap Process amount to a planned investment volume of more than EUR 2 billion. |[36] In addition, there are operating and personnel costs, which make up a substantial proportion of the overall costs of a research infrastructure throughout its life-cycle.

Due to their high demand for resources, their increasing organisational complexity, growing importance to science and research capabilities, and due to the fact that each decision creates long-term path decencies, it is necessary to prepare decisions on the establishment and operation of research infrastructures systematically. Decisions of such importance should not be made on a 'first come, first served' basis or according to random factors such as good lobbying or a public mood. The Council therefore expressly welcomes a continuation of the National Roadmap Process on a permanent basis. The science-driven

| 36 The information given here about investment volumes of individual projects and thus total investments are as provided by the proposers and have not been verified.

evaluation of research infrastructure proposals as the central element of the National Roadmap Process makes an important contribution to gaining an overall view of developmental trends in the field of research infrastructures. At the same time, the resource deployment can be optimised with a view to creating a high-performance research system and the risk of possible bad investments can be reduced.

The National Roadmap Process is embedded in science policy developments at national and European level, which are outlined below (see C.I). This is followed by an initial reflection on the process, in which experiences from the completed evaluation process are summed up and issues for further development are identified (see C.II).

C.I SCIENCE POLICY CONTEXT

Since the publication of the first National Roadmap in 2013, a series of activities and initiatives has been launched at national and European level, reflecting the growing importance of research infrastructures to the research system. In part, these address aspects which were already identified as challenges following the pilot phase and are associated with the establishment and operation of research infrastructures. This includes not only the funding of a research infrastructure throughout its entire life cycle and governance, but, importantly, also data management. |[37]

I.1 National developments

In 2011 the Helmholtz Association had already systematically surveyed its need for research infrastructures and published a first roadmap. |[38] The Helmholtz Roadmap, continued in 2015, lists the most important research infrastructure projects of the Helmholtz Association which are relevant to the strategic implementation of its science portfolio in the coming years. |[39] Two projects from the Helmholtz Roadmap – AtmoSat and Tandem-L – were included in the science-driven evaluation of the National Roadmap Process.

In 2013 the Leibniz Association also initiated an in-depth discussion process on research infrastructures and undertook an internal prioritisation of research

| 37 German Council of Science and Humanities: Report on the Science-driven Evaluation of Large Research Infrastructure Projects for the National Roadmap (Pilot Phase) (printed matter 2841-13), Cologne 2013: https://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 12/04/2017.

| 38 Helmholtz Association (HGF) (ed.): Helmholtz Roadmap for Research Infrastructures, as of 2011, Bonn 2011, p. 4.

| 39 Helmholtz Association (HGF) (ed.): Helmholtz Roadmap for Research Infrastructures II, Bonn 2015, p. 5; https://www.helmholtz.de/fileadmin/user_upload/publikationen/Helmholtz_Roadmap_2015_web_korr_150921.pdf, last accessed on 10/05/2017.

infrastructures with a time-scale of 10–15 years. |[40] As a result of this prioritisation process, the Leibniz Association published its first roadmap for research infrastructures in 2016. Five of the research infrastructure projects listed – ACTRIS-D, BioM-D, DCOLL, EST and LPI – were also included in the science-driven evaluation in the National Roadmap Process. |[41]

A body which is specifically concerned with the creation of sustainable information infrastructures is the Council for Scientific Information Infrastructures (RfII, *Rat für Informationsinfrastrukturen*), which was appointed in November 2014 on the recommendation of the German Council of Science and Humanities |[42] by the Joint Science Conference (GWK, *Gemeinsame Wissenschaftskonferenz*) as part of the federal government's Digital Agenda. In its policy paper "Performance through Diversity", published in 2016, the RfII recommends the establishment of a National Research Data Infrastructure (NFDI, *Nationale Forschungsdateninfrastruktur*) as a "future new backbone for research data management in Germany". |[43]

As a networked and distributed infrastructure, the NFDI is intended to overcome the high fragmentation, harmonise standards and methods, and ensure long-term data availability. The NFDI also ought to be linkable to international projects, such as the widely discussed European Open Science Cloud, other initiatives like developed in PRACE (Partnership for Advanced Computing in Europe) |[44] and concepts as discussed in the Research Data Alliance (RDA) |[45]. A working group within the Priority Initiative "Digital Information" of the Alliance of Science Organisations in Germany is also developing guidelines on research data management as well as the reuse and availability of research data. |[46]

In medical research there is a particular need for coordination in the development of research infrastructures with high data management requirements. |[47] Medical research infrastructures include not only major instrumen-

|[40] Leibniz Association (ed.): *Forschungsinfrastrukturen in der Leibniz-Gemeinschaft*. Research Infrastructures in the Leibniz Association, Berlin 2015; Leibniz Association (ed.): *Forschungsinfrastrukturen im Wissenschaftssystem*, Berlin 2015.

|[41] https://www.leibniz-gemeinschaft.de/infrastrukturen/leibniz-roadmap-forschungsinfrastrukturen, last accessed on 12/04/2017.

|[42] German Council of Science and Humanities: *Empfehlungen zur Weiterentwicklung der wissenschaftlichen Informationsinfrastrukturen in Deutschland bis 2020* (printed matter 2359-12), Berlin 2012.

|[43] RfII – Council for Scientific Information Infrastructures: Performance through Diversity. Recommendations regarding structures, processes, and financing for research data management in Germany, Göttingen 2016, p. 2.

|[44] For more information see http://www.prace-ri.eu, last accessed on 08/05/2017.

|[45] For more information see https://www.rd-alliance.org, last accessed on 08/05/2017.

|[46] http://www.allianzinitiative.de/en/, last accessed on 12/04/2017.

|[47] German Council of Science and Humanities: *Perspektiven der Universitätsmedizin* (printed matter. 5663-16), Weimar 2016, p. 35.

tation but also, above all, near-to-patient, networked and integrated data and specimen collections such as biobanks and data management systems for epidemiological longitudinal studies. |[48] The *Forum Gesundheitsforschung* (Health Research Forum) |[49], established within the BMBF in November 2015, is currently drawing up proposals for i. a. the coordinated further development of research infrastructures in the life sciences.

The growing importance of research infrastructures to the advancement of knowledge in a wide range of scientific disciplines results in specific systemic challenges. This was made especially clear in the contributions to a hearing of the Committee on Education, Research and Technology Assessment of the German *Bundestag* on the funding of research infrastructures in June 2016, as well as the recently published statement of the Alliance of Science Organisations in Germany on research infrastructure excellence and sustainable funding throughout the life cycle of an infrastructure. |[50]

I.2 European developments

In the European Research Area (ERA) and the Innovation Union, research infrastructures play an essential role in the generation of new knowledge and technologies and their utilisation. |[51] Over 15 years ago, the European Strategy Forum on Research Infrastructures (ESFRI) began a coordination process at European level with the aim of prioritising research infrastructure projects from a scientific perspective. In 2016 the third update of the ESFRI Roadmap was published. For the first time, this involved the evaluation of projects which were included in the first ESFRI Roadmap ten years previously in 2006. Projects which showed significant successes in implementation after this period were identified in the new Roadmap 2016 as Landmarks. |[52] The publication of the next ESFRI Roadmap is scheduled for 2018. |[53]

|[48] Committee on Education, Research and Technology Assessment: *Ausschussdrucksache* 18(18)232c, Unsolicited statement from Deutsche Hochschulmedizin e. V., Berlin. https://www.bundestag.de/blob/428766/13d0693334faba8c7d858fa52192cb18/hochschulmedizin_unangef-stellungnahme-data.pdf, last accessed on 12/04/2017.

|[49] http://www.gesundheitsforschung-bmbf.de/de/forum.php, last accessed on 12/04/2017.

|[50] https://www.bundestag.de/ausschuesse18/a18/fg-foerderung-fis/428316, last accessed on 12/04/2017; see Alliance of Science Organisations in Germany: *Exzellente Wissenschaft braucht exzellente Forschungsinfrastrukturen*, N.p. 2017. https://www.wissenschaftsrat.de/download/archiv/Allianz_Stellungnahme_FIS.pdf, last accessed on 12/04/2017.

|[51] http://www.eubuero.de/infra.htm, last accessed on 09/05/2017.

|[52] On the definition of projects and Landmarks: see: ESFRI (ed.): Strategy Report on Research Infrastructures. Roadmap 2016, Brussels 2016, p. 13.

|[53] European Strategy Forum on Research Infrastructures (ESFRI): PUBLIC ROADMAP 2018 GUIDE, Final version dated 9th December 2016. http://www.esfri.eu/sites/default/files/u4/ESFRI_Roadmap_2018_Public_Guide_f_0.pdf, last accessed on 12/04/2017.

The Research Framework Programme **Horizon 2020** launched in 2014 envisages funding measures for

_ the development of new research infrastructures, particularly within the framework of the ESFRI process;

_ the networking, opening-up and sustainability of existing infrastructures and innovations within research infrastructures;

_ supporting strategy developments for research infrastructures and international cooperations;

_ e-infrastructures.

However, at present no funding is available for the establishment and operation of research infrastructures. The (strategy) projects funded as part of Horizon 2020 include the recently launched InRoad initiative, which will conduct a survey of national roadmaps for promoting research infrastructures in the European area, and which aims to make them comparable with each other. |[54] The primary objectives are, firstly, to identify examples of best practice and trends for roadmap processes and evaluation mechanisms; secondly, to contribute towards synchronisation and possible harmonisation of roadmaps in the European member states and at a superordinate European level; and thirdly, to support the development of research infrastructures, e. g. through the drafting of recommendations and best practice examples for funding and business models.

At European level, special attention has also been given in recent years to the issues of the data concept and data management as strategic core tasks of large-scale research infrastructures, particularly to ensure a secure, sustainable and efficient working with data. Various national and international policy and strategy papers are now addressing the question of data infrastructures, the handling of research data in the broadest sense and requirements relating to the preparation of data management plans. For example, following an evaluation in 2012, the Max Planck Society (MPG) implemented a strategic reorientation and set up an independent body, the Max Planck Computing and Data Facility (MPCDF), which, in addition to bundling tasks and knowledge regarding data-intensive science inside the MPG, also has the aim of participating in data infrastructure initiatives in a national, European and international context. Such an institution should also support the implementation of data-intensive projects and supply basic capacity for this purpose. Other key actors in this respect include the Research Data Alliance and the e-Infrastructures Reflection

| 54 http://inroad.eu/, last accessed on 12/04/2017.

Group. |[55] In the context of open science and digitisation as focal points of the strategic orientation of European research policy, the importance of professionalisation of data management will continue to grow. Thus, completely free access to all scientific publications should be guaranteed throughout Europe and a fundamental new approach to the reuse of research data should be created. |[56] In the area of research infrastructures, compliance with the FAIR data principles |[57] (FAIR = Findable, Accessible, Interoperable, Reusable) and the implementation of comprehensive e-infrastructures for realising open science are key. The professionalisation of data management also includes systematically taking into account the necessary personnel requirements. Recruiting specially trained scientific staff is a challenge, as in many cases training structures still need to be established and working in data management has not yet acquired sufficient recognition as a scientific accomplishment.

One important aspect of the governance of research infrastructures is access to the utilisation of a research infrastructure. Depending on type and field of research, research infrastructures may offer access to machine and computing time, the preparation and examination of specimens, test set-ups and experiments, archives and collections, software and information technology services, education and training. In 2016 the European Commission published a "European Charter for Access to Research Infrastructures". |[58] This charter was drawn up by the European Commission in cooperation with ESFRI, e-IRG and the ERA stakeholder organisations (CESAER |[59], EARTO |[60], EUA |[61], LERU |[62], NordForsk and Science Europe). Although the Charter is not legally binding, it is intended to form the basis for a common understanding of access policies. At the same time, it is designed to encourage operators of research infrastructures to ensure maximum transparency regarding their access possibilities and processes. |[63] The requirements that distributed research infrastructures must sat-

|[55] e-IRG: White Paper, 2013: http://e-irg.eu/documents/10920/11274/e-irg-white-paper-2013-final.pdf; e-IRG: Best Practices for the use of e-Infrastructures by large-scale research infrastructures, 2015: http://e-irg.eu/documents/10920/277005/Best+Practices+for+the+use+of+e-Infrastructures+by+large-scale+research+infrastructures.pdf; Research Data Alliance (RDA): First year report on RDA Europe analysis programme, 2013; Research Data Alliance (RDA): Second year report on RDA Europe analysis programme, 2014.

|[56] https://english.eu2016.nl/documents/reports/2016/04/04/amsterdam-call-for-action-on-open-science.

|[57] The FAIR Guiding Principles for scientific data management and stewardship, DOI: 10.1038/sdata.2016.18.

|[58] European Commission, European Charter for Access to Research Infrastructures, Draft Version 1.0, June 2015.

|[59] Conference of European Schools for Advanced Engineering Education and Research.

|[60] European Association of Research and Technological Organisations.

|[61] European University Association.

|[62] League of European Research Universities.

|[63] https://ec.europa.eu/research/infrastructures/index_en.cfm?pg=access_ri, last accessed on 09/05/2017.

isfy in terms of formal structure, governance, funding and access are subject of an OECD-study published in 2014. |[64]

C.II LESSONS LEARNT

As part of a learning process, this section identifies potential for development of the science-driven process within the National Roadmap Process, which should be given appropriate consideration in the design of the next Roadmap Process.

II.1 Participation in the Roadmap Process

In order to take full advantage of the creativity and expertise of researchers in Germany, it is important to incorporate all fundamentally suitable initiatives for new research infrastructures in consultations for a National Roadmap. It is therefore highly welcome that, in the current Roadmap Process, the announcement in August 2015 allowed all research organisations, universities and non-university research institutions planning to establish a research infrastructure to submit their projects to the National Roadmap Process. Raising the threshold value of investment costs from EUR 15 million to EUR 50 million german share or EUR 20 million in humanities and social sciences and in educational research raises the question, if all research infrastructure projects that are relevant for a prioritisation in terms of research policy will be systematically included in the process. This needs to be examined especially with regard to the various types of research infrastructures and Germany's participation in national and international projects.

This opening-up of the process imposes new demands on the science-driven evaluation. These include variability in the maturity of submitted proposals and the difficulty of estimating the number of proposals requiring evaluation. Transparent access to the process, especially a comprehensible initial examination of proposals in accordance with clearly defined criteria, is crucial to the acceptance of the process in scientific communities.

Variability in the maturity of proposals

Research infrastructures are characterised by both a long development time until their implementation and a long lifetime. The Roadmap Process concentrates on a crucial phase in the life cycle of a research infrastructure, namely

| [64] OECD (ed.): International Distributed Research Infrastructures: Issues and Options, 2014.

the planning phase. [65] This follows on from the definition phase and comprises the concrete definition of project measures and goals. These include, for example, measures for risk minimisation as well as the finalisation of project structure plans and funding plans. The planning phase of a research infrastructure is generally very long and may last several years. By the end of this phase there should be a detailed proposal which, in principle, can be implemented. A research infrastructure project will vary in its scientific and technical maturity depending on whether it is nearer to the end or the beginning of the planning phase when the proposal is submitted. Accordingly, the committee was confronted with significant variability in the degree of maturity of the submitted proposals in the current evaluation process. In one case, the maturity of the project was so low that the proposal could not be included in the comparative evaluation because it included a large amount of research and development work yet to be carried out. Given the considerable workload involved on the part of proposers in preparing the proposal documents and on the part of the committee in evaluating and assessing a proposal, in future, suitable measures should be taken to avoid the inclusion of non-mature proposals in the science-driven evaluation. Conversely, with regard to future rounds of the Roadmap Process, it is necessary to ensure that projects which are sufficiently planned and mature will enter the process.

Number of proposals

The opening-up of access to the Roadmap Process means that the number of proposals to be evaluated in each round is per se open and thus very difficult to predict. In the current Roadmap Process, twelve projects progressed to the science-driven evaluation – three more than in the pilot phase. Even with this higher number of proposals, the science-driven evaluation was carried out successfully. However, a significantly higher number of proposals could have an impact on organisational and time planning in the established process. Reliable cyclic timing of the process would help to counter a development of this kind.

II.2 Challenges for the assessment

The structure of the evaluation process has essentially proved valuable. The approach of using four dimensions of evaluation allows for a differentiated and adequate evaluation as well as a comparative assessment of the projects' potential. The dimension structure is comprehensible and easy to use. Nevertheless,

[65] Federal Ministry of Education and Research: The National Roadmap Process for Research Infrastructures. Investing in the Future of Research. January 2016, p. 7 f.: https://www.bmbf.de/pub/The_National_Roadmap_Process_for_Research_Infrastructures.pdf, last accessed on 12/04/2017.

some challenges could be identified that are relevant for further developing the evaluation process. They are addressed below.

Diversity of proposals

The proposals submitted in this process exhibited far greater diversity than in the pilot phase. One challenge in the process was to make appropriate allowance for these differences to ensure a fair comparative evaluation in the various dimensions. While some proposals aimed at technical innovations with a high degree of risk, others concentrated on the networking and intelligent interlinking of technologies that essentially already exist. Diversity also meant that some projects addressed specific, current and original research questions, while others focused on the analysis and provision of data for a wide range of scientific communities. In the latter case, given the extremely broad community of users, it is difficult to predict exactly what research questions could in future be tackled with the processed data. These specific prerequisites and characteristics of research infrastructures must be taken into account – especially with regard to the assessment of the scientific potential of a project, which primarily examines the importance of a research infrastructure to the development of new or existing research fields in the context of existing and proposed research infrastructures.

Data concept and data management

As digital development advances and it becomes possible to collect, store, reuse and link large, complex volumes of data, the provision of research data for a broad user community is becoming increasingly important. Depending on the type and character of research infrastructures, they may not only generate large data volumes, but use existing data resources, making them available in a digital, processed form to a large user group. In light of this, the topics of data concept and data management were identified as challenges during the pilot phase. In many cases, the task and role of data management in a research infrastructure were underestimated. This is one of the reasons, why the work associated with data collection, archiving, access and processing was not adequately acknowledged and recognised. In view of these deficits on the one hand and, on the other, growing requirements for professional data management due to technological developments and the growth of open science (see C.I), the item "data concept" was added to the dimension "utilisation" as a separate aspect for evaluation. |[66] The evaluation of the twelve proposals revealed

| 66 BMBF: Guidelines for outlining proposals for the National Roadmap for Research Infrastructures, issued by the German Federal Ministry of Education and Research (BMBF), p. 9, 2015. http://www.wissenschaftsrat.de/download/archiv/FIS_Leitfaden_EN_Veroeffentlichung.pdf, last accessed on 12/04/2017.

that current trends and standards have not yet been consistently adopted and implemented. The majority of proposals do not refer to the FAIR principles and their possible implementations, nor is there any expectation that data repositories will be subject to structured quality assurance. In addition, few quantitative details are provided as to data volumes and their complexity, which would however be necessary in order to estimate, for example, the costs of storage, curation and long-term data administration as well as to assess structures of responsibility. Proposers face the challenge of developing an appropriate concept along these lines including the necessary technical and personnel resources. Consultation platforms may be helpful in this regard. However, most of the proposals explain in detail and convincingly how access rights to data are to be organised.

European interlinking

Often, research infrastructures can only be implemented transnationally – whether in Europe or globally – because the necessary investments and anticipated running costs exceed the budget of a single country. For instance, seven of the nine proposals evaluated in the pilot phase are represented in the current ESFRI Roadmap as Projects or Landmarks. |[67] Also in the current Roadmap Process, four of the twelve proposals submitted are linked in some way with research infrastructure projects at European level. For example, the proposed solar telescope EST as a cooperation project with a Spanish partner was added directly to the ESFRI Roadmap 2016. As an independent contribution, ACTRIS-D is directly linked to the ACTRIS project, which is also included in the ESFRI Roadmap, and is largely geared towards the structures envisaged there. GerBI-RI seeks to draw on the ESFRI Project Euro-BioImaging and thus form the currently lacking German share of the European infrastructure. For DCOLL, a partnership is planned with the European project EUCOLL |[68] and/or CETAF |[69], for which a proposal for inclusion in the ESFRI Roadmap is planned. In light of this, it is necessary to consider how more attention can be given to the European perspective of the projects in the process. The fourth dimension, which addresses relevance to Germany as a location of science and research, could be more clearly differentiated, with the result that the European per-

| [67] European Plate Observing System (EPOS), European Infrastructure of Open Screening Platforms for Chemical Biology (EU-OPENSCREEN), European Research Infrastructure of Imaging Technologies in Biological and Medical Sciences (Euro-BioImaging), Cherenkov Telescope Array (CTA), European Magnetic Field Laboratory (EMFL), In-service Aircraft for a Global Observing System (IAGOS) and Integrated Structural Biology Infrastructure (INSTRUCT). (On this, see: ESFRI (ed.): Strategy Report on Research Infrastructures. Roadmap 2016, Brussels 2016.)

| [68] European Science Collection Infrastructure.

| [69] Consortium of European Taxonomic Facilities.

spective and the question of the societal benefit of a project could also be addressed.

Calibration of a wide range of expertise in the evaluation process

As in all evaluation processes, one decisive factor in a sound science-driven evaluation of large-scale research infrastructure projects is the recruitment of suitable reviewers. The complexity of the research infrastructure proposals requiring evaluation and the comparative character of the evaluation process demand great care in the selection of reviewers as well as in the composition of the reviewing groups. Essentially, the recruitment of three reviewers per group, mainly from abroad, has proved a successful approach. A high degree of convergence in the appraisal of the projects was observed in the process. With regard to the question as to how review groups should be composed in the future, the committee, however, is confronted with particular challenges:

_ In addition to subject-area expertise, specific experience is required in data management and governance to review the dimensions “utilisation” and “feasibility”.

_ The international experience of the reviewers is also useful and necessary to understand how a research infrastructure project fits into the global research landscape.

_ In addition, the extensive networking of large-scale research infrastructures requires special attention to be given to the associated problem of conflict of interest. This alone explains why, in many cases, reviewers can only be recruited from outside Germany.

_ The use of a large number of internationally recruited reviewers confronts the process with the challenge of assessing comparatively across the diversity of disciplines and cultural differences. Evaluative terms are used differently in the evaluation and assessment process depending on the specific evaluation culture of the research area in question and on national background. A dialogue on the meaning of different terms and judgements is therefore essential.

Against this background, the process is not interactive solely in terms of dialogue and discussion with the proposers (see A.), but also in terms of common understanding within the group of reviewers and the committee. Personal interaction between the different reviewers and the committee members is thus a necessary element of the calibration process to create a differentiated evaluation which is appropriate to the various dimensions with their different aspects and to the wide variety of the proposals.

Research infrastructures at the highest level are an essential precondition for a high-performing research system. Research is increasingly dependent upon the deployment of such infrastructures to address scientifically challenging questions, conduct top-level research that links in to international research activities and open up scope for new, yet unforeseen types of research. In addition to developments relating to research questions and methods which are specific to a given research area, generic technologies also play a key role. As became clear in the new Roadmap Process, aspects such as the provision of higher-level data and sophisticated digitisation projects are growing in importance. At the same time, long planning and implementation times and high investment volumes mean that investment decisions create irreversible path dependencies.

Large-scale research infrastructures therefore present a complex, dynamically evolving field characterised by

_ wide-ranging scientific relevance and relevance in terms of scientific policy,

_ a large number of national and international actors (researchers, operators, funding providers, political decision-makers and advisory bodies),

_ a multitude of points of contact with information technology, legal, organisational and financial issues, and

_ a distinct international orientation.

Prioritisations in terms of research policy in this area therefore demand a decision-making process which takes the different aspects mentioned here into account and duly considers all actors, while giving appropriate consideration to current and diverse developments at national and international level in the further development of the process. It is therefore of vital importance to establish the Roadmap Process as a learning, regularly implemented process which responds to complexity and dynamism in the area of research infrastructures. Only a science-driven process of this nature can ensure that prioritisation decisions both now and in the future are made on a sound basis.

Appendix

D. Detailed project descriptions and assessments

D.I ENGINEERING AND NATURAL SCIENCES

I.1 Scientific landscape in Engineering and Natural Sciences

The area of Engineering and Natural Sciences encompasses a variety of scientific disciplines including physics, astronomy, chemistry, biology and engineering. Objects of research cover the whole range from the smallest building blocks of matter to the largest structures of the universe as well as the fundamental forces.

An enormous number of different fields of research constitute this heterogeneous area of science. At the boundaries of these fields, overlap and collaborations are often noticed. In the following, the focus will be on the three fields of research related to the proposed research infrastructures in the Roadmap Process, i. e. materials research, astrophysics and photonics.

I.1.a Scientific landscape for research infrastructures in materials research

Materials research deals with the structure, synthesis, processing and properties of matter. More specifically, it addresses primarily materials that are meant to serve current or future diverse applications such as metallic alloys, polymers, ceramics, composites, natural materials, photonic materials or semiconductors. The field is highly multidisciplinary and encompasses i. e. physics, chemistry and biology as well as engineering.

Traditionally, the main goals of materials research are the characterisation and the manufacturing of complex, mostly artificial materials. Modern basic materials research aims at a better understanding of structure-property relationships at the quantum and atomic level as well as at a better understanding of the passage from quantum mechanics describing the elementary building blocks of matter, material defects, to the macroscopic properties and materials failure. The experimental and theoretical approaches address these scales from the quantum and atomic level (e. g. quantum design of LEDs [70]) up to macroscopic dimension (e. g. materials for industrial equipment or consumer products). Recent developments in the realm of nanotechnology, which aims to control, manufacture and implement structures at the nano-scale (smaller than one micrometre) in various types of materials and environments, have underlined similar concepts as in materials research also in the life sciences. Fields of application include medical diagnosis and therapy (i. e. by the usage of magnetic nano-particles for cancer treatment and more generally by the application of nano-structures as transportation and storage systems), the production of bio-inspired and self-assembling materials as well as the advancement of measurement techniques in the life sciences.

The characteristics of a material include mechanical, magnetic, electronic, chemical and optical properties. They play an important role for structural, functional and biological materials. The analysis of biological samples includes molecular to atomic characterisation of molecules and protein conformations in isolation and within cells. Current examples of applications and products, where materials science progress is crucial, are micro- and nano-electronics (e. g. mobile communication), energy conversion (e. g. turbines), mobility (e. g. light-weight structures), health (e. g. implants), safety (e. g. power plants), magnetic materials (e. g. information storage or electrical power conversion) and photonic materials (e. g. solid state lighting) to name but a few. Materials science is related closely to the development and testing of new products.

Research infrastructures in materials science are of enormous diversity and include atomic-scale resolving electron microscopes, atom probe tomographs, magnetic field laboratories, free electron lasers, synchrotron radiation facilities, neutron sources or large parallel computer infrastructures. The research infrastructure **Ernst Ruska-Centre 2.0 – National Research Infrastructure for Ultra-High-Resolution Electron Microscopy (ER-C 2.0)** aims at the characterisation of soft, biological and inorganic materials via transmission electron microscopy. The proposed infrastructure is based on the existing Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons (ER-C) at FZJ. The aim is to expand the present ER-C into a national research infrastructure with unprecedented capabilities, providing opportunities for advancement of instrumental design and cross-fertilisation between materials and life science communities (see also list of competing and complementary research infrastructures).

[70] Light Emitting Diode

The terms astronomy and astrophysics are frequently used interchangeably and this convention will be adopted here. Generally speaking, astrophysical research deals with fundamental questions concerning the universe, which encompasses the origin, properties, and evolution of the universe and of all its constituents.

Historically, astrophysical research was based on observations and limited until the first half of the last century to the optical wavelength range only, by this, restricted to stars and interstellar gas emitting part of their continuous brightness and spectral lines in this range of the electromagnetic spectrum. With the opening of further non-optical electromagnetic wavelength ranges, ground-based by means of detector developments in the radio and near-infrared spectral range and of space-born telescopes, different subfields of astrophysics were defined according to the wavelengths to which they are related. By high-energy particles, subsumed as Cosmic Rays, and the newly detected Gravitational Waves two new windows have been opened for Astrophysical object types and processes. Therefore, the astrophysics community was divided into researchers working in the radio, infrared, optical, X-ray, or gamma-ray wavelengths.

Today, this categorisation has changed according to the research focus on targets and processes. Because most astronomers are focusing their research on objects, i. e. work target-oriented, as e. g. massive stars, galaxies, etc., they use information from the whole electromagnetic spectrum, gamma-rays at its highest-energy end, and also cosmic-ray particles. Basically, theoretical and computational astrophysics complete the observational astrophysical research tools, thus allowing the fullest possible understanding of the phenomena that are studied. Since the beginning of the last century modern astronomy has developed to a discipline of physics and more recently to a broader interdisciplinarity connecting with chemistry, biology, mineralogy, geology and planetology. In addition, computational science is influenced by computational astrophysics.

Examples of current questions of interest are the discovery and closer examination of planets outside of our solar system and the investigation of black holes that are known to exist in the centres of most galaxies. Furthermore, the age and evolution of structures in the universe, and its expansion are studied. Astrophysicists also strive to reveal the nature of the so-called dark matter, i. e. matter in the universe that is invisible but indirectly detectable through its gravitational effect. Together with the dark energy, an unknown energy source that accelerates the expansion of the universe, dark matter belongs to the most mysterious research questions in astronomy and physics in general.

Solar physics as part of astrophysics deals with the sun. As the sun is the star closest to us, its properties can be studied in greater detail. In addition to a better understanding of the sun and its working mechanism itself, solar physics also serves to understand other stars of similar properties and to explore the possible impact on the Earth, e. g. via solar activity and its influence on the climate.

Research infrastructures in solar physics, i. e. solar observatories, can be either satellite-based or ground-based. Basically, information coming from the whole electromagnetic range is of interest. The project **European Solar Telescope (EST)** as ground-based telescope on the Canary Islands disposes of a 4 m mirror. The main goal is to measure the magnetic field and its structure in the solar atmosphere with unprecedented precision. For competing and complementary research infrastructures see D.I.3.e.

Within the German astrophysics community, the internal process to set priorities for large research infrastructures is less well-defined and transparent, while for example in the US and the Netherlands, the communities come up with decadal strategic reports as continuous plans. Hosted by the German Research Foundation (DFG), contemporary reflections of the existing German astrophysical infrastructure and planned research facilities are compiled by an expert group of the *Rat Deutscher Sternwarten* (RDS) as “*Denkschrift*”. The last “*Denkschrift*” was released in 2003 |[71] and a new one is under completion. This “*Denkschrift*” primarily serves the streamlining of research initiatives in astrophysics.

I.1.c Scientific landscape for research infrastructures in photonics

Photonics deals with the creation, modulation, and detection of light and hence its constituent particles, the photons. The term photonics was created in analogy to electronics |[72] and is used interchangeably with optical technologies. It is a relatively new research field which developed since the invention of the first lasers around 1960. Photonics research is firmly rooted in physics. Research questions are for example the development of new lasers, the investigation of optically active materials such as fibres or crystals, the combination of electronic with photonic devices, physics with single photons or attosecond physics, which allows, among others, the real-time observation of electron motion.

|71 *Deutsche Forschungsgemeinschaft: Status und Perspektiven der Astronomie in Deutschland 2003-2016. Denkschrift*, Bonn 2003, http://www.dfg.de/download/pdf/dfg_im_profil/geschaeftsstelle/publikationen/status_perspektiven_astronomie_2003_2016.pdf, last accessed on 26/07/2016.

|72 In electronics, the signal transmission in circuits is carried out by electrons. In photonics, the photons are the particles carrying information.

However, the applications of photonics are much more wide-spread and cover e. g. materials analysis, detection methods in the environmental sciences, research methods in the life sciences, telecommunications, and medical applications (see also D.III.1 and D.III.3). At the moment, several emerging transdisciplinary fields based on photonic principles are developing, such as quantum information technologies, semiconductor nanophotonics, optomechanics, colloidal photonics, organic-/biophotonics, opto-atomics, quantum metrology or polaritonics.

Beside this broad range of applications in diverse fields of research, photonics also plays an important role in various branches of industry. The European Commission hence lists photonics as one of six Key Enabling Technologies which are said to provide the basis for innovations and economic growth. |[73] Examples are the energy sector with photovoltaics and the health sector with imaging methods. Further developments and a continuously large impact on science, economy, and the society are expected.

Research infrastructures in photonics can be divided into two classes. The first type aims at progressing photonics itself, whereas the prospect of the second type is mainly the application of photonic technology. In the US, a few RIs dedicated purely to photonics and hence belonging to the first type exist, such as e. g. the Centre for X-Ray Optics (CXRO) in Berkeley and the American Institute for Manufacturing Integrated Photonics (AIM Photonics) with headquarters in Albany. The second type encompasses ESFRI Landmarks such as the Extreme Light Infrastructure (ELI) or the European X-Ray Free-Electron Laser Facility (European XFEL) using highly energetic photons and photonic technologies for the investigation of e. g. matter-light interactions, biological processes, or materials research. Therefore, concerning the application of photonics, complementary RIs also include RIs in the materials sciences, in astrophysics, in energy research etc.

National Photonics Labs (NPL) is designed as a platform for research and development in photonics, and has unique capabilities in the design and production of precise and fine structured optical elements on large and/or heavy components. NPL is in contact with user groups from diverse fields of research which need photonic technologies as tools for their research. Hence, it is targeting basic research in big science areas as well as providing a user facility available for industry and academia.

|73 The other five Key Enabling Technologies are: micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, and advanced manufacturing technologies. https://ec.europa.eu/growth/industry/key-enabling-technologies_en, last accessed on 26/07/2016.

I.2.a Scientific potential

Description

The properties of novel materials and structures are often determined by physical phenomena that are specific to the nanoscale and distinct from bulk properties in the macroscopic world. In nanoscale structures, the importance of surfaces, internal interfaces, and quantum effects increases, resulting in new properties that can have high scientific, technological, and economic potential. According to the proposal, a thorough understanding of the atomic and molecular building blocks of such systems is required to achieve further progress. Atomic resolution characterisation is therefore expected to have a decisive impact on scientific research and engineering and beyond. ER-C 2.0 aims to enable the scientific communities in the advancement of the following research fields:

- Materials science: Materials can act as technology enablers and offer solutions to global challenges and industrial progress. There is an increasing requirement for applications, which provide a challenge for the development of new materials. Prototypical examples of new technologies that require highly precise examination of atomic structures are found in energy research, e. g. for improvements in energy efficiency or the realisation of new energy conversion and storage technologies.
- Solid state physics and chemistry: These often underpin progress in current and future technologies. Rapid developments require that relevant physical phenomena need to be understood and engineered on the atomic level. Two examples are provided by silicon CMOS (complementary metal-oxide-semiconductor) technology and catalysts.
- Soft matter: New chemical methods and technologies enable the synthesis of molecular and polymeric nanomaterials with novel functionalities. Potential applications range from new structural materials and electronic switching elements to catalysts and biocompatible materials. However, all high-spatial-resolution characterisation methods face challenges when they are applied to studies of such materials because of potential damage. ER-C 2.0 therefore aims at the development and application of minimally-invasive and non-destructive high-resolution electron-microscopy techniques.
- Life sciences: Two areas that will be tackled in the life sciences are the determination of the three dimensional architectures of complex molecular structures and the determination of the structures of biological cells and their components.

The expansion of ER-C into a national research infrastructure will be based primarily on the installation and operation of five new next generation instruments: A transmission electron microscope (TEM) for atomic-resolution tomographic materials analysis, a chromatic-aberration-corrected liquid-helium-cooled ultra-high-resolution TEM, a time-resolved in situ TEM, an ultra-high-energy-resolution spectroscopic TEM, and a cryo-PICO TEM [74] for biomedical applications. The selection and definition of these instruments is based on requirements to tackle key current scientific problems, as described above, as well as on the latest developments in electron optics and on discussions with leading manufacturers.

High-resolution transmission electron microscopy is one of the established methods for the examination of atomic and molecular structures. Complementary and competing methods include neutrons, synchrotron radiation, X-ray laser radiation (with free-electron lasers), scanning probe methods, and atom probe tomography. According to the proposal, no other existing or planned infrastructure will operate a similar spectrum of electron-optical instruments or devices with comparable performance characteristics to ER-C 2.0 in the foreseeable future.

Assessment

The proposal aims to develop and combine next-generation electron microscopy infrastructure to characterise and understand the functionalities of inorganic, soft and biological materials and their hybrids on the atomic and molecular scale. The proposed instrumentation will push the boundaries of the present state-of-the-art significantly regarding characterisation of both inorganic soft and biological materials, by advancing instrumentation, technique and rapid analysis methods. With very recent developments in the relevant instrumentation – including direct electron detector developments, phase plate developments, ultrafast source and the potential incorporation of aberration correction into these platforms – this proposed RI grant is very timely.

Generally, the electron microscopy community worldwide has been split between those who characterise ‘materials’ (inorganic matter, generally) and those who characterise biological (organic) matter. The establishment of world-leading facilities for the characterisation of both of these types of materials, along with the co-location of experts in technique and instrumentation development may allow cross-fertilisation of ideas between these two communities and can be expected to initiate new developments both across fields, and at the boundary between fields. This co-location is a significant strength of the pro-

[74] PICO is the name of an existing instrument in the ER-C; cryo refers to cooling with liquid nitrogen or liquid helium.

posal. It is to be commended that the world-leading group in electron microscopy of inorganic materials at ER-C is now proposing to expand into soft matter and biological samples, because it is obvious that there is synergy by this expansion. There is significant potential in this area since Germany is one of the leading centres for TEM biological research.

Each of the proposed five instruments has novel aspects that would require instrumental development, resulting in strong technological innovations.

The TOMO Instrument represents the first combination of atomic resolution scanning transmission electron microscopy and atom-probe microscopy in the same instrument and should lead to improved atomic-scale characterisation of real materials in three dimensions. As proposed, it is excellent mostly for its suggested pairing of Atom Probe Microscopy and aberration-corrected (S)TEM |[75]. If successful, this would deliver an enormous lead in 3D microanalysis to ER-C 2.0 and to Germany as it would be of significant interest for metallurgy and layered semiconductor materials research and application.

The CRYO Instrument would be the first to combine ultrahigh vacuum and liquid helium cooling of the sample stage with chromatic aberration correction which should lead to three-dimensional structure images with the measurement accuracy of a single atom. A major innovation suggested by the CRYO configuration is the reduction of Johnson Noise in electron optics and the proposed breaking of the 30 picometre resolution barrier. Cryo-cooling the specimen and reducing the acceleration voltage should make accessible much more high quality studies of light element and more volatile specimens than previously possible. Phenomena such as lattice distortions in the smallest possible clusters and even certain simple molecular structures should be possible. The use of liquid helium cooling for the lenses is entirely novel. This not only makes lattice images more quantitative but also provides much higher quality imaging data on light elements such as O, N, C, B, Be, Li and even hydrogen. The combination of cryo-cooling and superconducting objective lens has the potential to deliver extraordinary performance which renders this project exciting and of high value.

The FEMTO Instrument would allow for the first experimental demonstration of the combination of a pulse coherent high-brightness source with an aberration corrector and should lead to dramatic improvements in combined temporal and spatial characterisation of materials. Due to its ultrafast spectroscopy capabilities, this instrument suggests ground-breaking possible future developments.

|[75] (Scanning) Transmissions Electron Microscope

The SPECTRO Instrument would offer the first combination of leading monochromatic electron source capabilities with liquid helium cooled sample stage. It should allow for atomic scale characterisation of the electronic structure of condensed matter interfaces, in relevant regimes. In its capability to provide a unique combination of high spectral resolution with liquid helium cooling, the highly competitive SPECTRO instrument would be world-leading.

The BIO Instrument represents the first combination of chromatic aberration and liquid helium sample stage. This proposed instrument would allow for the highest level of specification currently available for a TEM designed for studying protein structures. It may improve both resolution and limit radiation damage in the characterisation of biological materials. The incorporation of correlative fluorescence microscopy and the incorporation of integrated cryo-FIB (focused ion beam) is ambitious and will require significant investment in personnel. Certainly the development of such a machine would provide truly unique capability to Germany. Based on the experience of the life science community, the configuration regarding the helium temperature for the BIO microscope should be re-examined. To better establish the C_C and C_S combination and its added value to biological samples, a comparison with available benchmark data from the C_S-corrected Titan Krios at Göttingen would be helpful. The incorporation of C_c-correction in the instrument has the potential to provide this machine with an advantage and give it world-leading performance.

These new instruments will in particular make use of the latest innovations in instrument design. Certainly they would provide ER-C 2.0 with an overall leading edge in terms of their ability to provide a much wider range of capabilities within Germany and also internationally. They already start from a very high level of instrumentation. In terms of their hard-core scientific potential, three of these instruments are clearly revolutionary: TOMO, CRYO, and FEMTO, whereas SPECTRO and BIO have some elements of novelty. “Revolutionary“ in this context means instrumentation that goes significantly beyond currently available instrumentation and which incorporates major innovation in terms of design whereas the others incorporate the most recently development detectors, in particular Direct Electron Detectors and latest refinements in aberration correction. The probably most ground-breaking possible future developments are suggested here by CRYO and FEMTO.

Regarding the life science part of the proposal, stronger ties with the electron microscopy community in Germany to share their know-how and technical expertise are strongly encouraged and would provide an immense advantage to this proposal. Germany has a long history as one of the leading cryo-EM developers in adapting and developing the technologies today used by life sciences. At the same time, Germany’s cryo-EM community is very strong nationally. Ties between these laboratories in Germany and Thermo Fisher (formerly FEI)

Company in the US provided major and key contributions that enabled the "resolution revolution" we are currently experiencing in the cryo-EM single particles field. Among others, the contribution of these teams was in co-developing, testing and engineering both hardware with FEI (cryo-TEM and cryo-Light microscopes), direct detector devices (jointly with MRC (Medical Research Council)), ion milling, and software tools.

Forefront infrastructure such as is being proposed here is inherently adaptable – it defines opportunities moving forward, and thus can be utilised to answer many different scientific questions as they arise. Having an open user model, based on peer-reviewed proposals will ensure that access to the instrumentation will be open enough to maintain flexibility over the lifetime of the instruments.

The proposal is highly competitive especially because of the established track record in material science. There are no other efforts of this size and ambition being proposed worldwide. Individual laboratories in e. g. Japan are developing some instrumentation that has similar characteristics.

I.2.b Utilisation

Description

The scientific focus of users of ER-C 2.0 will be in the areas described above, or in cross-disciplinary areas between them. These fields are represented at virtually all universities in Germany, as well as in non-university research institutions. The potential user base is therefore very broad and diverse. A significant increase in the number of users is expected for ER-C 2.0, as a larger number of techniques will be available and an increased range of problems will be investigated.

The utilisation concept for ER-C 2.0 is based on a project- and subject-oriented allocation of time to users and user groups. Instruments will be made available to external users for up to 75 % of the total measurement time, amounting to approx. 700 measurement days per year for the five new instruments. Applications for measurement time will be assessed by an external review panel in an excellence-driven evaluation process. |[76] Users whose applications are approved will be granted access to the required instruments and supervised by experienced scientists. Access will also include processing of data. Measurement time at the ER-C's instruments will be free of charge to external users from academia. The associated partners will scientifically supervise specific instruments

|[76] Procedures will comply with the European Charter of Access to Research Infrastructures and will be disseminated on the ER-C's website.

and, in addition, will be linked to user communities on a local level. Moreover, ER-C regularly conducts user surveys.

The development of a comprehensive data management system that will be adapted to the needs of electron microscopy is seen as an integral part of ER-C 2.0. It is foreseen to work closely with specialists from the Jülich Supercomputing Centre and to draw upon experience from other communities. Data will only be released to the broader user community on a web platform after a retention period of four years. The largest possible amount of metadata will be recorded, including, if possible, accurate descriptions of the synthesis and processing of materials. ER-C is already developing its own software packages, in addition to extensions to commercial software. These software packages will be freely available to users. The ER-C 2.0 concept includes a plan to expand these activities further and, in the future, offer free software repositories. The expected data volume amounts to approx. 500 Terabyte (TB) per year. Online storage resources will be made available locally for the primary analysis of data. Long-term storage will take place in the more cost-effective central data storage systems of the Helmholtz Data Federation.

A quality assurance system for research is in place in FZJ. For ER-C 2.0, a special Code of Conduct will be established at the beginning of the development phase.

Assessment

Although most of the data will be 'direct use', with increasing sophistication in data analysis, and more widespread adoption of data sharing across the world, there is likely to be increasing utilisation of data by researchers other than those that acquired the data.

The proposed instrumental acquisitions are significant in terms of financial investments and thus the expectation is that they will see high utilisation, i. e. approach 100 % of available time. The expected size/cost is commensurate with the size of the user community.

The mechanism they propose for access management for external users is fairly typical for these kinds of arrangements, incorporating an excellence-driven, transparent evaluation process that will conform to the European Charter of Access to Research Infrastructures. The methods for both cutting-edge electron microscopy and electron tomography are not mature technologies. They are highly specialised and require considerable training and expertise; even more so once data are collected. The existing staff at ER-C has a demonstrated track record at implementing these procedures and in supporting world class instrumentation. They also have demonstrated leadership in the development and utilisation of the complex instruments in a user environment and to host researchers from Germany, the EU and the international community to utilise this instrumentation and the local expertise to advance scientific discovery world-wide. By teaming with external partners, ER-C 2.0 will be able to provide appropriate expertise for instruments with a focus on soft matter and biological samples.

Access charges are free at the point of use for academic external users and they propose to allocate 75 % of the “available measurement time”. It is also worth pointing out that the existing ER-C infrastructure has significant capacity and one question to be asked is how much of their existing capacity will be used to fulfil this commitment.

Use of regular user surveys and the formation of a scientific and technical council will guide subsequent development. At present, this council is to be composed of representatives from the user group. It is recommended that an additional, independent external advisory committee will be established to provide input as well.

A major issue with regards to modern electron microscopy, in which all of the data acquired is almost exclusively digital, is data acquisition, data analysis, data storage and archiving. This issue is particularly prescient due to the recent advent of direct electron detection and faster cameras that can produce an immense amount of data in just a few seconds. Current usage at the existing ER-C facility is estimated around 50 Gigabyte/day but is projected, if ER-C 2.0 is funded, to reach at least 2 TB per day and 500 TB per year.

Data analysis and data mining strategies are different between the materials and life science communities. The applicants have a solid ground in their approach on data analysis and mining in the materials community and have indicated collaboration with the Jülich Supercomputing Centre, since managing this volume of data will be a formidable task. Some percentage of the data will no doubt be processed by members of the consortium for both their own and external work while the rest will be transferred for offline processing by the users, the whole being archived in the more cost-effective central data storage systems of the Helmholtz Data Federation Infrastructure for at least 10 years. In order to extract useful results from the electron microscopy data, images must be processed using software, which is currently complex, often lacking intuitive user interfaces and documentation. A positive development suggested by the authors is the development of their own non-proprietary software packages for the broader user community to get around the hurdle of offline image and data processing. Whereas in material science these resources are propriety, software development for image processing for biological samples is ongoing. In the life sciences, many of such routines are already available as an open source. Utilising those resources will have an advantage over separate own developments. Also, in the life sciences, the community is rapidly moving towards GPU |[77] computing and the use of single, low-cost desktop workstations rather than supercomputing centres.

A working group is also developing a strategy for the management of research data and recommendations for standards on the storage, management and sharing of research data, with a view to an open data policy. This is an important component of the programme.

ER-C is an operational facility, able to implement excellence practices to handle the users both from academic and industrial backgrounds as pertaining to confidential handling of information and data. ER-C 2.0 will comply with the standards of FZJ and the Helmholtz Association and, where it is deemed necessary during the development phase, develop additional standards. Overall, their measures for quality assurance, good scientific practice with regard to dealing with research data and publications, code of conduct and ethical standards are sound and appropriate.

I.2.c Feasibility

Description

Scientists in ER-C have conducted detailed discussions with manufacturers of electron-optical instrumentation about the technical feasibility of the proposed five additional instruments. During these discussions, the basic concepts, performance characteristics, required timeframes, and costs of the microscopes were established. All of the manufacturers agreed to implement improved specifications, e. g. for the vacuum systems, specimen stages, and detectors of the new microscopes. Specific new technical developments will include a superconducting objective lens to improve spatial resolution. In some cases, manufacturers or suppliers have already carried out proof-of-principle experiments confirming the validity of the proposed concepts.

According to the proposal, ER-C and its predecessors, together with industrial partners, have played a major role in establishing spherically and chromatically corrected electron optics as a reliable method for the examination of solid-state structures and processes at the atomic level. ER-C's staff have extensive experience in the management of similar electron-optical projects. Since its foundation in 2004, ER-C has offered access to these resources to external users within the framework of a collaboration with the DFG.

|[77] Graphics processing unit.

The central organs and responsible units will be a partners' assembly, a main committee, a directorate consisting of three directors who will be responsible for different scientific fields and an administrative office. Further advisory bodies of ER-C 2.0, which will be appointed externally, will be a scientific advisory council and a review panel.

According to the proposal, ER-C has sufficient scientific expertise and personnel at its disposal to realise the development and construction of the proposed infrastructure, as it is planned. The establishment of ER-C 2.0 and the successful installation of the new electron microscopes will result in a thematic and methodological broadening, which will be accompanied by the appointment of three professors (in Düsseldorf and Aachen). The three professors will contribute to the competences and personnel resources required for the new fields.

Assessment

The proposal has components of a high-risk nature with a high return value, especially, regarding CRYO, FEMTO and TOMO. The BIO, if combined with He-cooling, represents significant risk with unclear return. The SPECTRO machine has elements of novelty but is more evolutionary in nature.

For the success in the life science part of the proposal, acquisition of scientific expertise and capacity building in-house will be key components. The streamlined use of an available high-end Titan Krios, as ongoing in Jülich, set up for life sciences as well as soft matters (SP or tomography configuration), will provide a basis for the development proposed in this application. The immediate availability of high-end biological TEMs to the community in Germany should be made highest priority while supplementing this initiative with a critical mass of newly recruited investigators. The current proposal would be significantly strengthened by an explicit plan for community building in the biological sciences on top of the acquisition of high-end microscopes. Encouraging steps in this direction were taken by holding two search conferences in between submission and assessment of the proposal.

The applicants make clear that there are alternative manufacturers for each instrument (with quotes, at similar prices), which allows ER-C 2.0 to switch to a different instrument provider if necessary. This is clearly a good approach to mitigate risk.

The success of a centralised national facility like ER-C 2.0 will depend on its usability for the targeted communities. It is widely acknowledged that centralised facilities – staffed with resident experts in their scientific fields – provide a superior route to the utilisation of expensive characterisation facilities. This is apparent worldwide, as multiple nationals run their synchrotron x-ray sources, their neutron sources, and in many cases, their electron microscopy facilities in this way. In the past, this was less true in the biological community. However, the international community in the area of biological electron microscopy is also exploring the idea of central facilities such as those proposed here.

Processes will be further facilitated by extension of the core partners. Beyond the universities and non-university research establishments, who will make up the next tier of the network, this partnership also foresees more extensive industrial collaboration.

The existing ER-C has a demonstrated track record of managing instruments of similar complexity, and providing them to the broad international user community. The presented materials adequately describe a relevant staffing and management plan for facility operation, as well as plans for instrument procurement and specification. The funding structure outlined is adequate, so an appropriate number of staff will run the institute. Between proposal submission and this review, there was such invested in the life science areas, and continue prioritisation of this aspect is strongly encouraged.

A recommendation would be to establish an international advisory board to provide additional guidance to the facility.

A strong component of the feasibility criteria is also the quality of the personnel involved and the resources that are proposed to be allocated. All of the authors involved have demonstrated an impressive track record, both independently and collectively with regards to nearly all the important aspects of modern electron microscopy, from the application of theory, to the design of high performance instrumentation, to novel and prescient experimentation, quantitative simulation and high quality original science. The applicants are established world-leaders in their field, and the existing staff at ER-C as well as the affiliated institutions are equally strong. They are particularly skilled in the Physical Sciences but this proposal indicates their one significant weakness which was their comparatively small input into soft materials and biosciences. With the proposed addition of new facilities particularly dedicated to address this deficit and three new chairs (i. e. two new W3 professors and one Director) associated with soft matter, polymer research and the life sciences, the ER-C 2.0 consortium would become one of the most wide ranging and capable electron microscopy centres in the world.

The infrastructure is in place and the know-how for the new infrastructure is available at the centre. The plausibility of the envisaged embedding of the new designed instruments in the strategy of the three participants and the ER-C is well developed as pertaining to the space requirements as well as the organisational and project structures, administrative and personnel plans for the operation. The existing ER-C has a demonstrated world-leadership in this area, and is an established and mature entity.

Description

According to the proposal, few other experimental methods have been shaped by German science as extensively as has electron microscopy. The first TEM was developed by Ruska and Knoll in 1931, the first commercial TEM was constructed by Siemens in 1938 and correctors for spherical and chromatic aberration were developed by Rose and Haider.

ER-C 2.0 is intended to consolidate and further develop Germany's leading position in this subject. The project scientists state that the installation of the next generation of instruments will represent a new milestone in the development of atomic resolution microscopy and that ER-C 2.0 will be an internationally leading institution for ultra-high-resolution electron microscopy. ER-C will also conduct in-depth activities in fundamental electron optics, in order to maintain and further develop its expertise.

A new dimension of cooperation is intended to result from interaction with complementary infrastructures in the areas of synchrotron radiation, free-electron lasers and neutron sources. Complementary methods in these national infrastructures and in ER-C 2.0 will result in synergies that will reach far beyond current boundaries between disciplines.

According to the proposal, ER-C 2.0 will provide young scientists with a faster path to independent scientific work. The infrastructure will offer training courses and summer schools, opportunities for early career scientists to carry out independent research, and special visiting scientists' programmes. It is planned to strengthen knowledge transfer by the organisation of conferences, support for users in the publication of their results and other activities.

Assessment

Collectively, modern high performance electron microscopes have pushed materials science and soft matter sciences and the biosciences to the next frontier. Experiments on nanoscale objects such as graphene, single molecules, chains of atoms, proteins and polymer chains are becoming almost routine. German scientists also took the lead in the development and application of life science cryo-TEM. All of these things matter because they represent where technology (or nanotechnology) is heading in the coming years and decades, and countries that invest in these newest generation instruments will have a significant edge over those increasingly few that do not. It is fair to say that modern high performance electron microscopy now enjoys an exalted place in materials characterisation enjoyed by a comparatively few high budget analytical methods such as high-performance Synchrotron Facilities or NMR facilities. Yet, current

TEM instrumentation offers far greater flexibility than all of them including the ability to be a “Synchrotron inside a Microscope”.

ER-C at Jülich is already recognised as a world leader in electron microscopy of inorganic materials. The proposed research would dramatically build upon this leadership by incorporating both a broader scope of instrumentation, as well as instruments that would truly define the forefront of the material science field. No other group in Germany, or for that matter Europe could propose an effort of this size and scope and have the credibility that this group has to implement the proposed vision.

With ER-C 2.0 Germany would be very well placed to further develop its lead in electron optics, instrument design with spectacular advances in material sciences and potentially with significant advantages for Soft Matter and Life Sciences. If this proposal was to be funded, Germany would literally vault ahead of the rest of the world, and would establish a pre-eminence that would be hard for other countries to match down the line.

The proposed RI will create truly unique infrastructure, worldwide, and will certainly attract scientists from all over the world to conduct experiments that are at the highest level, and which solve the most pressing problems.

A strategic plan for an appropriate outreach programme to young scientists’ needs has to be implemented.

The existing ER-C has a demonstrated substantial impact to date, not only through its advance of scientific research, but also the development and dissemination of technique and technical knowledge to the broader scientific community. The resulting scientific research in advanced materials and in understanding biological function will advance the frontiers of knowledge, and benefit both Germany and the international community.

If successful, this initiative will have direct impact on basic research, supporting and strengthening of the manufacturers involved, and would push for leading in the development of new materials and processes, which in turn will have a direct influence on the economic strength of Germany and our quality of life.

I.2.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
	Forerunners		
ER-C – Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons	ER-C is a national user facility open to universities, research institutions and research laboratories in industry. It is run conjointly by two institutions, the Institute of Microstructure Research at Jülich Research Centre and	Since 2004	Jülich, DE

(competing)	the Central Facility for Electron Microscopy at RWTH Aachen University. The ER-C develops scientific and technical infrastructure and methods for present and future materials research. It is also a national user facility for ultrahigh-resolution electron microscopy. http://www.er-c.org, last accessed 15 September 2016 http://www.er-c.org/news/publications/er-c-booklet-english.pdf, last accessed 29 July 2016		
Existing research infrastructures			
APS – Advanced Photon Source (complementary)	APS, located at the U.S. Department of Energy's Argonne National Laboratory, provides ultra-bright, high-energy storage ring-generated x-ray beams for research in almost all scientific disciplines. https://www1.aps.anl.gov/, last accessed 2 August 2016	Since 1995	Argonne, US
Australian Synchrotron (complementary)	The Australian Synchrotron is a national research facility that uses accelerator technology to produce a powerful source of light – x-rays and infrared radiation – a million times brighter than the sun. The facility has ten different experimental stations, or beamlines, which harness that light so researchers can see the fundamental structure and composition of materials, on scales ranging from the atomic to the macroscopic. http://www.synchrotron.org.au/, last accessed 15 September 2016	Since 2007	Melbourne, AU
BNCEM – Beijing National Center for Electron Microscopy (competing)	BNCEM operates five high-end electron microscopes. It is planned to develop BNCEM into the largest cryo EM laboratory worldwide. http://www.tsinghua.edu.cn/publish/mseen/179/2011/20110418085408427394686/20110418085408427394686_.html, last accessed 15 September 2016	Start of establishment in 2006	Beijing, CN
CCEM – Canadian Centre for Electron Microscopy (competing)	CCEM was established to provide Canadian and international researchers world-class facilities to study materials at unprecedented spatial and energy resolution. The mandate of the centre is to provide unique electron microscopy capabilities and expertise to researchers working on a broad range of materials research. http://ccem.mcmaster.ca/index.shtml, last accessed 15 September 2016	Since 2005	Hamilton, CA
CNMS – Center for Nanophase Materials Sciences at Oak Ridge National Laboratory (competing)	CNMS at Oak Ridge National Laboratory (ORNL) integrates nanoscale science with neutron science; synthesis science; and theory, modelling, and simulation. Operating as a national user facility, the CNMS support a multidisciplinary environment for research to understand nanoscale materials and phenomena. https://www.ornl.gov/facility/cnms, last accessed 15 September 2016	Since 2006	Oak Ridge, US
DIAMOND – Diamond Light	DIAMOND is the UK's national synchrotron science facility. The facility is used by over	Since 2007	Didcot, UK

Source (complementary)	3,000 academic and industrial researchers across a wide range of disciplines including structural biology, energy, engineering, nano-science and environmental sciences. http://www.diamond.ac.uk, last accessed 15 September 2016		
eBIC – electron Bio-Imaging Centre (competing)	eBIC is located at Diamond Light Source and enables scientists to combine their techniques with many of the other cutting-edge approaches that Diamond offers; whilst a partnership with the University of Oxford allows users to access the Polara, a high-containment cryo-electron microscope. eBIC provides scientists with state-of-the-art experimental equipment and expertise in the field of cryo-electron microscopy, for both single particle analysis and cryo-tomography. Currently eBIC has two Titan Krios microscopes whereas the Polara microscope is located at the University of Oxford. http://www.diamond.ac.uk/Science/Integrated-facilities/eBIC.html, last accessed 03 April 2017	Official opening in April 2017	Didcot, UK
Electron Microscopy Facility at Brookhaven National Laboratory (competing)	The Electron Microscopy Facility at Brookhaven National Laboratory consists of four transmission electron microscopes, two of which are highly specialized instruments capable of extreme levels of resolution, achieved through spherical aberration correction. The facility is also equipped with extensive sample-preparation capabilities. The scientific interests of the staff focus on understanding the microscopic origin of the physical and chemical behaviour of materials, with specific emphasis on in-situ studies of materials in native, functional environments. https://www.bnl.gov/cfn/facilities/microscopy.php, last accessed 15 September 2016	Not specified	Brookhaven, US
EMC – Electron Microscopy Center at Argonne National Laboratory (competing)	EMC develops and maintains unique capabilities for electron beam characterization and applies those capabilities to solve materials challenges. EMC emphasizes three major areas: materials research, experimental technique and instrumentation development, and operation of unique and state-of-the-art instrumentation. http://www.anl.gov/cnm/group/electron-microscopy-center, last accessed 1 August 2016	Not specified	Argonne, US
ePSIC – electron Physical Science Imaging Centre (complementary)	ePSIC is the result of a collaboration between Johnson Matthey, Oxford University and Diamond Light Source. As part of Diamond's hard X-ray nanoprobe beamline (I14) and electron microscopy centre, Oxford University brings a unique JEOL 300kV electron microscope dedicated to atomic scale imaging at world-leading resolution and Johnson Matthey installs a world-leading JEOL double-EDX and EELS capable microscope dedicated to chemical analysis with atomic scale resolution.	Since 2016	Didcot, UK

	http://www.diamond.ac.uk/Science/Integrated-facilities/ePSIC.html, last accessed 30 March 2017		
ESRF – European Synchrotron Radiation Facility (complementary)	The ESRF is the world's most intense an X-ray source and a centre of excellence for fundamental and innovation-driven research in condensed and living matter science. X-ray radiation is used in fields as diverse as protein crystallography, earth science, palaeontology, materials science, chemistry and physics. http://www.esrf.eu, last accessed 15 September 2016	Since 1994	Grenoble, FR; 21 partner nations in all
FELMI-ZFE – Austrian Centre for Electron Microscopy and Nanoanalysis (competing)	FELMI-ZFE is a microscopy facility in the physical and biological sciences. The centre consists of two institutions working together: the Institute of Electron Microscopy and Nanoanalysis (FELMI) and the Graz Centre for Electron Microscopy (ZFE). FELMI's main research activities are devoted to developing new microscopic characterisation methods, functional nanostructures, and the practical applications of advanced microscopy. http://portal.tugraz.at/portal/page/portal/felmi/, last accessed 15 September 2016	Since 1951	Graz, AT
FLASH – Free-electron laser in Hamburg (complementary)	FLASH, the Free-Electron LASer in Hamburg, started user operation in summer 2005 as the first free-electron laser for VUV and soft X-ray radiation. Ultra-short X-ray pulses shorter than 30 femtoseconds are produced using the "self-amplified spontaneous emission" (SASE) process. http://flash.desy.de/, last accessed 16 September 2016 http://photon-science.desy.de/facilities/flash/index_eng.html, last accessed 18 October 2016	User operation since 2005	Hamburg, DE
FRM II – The Research Neutron Source Heinz Maier-Leibnitz (complementary)	FRM II is a central scientific institute of the Technical University of Munich. It provides neutrons for science, industry and medicine in four cycles of 60 days a year. https://www.frm2.tum.de, last accessed 16 September 2016	Since 2005	Munich, DE
ILL – Institut Laue-Langevin (complementary)	ILL is an international research centre with a high reputation in neutron science and technology. It provides scientists with a very high flux of neutrons feeding some 40 state-of-the-art instruments. https://www.ill.eu/, last accessed 16 September 2016	Since 1967	Grenoble, FR; DE; UK
ISIS – ISIS Neutron and Muon Source (complementary)	The ISIS pulsed neutron and muon source at the Rutherford Appleton Laboratory in Oxfordshire is a centre for research in the physical and life sciences. ISIS produces beams of neutrons and muons that allow scientists to study materials at the atomic level using a suite of instruments, often described as 'super-microscopes'. http://www.isis.stfc.ac.uk/, last accessed 2 August 2016	Since 1985	Didcot, UK
J-PARC – Japan	J-PARC consists of a series of proton accelerators and the experimental facilities that	Since 2008	Tōkai, JP

Proton Accelerator Research Complex (complementary)	make use of the high-intensity proton beams. It is operated by the High Energy Accelerator Research Organization and the Japan Atomic Energy Agency http://j-parc.jp/, last accessed 2 August 2016		
LCLS – Linac Coherent Light Source (complementary)	LCLS is a free electron laser facility located at SLAC (Stanford Linear Accelerator Center). LCLS takes X-ray snapshots of atoms and molecules at work, revealing fundamental processes in materials, technology and living things. Its snapshots can be strung together into movies that show chemical reactions as they happen. https://portal.slac.stanford.edu/sites/lcls_public/, last accessed 2 August 2016	Since 2009	Menlo Park, US
MCEM – Monash Centre for Electron Microscopy (competing)	MCEM is a central university Research Platform that conducts research in electron microscopy, and provides advanced instrumentation, expertise and teaching in electron microscopy. The MCEM suite of advanced instrumentation can determine the composition, structure and bonding of materials down to the atomic scale. https://platforms.monash.edu/mcem/, last accessed 1 August 2016	Since 2002	Clayton, AU
NCEM – National Center for Electron Microscopy at Lawrence Berkeley National Laboratory (competing)	NCEM features cutting-edge instrumentation, techniques and expertise required for exceptionally high-resolution imaging and analytical characterization of a broad array of materials. Having merged with the Molecular Foundry in 2014, the facility continues to conduct fundamental research relating microstructural and microchemical characteristics to materials properties and processing parameters, and develops advanced electron microscopy techniques, computer algorithms and instrumentation. http://foundry.lbl.gov/facilities/ncem/, last accessed 1 August 2016	Established in 1983	Berkeley, US
NCHREM – The National Centre for High Resolution Electron Microscopy (competing)	The NCHREM is capable of investigating the structure of materials on an atomic scale with an ultimate resolution of 0.12 nm (information limit). The chemical composition on a local scale (0.3 nm) can also be studied by the use of energy dispersive X-ray analysis. In addition, the unique combination of the atomic structure, the chemical composition, and the electronic structure on a local scale (0.2 nm) is available for service provision by the implementation of EELS and energy filtered imaging. http://nchrem.nl/, last accessed 29 July 2016	not specified	Delft, NL
nCHREM – The National Center for High Resolution Electron Microscopy (competing)	nCHREM offers expertise in imaging, element analysis, and sample preparation for a wide variety of sample types. http://www.polymat.lth.se/nchrem/, last accessed 29 July 2016	Since 1987	Lund, SE
NCMI – National	The missions of NCMI include technology development driven by a diverse spectrum of bio-	Not specified	Houston, US

Center for Macromolecular Imaging (competing)	logical samples to (1) achieve reliable atomic resolution structures of molecular machines; (2) derive structures from conformationally variable machines, and (3) characterize subcellular complexes within intact cells in normal and pathological states. http://ncmi.bcm.edu/ncmi, last accessed 1 August 2016		
NeCEN – The Netherlands Centre for Electron Microscopy (competing)	NeCEN is the open access research facility for cryo electron microscopy in The Netherlands and offers research institutes and companies access to advanced cryo electron microscopy and expertise. The cryo electron microscopes at NeCEN are specifically designed to explore complex biological structures. http://www.necen.nl/, last accessed 29 July 2016	Since 2012	Leiden, NL
NSLS II – National Synchrotron Light Source II (complementary)	NSLS II's purpose is to provide extremely bright x-rays for basic and applied research in biology and medicine, materials and chemical sciences, geosciences and environmental sciences, and nanoscience. Operated by Brookhaven National Laboratory. https://www.bnl.gov/ps/, last accessed 2 August 2016	Since 2015	Brookhaven, US
OPAL – Open Pool Australian Light-water (complementary)	Australia's OPAL reactor is a state-of-the-art 20 Megawatt reactor that uses low enriched uranium (LEU) fuel to achieve a range of nuclear medicine, research, scientific, industrial and production goals. OPAL is one of a small number of reactors with the capacity to produce commercial quantities of radioisotopes. Operated by the Australian Nuclear Science and Technology Organisation. http://www.ansto.gov.au/AboutANSTO/OPAL/, last accessed 2 August 2016	Since 2007	Sydney, AU
PETRA III – Positron-Electron Tandem-Ring Facility (complementary)	PETRA III, which took up operation in 2009, is a storage-ring-based X-ray radiation source. The special characteristic of PETRA III is the tightly collimated X-ray beams, which are up to 5000 times finer than a human hair. These make it possible to study extremely small samples, such as tiny protein crystals or nanocrystals that will be used in the hard drives of the future. PETRA III can also generate very "hard" (i. e. short-wavelength) X-rays, which penetrate deeper into materials than other X-ray radiation. http://petra3.desy.de/, last accessed 6 October 2016 http://www.desy.de/about_desy/desy/large_scale_facilities_for_science/index_eng.html, last accessed 18 October 2016	Since 2009	Hamburg, DE
SACLA – SPring-8 Angstrom Compact free electron Laser (complementary)	SACLA is a linear-accelerator-based XFEL built on the basis of the principle of SASE (Self-Amplified Spontaneous Emission). SACLA consists of an 8 GeV linear electron accelerator followed by in-vacuum undulators measuring 50 to 90 meters. Downstream of the linear accelerator, a dipole magnet switches the electron beam pass into five different FEL lines	Since 2011	Sayo, JP

	and a beam-transport to the Spring-8 storage ting. SACLA is operated by RIKEN (Institute of Physical and Chemical Research). Both SACLA and Spring-8 are housed by the RIKEN Spring-8 Center. http://xfel.riken.jp/eng/, last accessed 6 October 2016 http://www.riken.jp/~/media/riken/pr/publications/pamphlets/rsc-en.pdf, last accessed 18 October 2016		
SciLifeLab – Science for Life Laboraroty (competing)	SciLifeLab is a national centre for molecular biosciences with focus on health and environmental research. SciLifeLab provides large-scale molecular bioscience technologies and services within various fields of life science including next generation sequencing, SNP genotyping, mass spectrometry, affinity proteomics, small molecule and RNAi high-throughput screening, comparative genetics and bioimaging. Extensive bioinformatics support for analysing data is also provided. https://www.scilifelab.se/, last accessed 6 October 2016 https://www.scilifelab.se/wp-content/uploads/2013/09/Trycksak_140x297_EO03_webb.pdf, last accessed 18 October 2016	Since 2010	Stockholm and Umeå, SE
SNS – Spallation Neutron Source (complementary)	SNS produces neutrons with an accelerator-based system that delivers short (microsecond) proton pulses to a target/moderator system, where neutrons are produced by a process called spallation. State-of-the-art experiment stations provide a variety of capabilities for researchers across a broad range of disciplines, such as physics, chemistry, materials science, and biology. Operated by Oak Ridge National Laboratory. https://neutrons.ornl.gov/sns, last accessed 2 August 2016	Since 2007	Oak Ridge, US
SOLEIL – Optimized Source of LURE Intermediary Energy Light (complementary)	SOLEIL offers high-tech equipment using synchrotron light available in specialized laboratories called beamlines, to analyse, characterize, and monitor inert and living materials. A complete range of services, adapted to the specific needs of each client, is also provided by SOLEIL's teams of engineers and researchers. http://www.synchrotron-soleil.fr/, last accessed 2 August 2016	Since 2006	Saint-Aubin, FR
SPring-8 – Large-scale Synchrotron Radiation Facility (complementary)	Spring-8 is the Japanese national synchrotron facility. Synchrotron radiation produced at SPring-8 is used for materials analysis and biochemical protein characterization. It is operated by RIKEN (Institute of Physical and Chemical Research). Both SACLA and Spring-8 are housed by the RIKEN Spring-8 Center. http://www.spring8.or.jp/en/, last accessed 2 August 2016	Since 1997	Sayo, JP
SuperSTEM – The	SuperSTEM supports a wide variety of multi-	Since 2003	Daresbury,

National Facility for Abberation Corrected STEM (competing)	disciplinary research by providing access to cutting-edge instrumentation, state-of-the-art data analysis as well as expertise and training in electron microscopy. http://www.superstem.com/, last accessed 6 October 2016		UK
Planned research infrastructures/under construction			
CSSB – Centre for Structural Systems Biology (competing)	CSSB is a joint initiative of nine research partners from Northern Germany, including three universities and six research institutes. It devotes itself to infection biology and medicine by utilizing structural and molecular biology methods and imaging techniques in conjunction with systems biology approaches. Its purpose is to unravel the underlying mechanisms of important pathogenic processes in order to discover more effective treatment options against bacterial and viral pathogens. The operation of a number of cryo electron microscopes is planned. http://www.cssb-hamburg.de/, last accessed 6 October 2016	Cooperation agreement signed in 2012; construction of CSSB building to be completed in 2017	Hamburg, DE
ESS – European Spallation Source (complementary)	ESS is one of the largest science and technology infrastructure projects being built today. The facility design and construction includes the most powerful linear proton accelerator ever built, a 4-tonne, helium-cooled tungsten target wheel, 22 state-of-the-art neutron instruments, a suite of laboratories, and a supercomputing data management and software development centre. ESS entered the ESFRI Roadmap in 2006 and is currently an ESFRI-Landmark on the Roadmap 2016. https://europeanspallationsource.se/, last accessed 3 August 2016	User programme to begin in 2023; construction to be completed in 2025	Facilities in Lund, SE and Copenhagen, DK; members: CZ, DK, EE, FR, DE, HU, IT, NO, PL, SE, CH, UK; intent to become members: BE, NL, ES
European XFEL – European X-Ray Free-Electron Laser (complementary)	The European XFEL will generate ultrashort X-ray flashes—27 000 times per second and with a brilliance that is a billion times higher than that of the best conventional X-ray radiation sources. Using the X-ray flashes of the European XFEL, scientists will be able to map the atomic details of viruses, decipher the molecular composition of cells, take three-dimensional images of the nanoworld, film chemical reactions, and study processes such as those occurring deep inside planets. It is operated by DESY (German Electron Synchrotron). http://www.xfel.eu/en/, last accessed 3 August 2016	From 2017	Located in Hamburg, DE; partner countries: DK, FR, HU, IT, PL, RU, SK, ES, SE, CH
LCLS II – Linac Coherent Light Source II (complementary)	LCLS-II will be an upgrade of the Linac Coherent Light Source (LCLS) – a hard X-ray free-electron laser at the SLAC National Accelerator Laboratory. LCLS-II will provide a major jump in capability – moving from 120 pulses per second to 1 million pulses per second. https://portal.slac.stanford.edu/sites/lcls_	Scheduled to begin operations in early 2020s	Menlo Park, US

	public/lcls_ii/, last accessed 6 October 2016		
SwissFEL – Swiss Free Electron Laser (complementary)	The SwissFEL, being built at the Paul Scherrer Institute, will produce very short pulses of X-ray light, with laser-like properties. Researchers will be able to use these pulses to visualize extremely fast processes, such as how new molecules are created in a chemical reaction; to determine the detailed structure of vital proteins; or to determine the relationship between electronic and atomic structure in materials. https://www.psi.ch/swissfel/, last accessed 6 October 2016	From 2016	Villigen, CH

I.3 European Solar Telescope (EST)

I.3.a Scientific potential

Description

According to the proposal, EST will help to improve the study of the fundamental interactions between the plasma, the magnetic field and radiation in the solar atmosphere by enabling a more thorough observation of a variety of energetic events resulting from these interactions. From the expected deeper insights into these fields both the disciplines of plasma physics and stellar physics will benefit.

EST will employ multi-conjugate adaptive optics and integral-field spectropolarimeters to resolve scales of 20 km in the solar atmosphere that is to observe astrophysical processes at their intrinsic scales. The following key questions will be addressed:

_ What can the sun teach us about fundamental astrophysical processes?

_ What drives solar variability on all scales?

_ What is the impact of solar activity on life on Earth?

EST will simultaneously observe in various wavelengths in order to exploit the solar photon flux more efficiently than other current ground-based or space telescopes. The implementation of a powerful adaptive optics system is essential to correct the distorted wave front across the full 4 m aperture of the telescope. Thereby the spatial resolution power is only limited by the size of the telescope aperture.

EST will be equipped by a suite of postfocus instruments, including a broadband imager, three narrow-band spectropolarimeters based on Fabry-Pérot interferometers, and four grating spectropolarimeters for different wavelength bands, with integral-field units. Based on the experience with other astronomical telescopes, the proposers expect the availability of a new generation of instruments after about 10 to 15 years.

According to the proposal, over the last 25 years, different European countries built telescopes for solar observation on the Canary Islands. |[78] Except for the recently inaugurated German telescope GREGOR, the European high-resolution solar physics facilities have been in operation for 15 to 30 years and their technology is ageing. With the instalment of EST, Europe is expected to be able to hook up to the previous development and to ensure continuity in this research field. Through its specialisation in high-precision polarimetry at many simultaneous wavelengths, EST is furthermore described as being able to catch up or even outperform the US American Daniel K. Inouye Solar Telescope (DKIST), which is focused on observing the solar corona and therefore has been built as off-axis telescope. By contrast, EST's focus are small-scale magnetic fields in the photosphere and chromosphere, which is the reason for its design as on-axis telescope. In that respect, EST and DKIST are expected to complement each other.

Assessment

Solar physics is a cornerstone of astrophysics and a prerequisite for understanding the space weather environment of the Earth and, potentially, exoplanets around solar-type stars. The field has witnessed fundamental breakthroughs in recent years in broadly the following areas:

_ Solar neutrino problem in elementary particle physics and its resolution,

_ Helioseismology as diagnostics of the interior solar structure,

_ Solar magnetic fields and how they underlie all solar activities.

Solar Physics is a vital and dynamic area of scientific research. High resolution observations have revealed the fine structure of sunspots, numerous wave modes in the solar atmosphere, and magneto-convection. Understanding the processes by which magnetic energy is built up in the solar atmosphere and released in the form of radiation, fast particles, and large-scale mass ejections are central research questions in solar physics and necessary to understand solar-type stars.

Progress toward answering these questions requires a ground-based research infra-structure (RI) in the form of a large aperture (4 m or greater) telescope and state-of-the-art instruments to simultaneously achieve high angular reso-

|[78] There are to be found the GREGOR-Telescope, the Heliographic Telescope for the Study of the Magnetism and Instabilities on the Sun (THEMIS), the Vacuum tower telescope (VTT), the Swedish Solar Telescope (SST), the Dutch Open Telescope (DOT) and the Solar Laboratory.

lution, high temporal resolution, and high polarimetric sensitivity. In this way, the EST is an important and timely initiative taken by the European community and spearheaded by German (and Spanish) institutions to construct a major observational facility for studying the Sun at high resolution. The EST will enable the discovery of small-scale energy release in flares and is expected to reveal the mechanisms of coronal heating and space weather. Germany will undoubtedly take a leading role in such discoveries, as well as play a leading role in the instrumentation of EST.

The high spatial resolution (around 10 km on the solar surface) and extraordinary polarisation sensitivity (< 0.01 %) of EST will resolve many fundamental questions in astrophysics. EST covers a wide range of visible and near-infrared wavelengths and consequently will be complemented by UV/EUV (ultraviolet/extreme ultraviolet) and X-ray observations from satellites (such as the European Solar Orbiter mission), as well as radio observations. EST will contribute to innovative technologies, especially in the areas of Multi-Conjugate Adaptive Optics (MCAO), detector development, and ultra-precise polarimetry.

The only competing international facility that is under development is the US 4 m Daniel K. Inouye Solar Telescope (DKIST). Together, EST and DKIST will enable a greater understanding of several profound questions, such as the detailed nature of the sun's magnetic field from the surface to the corona. Furthermore, EST and DKIST are complementary in terms of their locations, separated 138 degrees in longitude, which will allow a coverage of the full 24h duty cycle. Other existing facilities such as the 1.6 m New Solar Telescope (NST) will provide complementary observations to EST. EST will also complement several existing or proposed space based RIs, among which the ESA Solar Orbiter mission is of particular importance.

I.3.b Utilisation

Description

EST will serve a pan-European user community. Potential users of EST are a group of 400-500 European solar physicists. The proposing institutions aim at a total of 240 observing days per year. The observing programme will be conducted in two modes – in the 'principal investigator mode' (PI mode) and the 'queued service mode' (QS mode). In the PI mode, observers will in collaboration with the EST staff perform the observation directly and will work at the telescope. It will as well be possible to remotely access the telescope and instruments controls from the Telescope Operation and Sciences Centre (TOSC) at sea-level and the SDC in Germany. In the QS mode, researchers can ask for permission to receive observing-time and an on-site scientist especially appointed for this task will decide on which observing programme will be executed at which time. In this mode the actual execution of the observing run will be performed by scientific observing staff of EST. EST will assign increasingly more observing time to the QS mode, which will become the standard mode of observation. As a consequence two groups of users of EST can be identified: the described observers in situ and the virtual observatory users. This second group will, according to the proposal, benefit from the open access to the EST data which will be disseminated via virtual observatories.

To enable a broad range of science inquiries, the data created out of the facility instruments will be managed and processed by a distributed operational data centre, with resources for data access housed at the SDC in Germany, but with core storage in the Canaries. The SDC's tasks will comprise several functions, including data processing pipelines, a petascale storage infrastructure and an advanced networking infrastructure to achieve reliable transfer of data from the telescope to the EST headquarters.

Ground-based solar observations suffer from instrumental effects and from effects of atmospheric seeing. This constitutes a great challenge for the data pipelines that produce science-ready data. It will be the task of the SDC to ensure that the science-ready data are free of artefacts introduced by atmospheric seeing or instrumental effects. Additionally, the EST consortium plans to impose rules ensuring good scientific practice for the usage of EST data.

Assessment

EST will provide both service and principal investigator (PI) modes of operation. The target selection can be adjusted quickly according to solar activity in real time. Second-generation instruments (for which development funding is included) and visiting instruments will enable the RI to respond to new or evolved scientific questions in the second half of its operational lifetime. The design of the RI allows for accommodating new instruments.

EST will be the flagship RI for the entire European solar physics community, which is among the largest in the world. Non EST-consortium users are likely to utilise 10-20 % of the telescope observing time. Although there are about 500-600 solar physicists in Europe of which a large fraction are observers, EST is expected to be in high demand and heavily oversubscribed both for direct use and for archive data via virtual observatories. Since smaller solar telescopes as the Vacuum Tower Telescope (VTT) and GREGOR on Tenerife will be decommissioned by 2026, EST would be the only major ground-based facility available at that time to the European solar community for observations. Moreover, many international researchers from non-EST consortium member countries will continue or initiate collaborations with German colleagues through access to EST. They will also benefit from German expertise.

The proposers have correctly recognised the importance of training young researchers for effective utilisation of the facility. Presently, this is being carried out mainly through the EU-funded SOLARNET |[79] project.

The utilisation concept is sound and reflects long experience with existing RIs. Many measures in the proposal are excellent for its management and service. High-level planning and decisions will be taken by a Council consisting of delegates from all member countries. Access to the facility will be managed by a Time Allocation Committee that comprises experienced scientists appointed by the Board of EST Science. The proposed observing time allocation process is conventional and adequately represents the user community. The gradual transition from the PI-mode to a more efficient queued service mode is well considered.

The top-level concept for handling, processing, archiving, and distributing data is sound and reflects considerable experience acquired through the European SOLARNET consortium and standard-based virtual observatories. Importantly, the EST Science Data Center will be hosted in Freiburg.

The project team has carefully planned its strategy in dealing with various issues. EST will have an open data policy after a one-year proprietary period, which is a welcome step.

EST satisfactorily addresses ethical standards and good scientific practice through reference to European and German standards.

I.3.c Feasibility

Description

As important technological challenges for EST the proposal describes the development of a new generation of detectors for observations at high framerates and large fields of view (also for high-precision polarimetry), the development of a Fabry-Pérot interferometer with a control of the parallelism of the etalon plates that reaches a precision 1^{-10} m, new techniques for 2D solar spectro-polarimetry, the development of large-format liquid-crystal modulators and evaluating the performance of the EST-MCAO (multi-conjugate adaptive optics) deformable mirrors. To meet these challenges, the project H2020 |[80] “GREST – Getting Ready for the EST” was installed. The project’s aim is to improve the performance of the current state-of-the-art instrumentation of EST by addressing legal, industrial and socio-economic issues.

|[79] High Resolution Solar Physics Network

|[80] Horizon 2020

Among potential risks in the process of instalment and maintenance, the proposers describe firstly the used new-generation instruments regarding spectroscopy. Although integral-field spectroscopy is a technique often used in night-time astronomy, no such instruments operate at any solar telescope so far. Furthermore, the MCAO system included in the optical path of the telescope contains risks: It is described as the most complex system ever designed with five deformable mirrors included. A third risk can be identified in the used cameras and near-infrared (NIR) detectors: For the visible and near-UV spectral range the project will use both commercial cameras and dedicated sensors and camera systems. Dedicated camera developments, however, involve the risk that the initial performance requirements cannot be fully met within the initial development schedule and budget.

Following the proposers' description, the EAST consortium agrees that a European Research Infrastructure Consortium (ERIC) would be the most appropriate structure providing an adequate framework of transnational cooperation among the partners involved. The baseline governance concept includes an EST council, a board of EST science, a director, an administrative and finance committee, as well as a scientific and technical committee.

The procedure of selecting and hiring human resources is described as a key issue of the project. The chair of the directorate will be appointed first. This person shall be independent of other scientific organisations or funding agencies and shall be fully employed by the EST organisation, while the heads of the TOSC and the SDC may be employees of specific EAST institutions. Specific activities of the technical and scientific operations may be outsourced.

Assessment

The scientific objectives of the RI are mature, as is the 4 m telescope concept (including site selection) for a project at the proposal stage. The instruments in core form are relatively mature in that they are based on realised instruments with which members of the EST consortium have great experience. The concept and planning of the EST is initiated by EAST, a consortium of 15 European institutions supporting solar physics. EAST has completed a conceptual design study and is currently carrying out integration and development studies with costs of about 20 MEUR . These are mostly funded by various European programmes, such as SOLARNET (2013–17), GREST (2015–18), and PRE-EST |[81] (2017–21). EST is included in the ESFRI roadmap 2016. However, the instruments in their "aspirational" forms, including elements such as next-generation detectors, integral field units, tight-tolerance etalons, and large-

| [81] Preparatory Phase of the European Solar Telescope

aperture liquid crystal modulators, are at uneven and lower technical readiness levels. The data concept is similarly at a lower state of development that is adequate at this stage of the project.

The risk estimates look convincing and conservative, because the cost estimates are based on experiences from existing solar telescopes (in which both German main institutes are heavily active and involved) and from night-sky telescopes of the same mirror size.

The technical and related aspects of the project have undergone considerable scrutiny and the present proposal is a culmination of an effort that began several years ago. The telescope instruments pose the major remaining technical and cost risks, but that risk is mitigated by the extensive experience of the proposing team and their involvement with similar instrumentation at the VTT, GREGOR and DKIST.

An important aspect of the project is the identification of a high-quality observing site that allows the full potential of a 4 m class telescope to be realised. Two sites in the Canary Islands are being considered; both meet this requirement and are already hosting solar or night-time telescopes.

The responsible institutions have carefully planned the RI in their institutions. A consortium has been set up for providing an adequate framework of transnational cooperation among the partners involved. The baseline governance concept includes an EST council, a board of EST science, a director, an administrative and finance committee, as well as a scientific and technical committee.

Human resource development is clearly a critical aspect for the operation of a major facility such as EST. The personnel concept is appropriate from a scientific perspective with regard to adequacy, diversity management, and personnel development. Recruiting a suitable mix of skills for the Assembly, Integration and Verification (AIV) and for the operational phases at the observatory site is a potential challenge, although experienced personnel should become available as EST ramps up and existing facilities ramp down. The fact that key scientific skills reside at European partner institutions is both a strength (depth of expertise) and a potential challenge to smooth coordination at the project level.

I.3.d Relevance to Germany as a location of science and research

Description

According to the proposal, Europe in general and Germany in particular currently play an important and leading role in Solar Physics, especially with regard to ground-based solar observation facilities. Of the current leading inversion codes for inferring the solar magnetic field almost all have been developed by European institutions, and the solar groups in Freiburg and Göttingen are described as having an important role in the development and usage of these. According to the proposal, with the advent of the American four-metre-class solar telescope DKIST, Europe could be threatened to lose its leading role in ground-based solar instrumentation. Given the described situation, EST could play an essential role to ensure Germany's and Europe's leading role in ground-based solar physics. Next to this, the developments in solar theory are described as greatly benefitting from EST. Especially leading groups on three-dimensional numerical models of magnetoconvection near the surface based in Norway, Denmark, UK and Germany are described as profiting from high-standard observing facilities.

With regard to transfer and impact, the proposers argue that the field of solar physics is a solid provider of new concepts and technologies for other fields of wide industrial and socio-economic impact. One of the ten work packages in the related project EU FP7 "SOLARNET – High-resolution Solar Physics Network" [82] is devoted to developing the transfer of innovation to the industry. Its goal is to identify and analyse technologies, techniques and new concepts that are in use at the forefront of solar physics and might be of interest for other sectors.

Assessment

Although the present research infrastructures (VTT and GREGOR) make Germany attractive internationally as a hub of solar physics, this situation is likely to change in the next decade e. g. by the advent of the 4 m DKIST telescope beginning in 2019. Only with EST as an equally strong and complementary new facility will it be possible to guarantee a high international visibility for German solar physics and astrophysics that will retain Germany's and Europe's dominant position for solar physics. Moreover, the German astronomical community strongly supports this project and will include it in its forthcoming "Whitebook". The membership of Germany is essential to the RI on scientific, technical, and financial grounds.

EST represents a unique opportunity for further enhancing the already existing attractiveness of Germany as a location for science and research in solar physics, because EST will be one of only two 4 m solar telescopes in the world. This is in contrast to multiple 8 m and larger aperture night-time telescopes. The proposal rightly points out that EST will enable Germany and Europe to retain its dominant position as a top research centre and attract the best young minds to the project as well as the most talented scientists to use the facility. EST will strongly support young academics by providing them priority access

[82] An ongoing related project with the goal of integrating all the major European infrastructures in the field of high-resolution solar physics including EST.

to, and active participation in, a state-of-the-art RI. Simply put, there is no stronger recruiting and career support tool than a well-conceived flagship telescope.

EST is expected to contribute to dramatic advances in understanding the Sun that will lead to predictive models. It will provide spin-off in many areas of technology. Adaptive Optics has application in military and medical areas. Image processing techniques are highly relevant to computer sciences. Space Weather prediction is critical for human beings and society, including communication and aviation. The project has a work package specifically devoted to transfer to new technologies and knowledge to industry. However, presently there is hardly any information on the societal and economic impacts. The proposed RI can be expected to have important social and economic impacts over its operational lifetime because it will play a key role in understanding the build-up and release of magnetic energy in the solar atmosphere, which is the source of all space weather effects.

Principal remaining technical and cost risks are associated with the telescope instrumentation which is not yet at the level of maturity as the rest of the project concept. However, there is time to mitigate these risks before the advent of construction.

The proposers have yet to finalise the human resource requirements for the project, which needs to be done expeditiously.

I.3.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
	Forerunners		
SUNRISE I **SUNRISE II**	SUNRISE is a balloon-borne solar observatory dedicated to the investigation of the key processes governing the physics of the magnetic field and the convective plasma flows in the lower solar atmosphere. SUNRISE is designed for operation in the stratosphere (at heights around 37 km) in order to avoid the image degradation due to turbulence in the lower terrestrial atmosphere and to gain access to the UV range down to 200 nm. Launched from above the polar circle at solstice conditions, SUNRISE enables an uninterrupted view at the Sun for extended periods of several days. http://www.mps.mpg.de/solar-physics/sunrise, last accessed 09 August 2016	SUNRISE I: 2009 SUNRISE II: 2013	DE (coordinating), US, ES
	Existing research infrastructures		
ALMA – Atacama Large Millimeter	Telescope to study light from some of the coldest objects in the Universe. This light has	Since 2013 (partial ob-	Chajnantor plateau, CL;

Array	wavelengths of around a millimetre, between infrared light and radio waves, and is therefore known as millimetre and submillimetre radiation. ALMA comprises 66 high-precision antennas, spread over distances of up to 16 kilometres. This global collaboration is the largest ground-based astronomical project in existence. http://www.eso.org/public/teles-instr/alma/, last accessed 08 August 2016	servations since 2011)	US; JP; CA; TW; KR; ESO
DOT – Dutch Open Telescope	Solar telescope located at the Observatorio del Roque de los Muchachos of the Instituto de Astrofïsica de Canarias. The DOT achieves high-resolution imaging of the sun simultaneously in multiple wavelengths which sample the solar atmosphere tomographically at different heights. The DOT is a reflector with a parabolic mirror that sits out in the open at a height of 15 m. The mirror (presently Cervit, 45 cm diameter, focal length 200 cm) focuses the incoming beam onto a water-cooled 1.6 mm field stop that reflects most of the image out of the telescope and transmits only a 2.5 by 2.5 arcmin subfield to the re-imaging optics and cameras. http://www.staff.science.uu.nl/~rutte101/dot/, last accessed 08 August 2016	First light: 1997	La Palma, Canary Islands, ES; NL
DST – Dunn Solar Telescope	The **Richard B. Dunn Solar Telescope** (DST) specializes in solar high resolution imaging and spectroscopy. It has two high-order adaptive optics benches to compensate for blurring by Earth's atmosphere, and a 40-foot-wide observing platform hosting an array of instruments. Scientists and engineers use the Dunn to investigate a range of solar activities, often in concert with satellites, and to develop new technologies for the 4-meter Advanced Technology Solar Telescope. http://nsosp.nso.edu/dst, last accessed 08 August 2016	Since 1969 (named "Vacuum Tower Telescope" until 1998)	Sacramento Peak, New Mexico, US
GREGOR (complementary)	GREGOR is the largest solar telescope in Europe. It is designed for observations of the solar photosphere and chromosphere in the visible and near infrared. Presently it is equipped with the following post-focus instruments for solar observations: _ a multi-channel high-resolution imager _ a filter spectrometer for the measurement of material flows and magnetic field in different layers of the solar atmosphere _ a grating spectro-pollarimeter for the near infrared (1.0 to 2.2 μm) GREGOR is equipped with a high-order adaptive optics, which is presently being upgraded to a multi-conjugated system.	Since 2012	Teide Observatory, Tenerife, ES; DE

	www.kis.uni-freiburg.de/en/observatories/gregor/, last accessed 03 August 2016 RI will be shut down after EST is operational.		
Kodaikanal Observatory	The Kodaikanal Observatory of the Indian Institute of Astrophysics is located in the Palani range of hills in Southern India. It was established in 1899 as a Solar Physics Observatory and all the activities of the Madras Observatory were shifted to Kodaikanal. A 20 cm refractor at the Observatory is used occasionally for cometary and occultation observations. It is also sometimes made available to visitors for night sky viewing. http://www.iiap.res.in/centers/kodai, last accessed 08 August 2016	Since 1899	Kodaikanal, IN
LOFAR – Low Frequency Array	Radiotelescope system that uses a large number of low-cost sensors (antennas, geophones and more) and relies on broad-band datalinks and advanced digital signal processing to implement the majority of its functionality in (embedded) software. For the astronomy application, LOFAR is an aperture synthesis array composed of phased array stations. The antennas in each station form a phased array, producing one or many station beams on the sky. Multi-beaming is a major advantage of the phased array concept. It is not only used to increase observational efficiency, but may be vital for calibration purposes. The phased array stations are combined into an aperture synthesis array. The Remote Stations are distributed over a large area with a maximum baseline of 100 km within the Netherlands and 1500 km within Europe. http://www.lofar.org/, last accessed 08 August 2016	Since 2010	NL (coordinating), DE, SE, UK, FR
NST – New Solar Telescope (complementary)	The NST is configured as an off-axis Gregorian system consisting of a parabolic primary, prime focus field stop and heat reflector (heat-stop), elliptical secondary and diagonal flats. An off-axis design was chosen principally because of its vastly reduced stray light, since there is no central obscuration, which reduces the telescope's MTF (Modulation Transfer Function) at high spatial frequency. The primary mirror (PM) is 1.7 m with a clear aperture of 1.6 m with a final figure residual error of 16 nm rms. The PM is made of Zerodur from Schott. The PM was figured by Steward Observatory Mirror Lab. The off-axis nature of the PM presented a number of problems in measuring the figure of the mirror. Such measurements will be essential in the precise figuring of large night-time telescopes, like GSMT. https://www.bbso.njit.edu/nst_project.html, last accessed 08 August 2016	First light: 2009	Big Bear Lake, California, US

NVST – New Vacuum Solar Telescope	1m IR solar observation telescope. The main science mission of NVST consists of obtaining high-resolution images and spectra of the sun at wavelengths ranging from 0.3 to 2.5 micrometres, for the purposes of studying the fine structures of solar magnetic fields, and evolutionary processes in high temporal and spatial resolution. The NVST is an altazimuth telescope with a 1200mm vacuum seal and an effective aperture of 980mm, effective field observation of 3 arcmins, focal length of 45m. It incorporates many new technologies, such as the Multi-channel High Resolution Imaging System, the multiband spectrograph, the large dispersion spectrograph, a polarimeter and an adaptive optics system. http://english.ynao.cas.cn/ti/nvst/ last accessed 08 August 2016	First light: 2010	Fuxian Lake, CN
SST – Swedish Solar Telescope	The SST replaced the previous 50 cm Swedish Vacuum Solar Telescope (SVST). The clear aperture of the front lens of the SST has a diameter of just under 1 meter and can see details as small as 70 km on the solar surface. The unobscured optics consists of a singlet lens used as Vacuum window and two secondary optical systems. The first of these enables narrow-band imaging and polarimetry with a minimum of optical surf aces. The second optical system uses a field mirror to re-image the pupil on a 25 cm corrector which provides a perfectly achromatic image, corrected also for atmospheric dispersion. The adaptive optics system is integrated with the design of the telescope but is sufficiently flexible to allow future upgrades. http://dubshen.astro.su.se/, last accessed 08 August 2016	Since 2002	La Palma, ES; SE
THEMIS – Téléscope Héliographique pour l'Etude du Magnetisme et des Instabilité Solaires	Aperture telescope with high-accuracy spectropolarimetry of the solar surface together with monochromatic high resolution imaging. THEMIS has been designed and fabricated to measure the intensity and the direction of the solar magnetic field and one of its main features consists in the possibility to operate on different bands simultaneously. THEMIS is provided with a Ritchey-Chrétien 90cm diameter primary mirror, installed inside the upper part of a 22.5m long cylindrical tower. The frontal part of the telescope is closed by a sort of window which allows the telescope to be vacuum-sealed thus avoiding heavy temperature variations. A 9m diameter dome protects the instrument from the elements. http://www.iac.es/eno.php?op1=3&op2=6&id=2&lang=en http://www.eie.it/en/progetti/themis, last accessed 08 August 2016	First light: 1996	Teide Observatory, Tenerife, ES; FR; IT

Udaipur Observatory	The Udaipur Solar Observatory is situated on an island in the middle of the Lake Fatehsagar and the main office building is located at its NW-shore near Bari Road - Rani Road Junction. The sky conditions at Udaipur are quite favourable for solar observations. The large water body surrounding the telescopes decreases the amount of heating of the surface layers. This decreases the turbulence in the air mass and thereby improves the image quality and seeing. The main objective of obtaining the high spatial and temporal resolution observations of solar photospheric and chromospheric activity is to understand the various dynamic phenomena occurring on the surface of the Sun. https://www.prl.res.in/~uso/ http://www.iiap.res.in/icw05/Posters/P19_Asingh.pdf, last accessed 08 August 2016	Since 1976	Udaipur, IN
VTT – German Vacuum Tower Telescope	Classical solar telescope: two Coelostat mirrors feed the sunlight into the telescope. The primary mirror has a diameter of 70 cm and a focal length of 46 m. The telescope is located in a building with a height of some 38 m spanning more than 10 floors. An adaptive-optics system is permanently installed and available to all instruments; this leads to a substantial improvement of the image quality. On good days, this provides a spatial resolution of about 0.2 arcsec at 500 nm for short exposures, and of some 0.5 arcsec for exposures as long as 10 seconds. www.kis.uni-freiburg.de/en/observatories/vtt/, last accessed 03 August 2016 RI will be shut down after EST is operational.	Since 1988	Teide Observatory, Tenerife, ES; DE
Planned research infrastructures/under construction			
CGST – Chinese Giant Solar Telescope	Due to the advantages of ring structure in polarization detection and thermal control, the current design of CGST is an 8 meter ring solar telescope. The spatial resolution of CGST is equivalent to an 8 meter diameter telescope, and the light-gathering power equivalent to a 5 meter full aperture telescope. https://doi.org/10.1117/12.926033, last accessed 08 September 2016	Not specified (Construction time: 10-15 years)	CN
DKIST – Daniel K. Inouye Telescope	Solar telescope with: _ An angular resolution of 0.1 arcsec or better to resolve the pressure scale height and the photon mean free path _ A high photon flux at the critical spatial resolution for precise magnetic and velocity field measurements _ Access to a broad set of diagnostics, 0.3 to 35 mm The 4-m facility will have broad impacts on astronomy, plasma physics, and solar-	From 2019	Haleakala Observatory, Hawaii, US (coordinating); DE

	terrestrial relations by resolving fundamental astrophysical processes in space and time on the Sun. The DKIST will attack critical details of the non-linear dynamical processes that govern the highly conducting, turbulent solar plasma. The broad research areas are cosmic magnetic fields and solar variability. http://dkist.nso.edu/science/intro, last accessed 09 August 2016		
NLST – National Solar Large Telescope (complementary)	The Indian National Large Solar Telescope (NLST) will be a state-of-the-art 2-m class telescope for carrying out high resolution studies of the solar atmosphere NLST is an on-axis alt-azimuth Gregorian multi-purpose open telescope with the provision of carrying out night time stellar observations using a spectrograph. The telescope utilizes an innovative design with low number of reflections to achieve a high throughput and low instrumental polarization. High order adaptive optics is integrated into the design that works with a modest Fried's parameter of 7-cm to give diffraction limited performance. The telescope will be equipped with a suite of post-focus instruments including a high resolution spectrograph and a polarimeter. http://dx.doi.org/10.1017/S1743921309993206, last accessed 08 September 2016	Early 2020s	Ladakh, IN
Solar Orbiter (complementary)	Solar Orbiter will be used to examine how the Sun creates and controls the heliosphere, the vast bubble of charged particles blown by the solar wind into the interstellar medium. The spacecraft will combine *in situ* and remote sensing observations to gain new information about the solar wind, the heliospheric magnetic field, solar energetic particles, transient interplanetary disturbances and the Sun's magnetic field. The mission will provide close-up, high-latitude observations of the Sun. Solar Orbiter will have a highly elliptic orbit – between 0.9AU at aphelion and 0.28AU at perihelion. It will reach its operational orbit three-and-a-half years after launch by using gravity assist manoeuvres (GAMs) at Earth and Venus. Subsequent GAMs at Venus will increase its inclination to the solar equator over time, reaching up to 25° at the end of the nominal mission (approximately 7 years after launch) and up to 34° in the extended mission phase. http://sci.esa.int/solar-orbiter/51168-summary/, last accessed 09 August 16	Launch: 2018	ESA
Solar-C (complementary)	Using high-resolution spectropolarimetry, SOLAR-C will measure magnetic fields of both the photosphere and the chromosphere. In addition, SOLAR-C will observe the corona at resolutions far higher than with *Hinode*, and will attempt to capture the finescale dynamics of the chromosphere and corona by means of	Launch: 2025-2029	JP (coordinating), US (NASA), ESA

	spectroscopic observations. By determining the diversity of elementary processes (fine-scale structures) and global structures involved with the magnetic field as well as their changes, while at the same time observing the corona at unprecedentedly high resolution, the mission will clarify the processes that create the high-temperature atmosphere of the sun, and also the atmospheres of stars in general. Overall, the mission will yield a complete picture of the sun's vigorously changing magnetic activity. http://hinode.nao.ac.jp/SOLAR-C/Documents/Solar-C_e.pdf, last accessed 09 August 2016		
SPRING – Solar Physics Research Integrated Network Group	SPRING is a project to develop a geographically distributed network of instrumentation to obtain synoptic solar observations. Building on the demonstrated success of networks to provide nearly-continuous long-term data for helioseismology, SPRING will provide data for a wide range of solar research areas. Scientific objectives include internal solar dynamics and structure; wave transport in the solar atmosphere; the evolution of the magnetic field over the activity cycle; irradiance fluctuations; and space weather origins. http://www.solarnet-east.eu/joint-research-activities http://www.kis.uni-freiburg.de/fileadmin/user_upload/forschung/forschungsplan/kis-research-plan-2013-2017.pdf, last accessed 09 August 2016 http://www.mat.uc.pt/~cspm2015/abstracts/113_Markus_Roth.html, last accessed 08 September 2016	Concept Study: 2013-2017	US, ES, AT, BE, HR, CZ, FR, DE, IT, NO, PL, SK, SE, CH, NL, UK
Sunrise III	SUNRISE is a balloon-borne solar observatory dedicated to the investigation of the key processes governing the physics of the magnetic field and the convective plasma flows in the lower solar atmosphere. SUNRISE is designed for operation in the stratosphere (at heights around 37 km) in order to avoid the image degradation due to turbulence in the lower terrestrial atmosphere and to gain access to the UV range down to 200 nm. Launched from above the polar circle at solstice conditions, SUNRISE enables an uninterrupted view at the Sun for extended periods of several days. http://www.mps.mpg.de/solar-physics/sunrise, last accessed 09 August 2016	Not specified	DE (coordinating), US, ES

I.4.a Scientific potential

Description

NPL aims to establish a unique platform for research and development in photonics and photonic technologies. The role of photonics is described as two-fold in the proposal: First, it is an interdisciplinary research topic that enables important contributions to physics, chemistry, material sciences, nanotechnology, engineering, and further fields of research. Second, photonics is used as a universal scientific-technological tool that empowers science to make new discoveries and industry to implement important innovations in areas such as e. g. energy, environment, communications, and medicine.

According to these roles, NPL is oriented along two directions of action. On the one hand, NPL aims at enabling scientific disciplines to carry out their missions. These so-called science cases are said to pose most extreme requirements on optical components and instrumentation to exploit their potential for ground-breaking results. According to the proposal, these components can neither be developed within the respective community itself nor commercially. Promising science cases are:

- Gravitational wave astronomy: In order to employ gravitational waves as a new tool of astronomy to open a new window to the cosmos, the sensitivity of existing detectors has to be improved by at least one order of magnitude.
- Astrophotonics: For currently developed telescopes with mirror dimensions of up to 40 m to unfold their full potential, the performance of the subsequent instruments such as optical gratings for spectrally resolved measurements needs to be increased likewise.
- Extreme light sources incl. quantum physics: In order to gain more detailed insights into the structure of matter, free electron lasers or laser-driven beam sources are used. The crucial challenges are posed by the design, development, and fabrication of specialised optical components.
- High-intensity laser systems: For the advancement of high-intensity ultra-short-pulsed laser systems, which are used e. g. for biomedical applications, optical pulse compression systems based on adapted diffraction gratings are needed.

NPL monitors and advises the science cases' communities in a continuous strategy and investment process and meets the challenge to empower the science cases sustainable to outstanding science. The science case communities reflect, however, no closed and exclusive user community. According to the proposal, the embedding into the scientific and technological network provided by the host institutions allow NPL to address scientific challenges of a broad group of scientific communities, including those of upcoming science cases, such as applied quantum optics.

To help realise the mission of the science cases, NPL is supposed to elevate eight mutually interlinked specific branches of the photonic process chain onto exceptional levels of quality, enabling scientists in these branches of photonics to conduct excellent science. These so-called core technologies correspond to the fields of action of NPL and also result from the technological demands of the science cases. The core technologies encompass:

_ Optics design and modelling: This core technology includes holistic and spatio-temporal design, nano-macro-modelling, and illumination models. Holistic design and modelling enable a more rapid and more secure system development.

_ Sample preparation: The improvement of surfaces by sample cleaning and figuring can result in enhanced optics and open up new applications.

_ Freeform fabrication: In addition to the fabrication of freeforms and low-weight components, structuring plays an important role in this core technology. Freeforms enable light and robust high-performance system designs for all wavelengths.

_ Optical coatings: This field contributes a large pool of coating and atomic layer deposition technologies, as modern optical systems cannot be realised without high-tech coatings.

_ Crystal optics: The core technology crystal optics improves crystal cutting, polishing, structuring and bending techniques. Crystal optics allow for the manipulation of intense radiation from X-ray sources or high power laser light, among other applications.

_ Nanostructuring: The core technology nanostructuring encompasses the fields lithography, etching technologies, and nanoreplication. Subwavelength nanostructures define the new standard of modern optics and can be scaled to sizes of more than 30 cm by NPL.

_ Characterisation: Several analysis methods are used for characterisation, e. g. scattered light, wave field, nanostructure or efficiency analysis. Innovative characterisation techniques enable increasingly powerful fabrication methods.

_ System integration: In this field, joining technologies and component integration are used to create highly integrated optical systems which resist extreme powers, mechanical stress, and temperature variations.

According to the proposal, NPL marks a paradigm shift towards a new era of facility-based photonics research in creating a RI, following the path, which has been successfully plotted out by disciplines such as astronomy and high energy physics.

Currently, similar aspirations in photonics can only be found at the "American Institute for Manufacturing Integrated Photonics" (AIM Photonics) which partly inspired NPL, but which is organised in a decentralised manner. In contrast to NPL, AIM Photonics is focussed on integrated photonics for products in the field of consumer electronics. Both centers are designed in an intrinsically complementary manner; a formal collaboration is currently under development.

It is stressed in the proposal that NPL follows a unique approach, grows on existing structures, is firmly anchored in established, globally visible clusters of excellence, and already is linked to user communities. Moreover, NPL is said to stand out from other institutions having a narrower scope and addressing only individual sub-fields of photonics. Moreover, NPL, as a research infrastructure, is supposed to be unique in its openness towards industrial partners.

Assessment

NPL will fundamentally contribute to scientific breakthroughs in fields of photonics where the limits are set by the status of existing optical technology.

The chosen topics – i. e. science cases – are extremely timely and of very strong interest to the physics community. The focus on these "grand challenges" as primary research field for the centre is unique and of strategic significance. Furthermore, the NPL applicants identified the four science cases with the corresponding key technologies in which they are nationally and internationally competitive. NPL aims at providing a unique and state-of-the-art capability for building components that could not be obtained readily from other sources.

The overall concept of the RI is to develop processes and modify processing equipment to handle large, free-form and heavy components using otherwise typical semiconductor processing know-how. Without this adaptation, the fabrication of these components would be difficult at best and left to other institutions to attempt to solve with inferior capabilities. The focus on the three differentiating characteristics (large, heavy, free-form) is unique world-wide and fills an important niche of key interest to the science community. This does not apply equally to all elements of the proposal, in particular where not all three differentiating components are present.

Given the unique nature of the proposed RI equipment set and design capabilities, international interest in collaborating is expected to increase. The list of potential candidates includes developers, operators, and users of extreme light sources, commercial manufacturers of XUV (extreme ultraviolet)- and X-ray optics, and hardware manufacturers during the installation phase.

Based on previous and current efforts, the *Physikalisch-Technische Bundesanstalt* (PTB) as well as the Fraunhofer IOF, as leading responsible institutions, can be described as global leaders of innovations. It can therefore be expected that this fact will be further continued and strengthened by NPL. However, details of the planned innovations are missing.

The foreseen cohesive design system that allows virtual prototyping is particularly significant in an area where the establishment of experimental prototypes for extreme applications is too time consuming and prohibitively expensive.

The equipment suggested by NPL for the combination of large, heavy, ultra-precise, and free-form objects at extreme precision alignment is not commercially available today. It is doubtful that companies would develop such capability without the impetus of federal funding for a project like this. However, the proposal does not provide sufficient detail to assess the proposed equipment approach. The methods chosen (e-beam, nano-imprint) are likely good choices for the unique application, but too little is stated to comment further.

The surface treatment of free-form objects to the level of precision aimed at here is virgin territory as well. Substantial process development and novel characterisation techniques are the expected outcome of the effort.

The wide range and flexibility of operation during the life-time of NPL is based on its scientific, technological, strategic, and financial agility. The suggested number of concurrent projects (50–80) already implies a substantial range of topics to be tackled. The process of how to react to changed research questions is planned as an ongoing review process of recent and future developments in the framework of the Fraunhofer model.

The equipment suggested implies a complete set of capabilities that can be brought to bear on numerous problems that share common characteristics (large, heavy, free-form, ultra-precise). The financial model that uses a "depreciation allocation" to provide funds to rejuvenate the equipment set can also be used to acquire additional capability if an unforeseen need arises.

Concentration on large, heavy, free-form, ultra-precise optical components makes NPL largely complementary to other institutions world-wide and puts it into unique position worldwide.

I.4.b Utilisation

Description

In accordance with the Fraunhofer model, NPL's activities will be allocated to scientific partners (~40 %), internal research (~30 %), and industry partners (~30 %). Scientific users will be engaged either in the scientific aspects of optics and the advancement of photonics in general or in fundamental research in natural sciences and the development of mission-critical components or instruments.

The selection process of projects includes the examination of scientific excellence, of feasibility, overlap with the strategic goals of NPL, and compatibility to other projects. The funding for the projects has to be secured by the respective users.

In general, technical installations, facilities, and hardware will be operated by experts of NPL. Users may serve as advisors or as observers and are included in the development phase of the project. NPL will continuously document the progress of projects and will report to users in case of important events and at predefined milestones. NPL also plans to actively incorporate users in the strategy process, e. g. via the mediation of a key community scientist (KCS). This KCS will provide assistance during the application cycle for scientific projects and establish seminars as well as workshops for active and potential users of the facility. This is supposed to bring about a technological-organisational forum that encourages the previously decentralised community of fundamental scientists, application developers, and industrial users to collaborate. Moreover, the KCS stays in contact with the principal investigators of NPL.

During the usage of NPL mainly two types of data are expected. The first type is vertical data which is bound to a project and concerns all processing steps. It will be filed in a virtual project record, will be visible to all project partners, and will hence allow users to monitor and steer their projects. Disclosure of project data will in general be encouraged by NPL. The second type is horizontal data being related to a technology and concerning all projects with comparable technological requirements. It can be used to optimise and develop processes and ensure quality control. The further open data and open access strategy of the facility is based on the corresponding regulation of the Fraunhofer society.

Quality control of the processes and project results rely particularly on the core technology "characterisation" where the specifications of components and systems, which are defined as deliverable parameters in the related project definition, will be checked. Furthermore, NPL will implement measures for quality assurance and adopt codes of conduct established by the Fraunhofer society and the Fraunhofer IOF.

Assessment

The scientific user community will largely be represented by the four focus areas and hence be significantly dependent on large publicly funded projects, such as gravitational wave detection, or similar space applications. NPL is in an early planning phase with respect to future interaction with potential users. Sufficient interest from the anticipated user community exists and the preexisting skill base at IOF leave the impression that the RI can be established without major issues.

For industrial projects, those of SME (small and medium-sized enterprises) industrial partners will receive preferential support by NPL. There are numerous examples of SMEs in the Jena-Dresden corridor. Especially equipment and component providers for advanced optical instrumentation are expected to benefit from the capabilities and, given the nature of SMEs, would be enticed to utilise a central facility.

Europe provides a substantial percentage of research capabilities and funding in grand challenge research. It is reasonable to expect that the proposed NPL captures a significant "market share" of the European demand. Most users are expected to make direct use of the RI. However, the data generated by the modelling and design enablement segment could interest a large user group.

For the given astrophysical scientific projects the level of utilisation will depend on how the NPL can get involved into the instrumentation projects. For ESO |[83] (excepting the telescope construction itself), this is usually determined by the instrument building consortia that are contracted under ESO. For the gravitational wave observatories, this will depend on their development plans. For laser research and applications, similar mechanisms are expected to be at work. For Germany, the user groups in astrophysics (including gravitational waves) will be of the order of one institute (the Max Planck Institute for Gravitational Physics) and for Europe up to five larger instrumentation groups that build (mainly) for ESO. Internationally, the market is estimated to be 5–10 times larger. For laser applications, the total numbers will be larger. How big a portion of this community can and will be served by the NPL depends on its involvement with the individual groups and facilities.

The global market potential is estimated to lie between EUR 100 million and EUR 200 million over ten years. The implied market penetration is rather high, around 50 % or more. These assumptions are reasonable for a unique capability unless another facility with similar capabilities is built elsewhere. Similarly, the penetration rate also applies to the user community. The facility is assumed to bring in around EUR 8–10 million per year in direct income. The anticipated benefits for the local economy and the associated SMEs in the Jena area should make this a plausible long-term investment.

The execution of scientific projects follows the Fraunhofer policies of governance and management. These access conditions are in line with similar rules

| 83 European Southern Observatory

at other organisations (Leti, imec, AIM Photonics, etc.). No specifics are given, however, on how access will work in each class of cases.

In a future management concept, NPL should ensure that the user groups and the utilisation and access to core-technologies are dominated by research projects.

The implementation of key community scientists is a very good concept. The KCSs serve as a link between NPL and users and will provide assistance during use and application for scientific projects. A lot of responsibility is being placed on the KCSs, in terms of engaging the user community in strategy, education and demand statement.

Training for young researchers is foreseen within established structures, like the Abbe School of Photonics of the University of Jena. Furthermore, it is part of the role of the KCSs to coordinate training or educational formats for students. It is planned to train excellent staff with the help of these programmes in the long term.

Legal conditions are not much elaborated in the proposal. It seems to be assumed that Fraunhofer will provide or develop most of the intellectual property (IP), and licensing rights are not addressed. While this approach might work with SMEs without sufficient development budget, engaging larger entities (Zeiss, Zygo, ASML) would likely be more complex.

The data concept follows Fraunhofer regulations and information security policies. It is convincing and sufficient with respect to responsibility, the use of discipline specific standards, use and re-use, data protection and data security, and professional data management. What is missing is a new attractive concept in which the NPL interactively supports the (potential or actual) user to make appropriate and efficient use of available (NPL or others) information. Such a system would be a real add-on and would foster constructively future (technical) developments. Multiple references are being made to technological infrastructures but e-infrastructures are not referred to.

As NPL will be embedded in the organisation of Fraunhofer, the “Fraunhofer policies” for management, quality assurance measures etc. shall be implemented. This also applies for the collaborations with the relevant scientific user community, ethical standards, and good scientific practice with regard to dealing with research data and publications. The structure of NPL proceeds according to the Fraunhofer-model with separate parts of scientific and industrial use.

Description

According to the proposal, the initial strategy process also aimed to ensure NPL's implementation with scientific, technological, strategic, and financial agility. Therefore, the scientific-technological risk in implementing the research infrastructure is described as limited and minimised at various levels.

NPL will be integrated as an independent department of the Fraunhofer IOF which is embedded in the Fraunhofer institution network "Light & Surfaces". During the planning stage as well as the development phase, NPL's project management will follow the regulations and internal procedures of Fraunhofer IOF. The eight expert groups of NPL corresponding to the core technologies will be headed by a "junior director" (being subordinate to the director of Fraunhofer IOF). Central organs of NPL will be a directorate as scientific control body defining the future development and an advisory board comprising one representative each from the Federal Ministry of Education and Research, from the Free State of Thuringia, and from the potential user group.

The strategic embedding of cooperating partners is achieved by the direct inclusion of representatives of the Helmholtz centres DESY |[84] and GSI |[85] as well as the PTB in the directorate. The cooperation will be designed in a collaboration contract, including a model for the coordination of joint fundamental research, joint business models and the embedding of scientific apparatuses, as well as experts into the facilities of each other partner. NPL can draw on experienced staff of the Fraunhofer IOF as well as of the partners for its realisation. The strategic planning is supposed to pave the way for a timely start of NPL. Appropriate funds have been reserved by the partners and the Free State of Thuringia. Expressions of interest in joint research activities and directly commissioned research have been received from national and international institutions.

Assessment

In total, ethical, legal, and environmental risks are judged adequately, being generally modest to low. The risk analysis done by the applicants is very professional. It covers the scientific as well as the economic perspective in a balanced way. However, there is a risk of equipment availability.

| 84 *Deutsches Elektronen-Synchrotron*

| 85 *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

Embedding the NPL in the infrastructure of the Fraunhofer IOF is plausible, given the existing administrative infrastructure and technical focus/breadth of the IOF. The overall size of the NPL is roughly half or slightly less than half of the existing IOF, such that the IOF infrastructure can be readily expanded without burdening it too much. Almost all focus areas of the IOF are represented in the NPL thrusts as well, so a very good alignment and hence incremental growth only can be assured.

The proposed close cooperation between more applied institutions (Fraunhofer), basic science institutions (Helmholtz) and the PTB with its focus on standards and measurement is an intriguing concept with large potential for breakthrough innovation.

It appears that the management of the projected 50–80 concurrent projects is done at the level of the individual engineer. With a projected staff of approx. 40 people, each project seems to be assigned to an engineer who also performs the required project management. There seems to be no proposed central project management infrastructure, nor has there been much of a discussion on how projects are strategically chosen and prioritised.

The governance plan for NPL should be revisited and modified taking into account an independent advisory board. By now, it appears that the NPL will have little to no autonomy. The embedding of the NPL into the IOF is done to minimise administrative overhead growth, but there is no defined ownership of the revenue within the NPL. Also all outward focusing personnel, the KCSs', reports to the IOF director.

Another lacking institutional element is the user input. It is stated as the role of the KCSs. An Advisory Board is mentioned, but not listed in the organisational chart nor in the governance plan. It appears as if all such inputs are collected via the KCSs rather informally and decided upon by the Steering Committee based on their top-down view. Industry, in particular, does not seem to be represented in any decision making body.

The number of staff seems appropriate to the number of concurrent projects assumed. Being fully embedded into the IOF organisation, the required growth in staff should be manageable. However, the time line and organisation in the required staffing are not discussed in a comprehensive way.

The director of the Fraunhofer IOF as head of the initiative is a highly renowned scientist possessing at the same time managerial expertise. The contributing 25 principal investigators comprise experts in all necessary fields of knowledge. However, their planned involvement in NPL is not laid out in great detail.

Over a period of 7 years until steady-state, hiring approx. 40 personnel should not be a problem, especially given that local universities (the Abbe School of

Photonics at the University of Jena and the Ernst-Abbe University of Applied Sciences, Jena) can provide a timely supply of highly skilled graduates. With few exceptions, new hires will be imbedded into existing departments.

Financial support from the state as well as the participating institutions has been committed. There is a long-term support from the Fraunhofer IOF assumed, which the director is presumably willing to cover from operations or other sources.

I.4.d Relevance to Germany as a location of science and research

Description

In the proposal, the globally unique character of NPL is stressed. The combination of photonics with nanostructuring is said to promote the expansion of Germany's position in the respective fields of research. A continuing trend towards regional nucleation and specialisation due to the competitive advantages of individual locations is expected. The strength of Europe, and in particular of Germany, is seen in its manufacturing-oriented technology disciplines. The location of Jena with its focus on applied optics would be further strengthened by the technological infrastructure along the photonic value generation chain as proposed by NPL. NPL is supposed to have the potential to generate a boost in innovation that will enable a key sector of German economy to maintain and expand its global leadership.

According to the proposal, the principal investigators of the leading institutions already are renowned photonics scientists. Their capabilities are clustered in an academic inter-departmental centre of optics and photonics, the Abbe School of Photonics at the University of Jena, offering international Master and doctoral programmes. The leverage of NPL is expected to extend to this area as well.

The structure of NPL relies crucially on technology transfer. Measures that will be employed to ensure the transfer of knowledge and technology include for example the concept of the KCS, workshops, and a user-oriented strategic orientation with close links to and active contributions of prospective users. Outreach actions will include open house days and other events designed to engage students and youths in science.

Assessment

NPL will certainly help and enable the international scientific communities to carry out excellent research and experiments, essentially in the field of cutting-edge optical technology. Together with its focus on grand challenge science projects and the experience of the principal investigators, this assures that the research performed or enabled will have high visibility. Hence, the expansion of Germany's position in the respective fields of research will be promoted.

The proposal identifies as a weakness in the German research landscape that it is decentralised and partially scattered. One could argue that the presence of Fraunhofer Institutes and Max Planck Institutes in addition to DFG supported centres of excellence already represents a significant trend towards (regional) nucleation and specialisation. This indeed gives an advantage of the German research landscape with respect to European and potentially extra-European international landscapes. The importance of the planned NPL in this arrangement will certainly be strongest in the Free State of Thuringia. Importance within Germany and beyond will depend on the degree to which national and international research cooperation can be set up.

NPL will definitely add to the attractiveness of Germany as a location of science and research.

NPL will also contribute to the support of young academics. Assuming that the 50-80 annual projects include a substantial fraction of scientific research, NPL offers a rather unique playground for young scientists. Moreover, the chance of getting knowledge for start-ups in the field of photonics might be attractive. NPL should also increase the already substantial attraction that the Abbe School of Photonics provides. However, a plan how to organise and foster the required interaction between NPL and the local universities or institutes in/near Jena in praxis is needed.

User groups, workshops and the KCSs are listed as technology transfer vehicles. This will be accompanied by an appropriate controlling and reporting structure (which still needs to be established) on the basis of existing rules and procedures of Fraunhofer IOF. Moreover, appropriate outreach actions to contact students and young people are foreseen.

Instalment of an institution like the NPL will certainly add to the local economy and educational landscape. Being at the forefront of big science projects it is expected to have the societal impact and the impact on national and regional prestige intended. The economic impact is less clear, as the RI revenue in the years beyond 2023 should be a good indication of the overall regional business development. The proposers indicate that a wide range of adjacent fields (avionics, lithography, information technology, etc.) can benefit from the establishment of the RI, but the connections are not well established.

There is a strategic process promoted in which German photonic technology is defending its leading position. The medium and long term impact will be essentially determined by the ability of NPL to stimulate and support a nationwide network, going beyond Jena, in photonic science.

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
Existing research infrastructures			
AIM Photonics – American Institute for Manufacturing Integrated Photonics (complementary)	AIM Photonics is an industry driven public-private partnership. It supports Small and Medium Enterprises, providing practical access and technology on-ramps for U.S. industry, government, and academic communities. Its vision is to establish a technology, business and education framework for industry, government and academia to accelerate the transition of integrated photonic solutions from innovation to manufacturing-ready deployment in systems spanning commercial and defence applications. AIM Photonics focuses on wafer-based integration of optical elements and standard semiconductor device processing in addition to low-cost packaging solutions for commercial applications ranging from Datacom to sensors and lidar. http://www.aimphotonics.com/, last accessed 6 October 2016	Since 2015	US
CNSI – California NanoSystems Institute	CNSI at UCLA is exploring the power and potential of organizing and manipulating matter to engineer new integrated and emergent systems and devices, by starting down at the nanoscale level that will advance information technology, energy production, storage and saving, environmental well-being and diagnosis, and prevention and treatment of chronic and degenerative diseases. To support the research, the CNSI encompasses eight core facilities which include both wet and dry laboratories, equipment in the form of electron microscopes, atomic force microscopes, X-ray diffractometers, optical microscopies and spectroscopies, high throughput robotics and class 100 and 1000 clean rooms for projects led by CNSI and other faculty. http://www.cnsi.ucla.edu/staticpages/core-facilities, last accessed 24 August 2016	Not specified	Los Angeles, US
CXRO – The Center for X-Ray Optics at Lawrence Berkeley National Laboratory	CXRO works to further science and technology using short wavelength optical systems and techniques. They create and operate advanced experimental systems to address national needs, support research in material, life, and environmental science, and extend the forefront of semiconductor manufacturing. http://www.cxro.lbl.gov/, last accessed 24 August 2016	Not specified	Berkeley, US
FELS of Europe (complementary)	FELS OF EUROPE is a collaboration of all free electron laser (FEL) facilities in Europe, with the goal to meet the technological and scien-	Memorandum of Understanding	TR, DE, IT, SE, PL, FR, CH, NL, UK

	tific challenges of these novel and rapidly developing technologies and to provide a worldwide unique, pan-European research infrastructure that enables exploiting the full scientific potential of these unique accelerator based short-pulse light sources. The collaboration is an initiative of the ESFRI projects EuroFEL and European XFEL. https://www.fels-of-europe.eu/, last accessed 6 October 2016	signed in 2012	
INSTRUCT – Integrated Structural Biology Infrastructure (complementary)	INSTRUCT is a distributed, dynamic infrastructure of integrative science, in which the free access to state-of-the-art structural biology technologies for researchers is promoted in the member states. INSTRUCT intends to enable innovation at the boundaries of different technologies by the development of instruments and methods. INSTRUCT entered the ESFRI Roadmap in 2006 and is a Landmark on the ESFRI Roadmap 2016. https://www.structuralbiology.eu/, last accessed 24 August 2016	Operation start 2012	UK, SE, ES, PT, NL, IT, IL, DE, FR, DK, CZ, BE
The Integrated Optics Lab at ESL (ElectroScience Laboratory)	The Integrated Optics Lab at ESL of the Ohio State University enables in-house fabrication, test, and measurement of planar lightwave circuits. Equipment includes continuous wave tunable laser at telecommunication wavelengths, InGaAs photo detectors, numerical simulation tools and data acquisition software, floating optical tables, optical components such as quarter waveplates, half waveplates, polarizers, single mode and polarization maintaining optical fibre, fibre polarization control, translation stages, XYZ stages for high precision sample positioning, digital-video measurement inspection unit for optical micrographs and optical alignment to integrated optics. https://electroscience.osu.edu/facilities-equipment/integrated-optics-lab, last accessed 24 August 2016	Not specified	
IOL – The Boston University Integrated Optics Laboratory	The IOL is a multi-user facility and houses a Class 100 cleanroom and a standard laboratory. It is a multi-user facility equipped with state-of-the-art equipment for bonding and spectroscopic analysis of components. http://www.bu.edu/photonics/sharedfacilities/iol/, last accessed 24 August 2016	Not specified	Boston, US
Planned research infrastructures/under construction			
E-ELT - European Extremely Large Telescope (complementary)	E-ELT is a currently under construction next-generation optical telescope for the European Southern Observatory (ESO). It will have a primary mirror (39 meters in diameter) which will be composed of 798 hexagonal mirror elements. It will be the world's largest optical telescope. http://www.eso.org/public/teles-instr/e-	First light is targeted for 2024	ESO

	elt/, last accessed 23 August 2016		
ELI – Extreme Light Infrastructure (complementary)	ELI is a European laser research project in the preparatory phase. It will be used to investigate processes with high time resolution. Therefore, the most intense laser will be brought into action worldwide. ELI entered the ESFRI Roadmap in 2006 and is a Landmark on the ESFRI Roadmap 2016. https://eli-laser.eu/, last accessed 23 August 2016	Operation start in 2018	CZ, DE, HU, IT, RO, UK; membership application in progress: GR
EU-SOLARIS (complementary)	EU-SOLARIS aims to create, explore and implement new policies in order to improve rules and procedures for Research Infrastructures of the Solar Thermal Electricity technology. EU-SOLARIS entered the ESFRI Roadmap in 2010 and is a project on the ESFRI Roadmap 2016. http://www.eusolaris.eu/, last accessed 23 August 2016	From 2020	15 partners from 7 EU countries: PO, ES, FR, IT, DE, GR, CY
HiPER – High Power Laser Energy Research Facility (complementary)	HiPER is a proposed experimental laser-driven inertial confinement fusion device (ICF) as a preliminary draft of possible construction in the European Union. http://www.hiper-laser.org, last accessed 6 October 2016	Preparatory phase: 2008 to 2013; construction and commissioning from 2028	HiPER preparatory phase: UK, FR, IT, GR, CZ, ES, DE, RU, PL, PT
IFMIF – International Fusion Materials Irradiation Facility (complementary)	IFMIF is a research facility planned since the 1990s. The facility is designed to test materials for their suitability for the usage in potential fusion reactors. The project is currently (2014) in the so-called Engineering Validation and Engineering Design Activities (EVEDA) phase. It has not yet been decided on the location of the plant. http://www.ifmif.org/, last accessed 6 October 2016	EVEDA phase to be completed in 2017	Management: IEA; JP, EU, RU, US

D.II ENVIRONMENTAL AND EARTH SYSTEM SCIENCES

II.1 Scientific landscape in Environmental and Earth System Sciences

Environmental and Earth System Sciences are based on contributions from a wide ranging spectrum of scientific disciplines including geosciences, biology, physics, chemistry, meteorology, social sciences and humanities, but also technical fields, e. g. computer sciences, engineering, economics and medicine. In many cases, research in the area of Environmental and Earth System Sciences is directly relevant for urgent political and societal questions, which are imposed by anthropogenic activities on the environment (e. g. air quality, environmental pollution and consumption of natural resources) and, vice versa, by natural phenomena on societies (e. g. earthquakes and weather phenomena).

After a general introduction, the following chapter focuses on four specific fields of research of Environmental and Earth System Sciences and on the corresponding research infrastructures of the Roadmap Process.

II.1.a Scientific landscape for research infrastructures in the Environmental and Earth System Sciences

Studies of processes in individual Earth spheres (atmo-, bio-, hydro-, and geosphere) are increasingly placed in the context of the complex and highly interconnected earth system. This term refers to the plurality of the participating disciplines and at the same time transports a more specific notion of the objects of research. |[86] The Earth System includes processes and interactions within the Earth spheres and between them, but also between these spheres and anthropogenic activities and artefacts (the so-called anthroposphere). Environmental and Earth System Sciences focus on these interdependencies. Important research fields are e. g. the climate system and its changes, ecosystem sciences, biodiversity, biogeochemical cycles, natural and anthropogenic trace-gas and aerosol emissions including their impact for human health.

Environmental- and Earth System Sciences require interdisciplinary problem solving approaches. Research is not only conducted in traditionally defined disciplines, but also affords the integration of local knowledge into a larger framework of socioeconomic and sociocultural domains, including the needs of a broad stakeholder community. Due to this inherent system oriented approach Environmental and Earth System Sciences tend to bridge the boundaries between many disciplines in the natural sciences, life sciences, medical sciences, engineering sciences, social sciences, and the humanities.

Climate change as one of the main global (also societal) challenges for humankind is an important example to illustrate the need for inter- and transdisciplinary cooperation. Atmospheric properties and components, including water vapour, clouds, trace gases, and aerosols play a key role in the Earth's energy budget which is the main driving forces influencing climate phenomena. At the same time, the atmosphere strongly interacts with constituent parts of the biosphere (e. g. land-biosphere and plants), hydrosphere (e. g. oceans, ice), geosphere (e. g. volcanoes, soils) and the anthroposphere (e. g. emissions of natural and men-made trace gases and aerosols). The combination of these complex interconnections causes feed-back loops which affect the atmosphere on many temporal and spatial scales.

|[86] A couple of further Earth-Sphere-concepts exist, i. e. the litho-, pedo-, and cryosphere. According to the used classification these spheres can be seen as sub-spheres or parts of the named main spheres.

Sustainable management of the natural and artificially built environments including the socioeconomic and sociocultural systems with which they are intimately coupled and requires a sound basic science foundation and multidisciplinary heuristics for informed decision making processes, especially when it comes to such complex and highly relevant challenging issues as i. e. climate change, ecosystem health, biodiversity, (de)forestation, agricultural production, natural and anthropogeneous induced hazards, and water resources. To meet these needs, novel tools and technologies for understanding environmental processes as well as for monitoring, prevention, mitigation of and adaptation to environmental risks and impacts of human activities on the Earth's spheres have to be developed. |[87]

II.1.b Large research infrastructures in context of Environmental and Earth System Sciences

Extending and deepening our knowledge of the complex Earth system, its dynamics and interactions, as well as its reaction to natural and anthropogenic perturbations, require increasingly large research infrastructures. These include ground-based infrastructures (e. g. seismometer arrays, remote sensing laboratories, stations that measure biotic and abiotic parameters etc.), as well as satellites and data-infrastructures. Furthermore, for a comprehensive system-oriented approach, integrating various devices, instruments, entire infrastructures, and observing and monitoring systems are essential. Also, networks, scientific collections and integrating programmes dedicated to the investigation in specific parts of the Earth System can serve as important research infrastructures.

The data needed to understand the Earth System and its future states, as well as approaches to handle data are becoming more and more complex. Numerical simulations and models as well as the digitalisation of objects from scientific collections require larger computational capacities and qualified model and data management. Therefore, e-infrastructures are also vital parts of the research infrastructural landscape in the Environmental and Earth System Sciences.

In order to embed the research infrastructures of the current Roadmap Process into the field of research, the following classification of earth spheres is used, which describes the key components of the Earth System. The single earth spheres are interlinked to each other due to numerous interactions and exchange processes.

|[87] Cf. amongst others: ESFRI: Strategy Report on Research Infrastructures. Roadmap 2010, Luxembourg 2011, p. 28 and HGF: Helmholtz-Roadmap for research infrastructures. As of 2011, Bonn 2011, p. 17.

Atmospheric research investigates the chemical and physical composition and dynamics of the atmosphere, the evolution of atmospheric motions, climate and weather systems, the interactions and linkages of the Atmosphere with other Earth spheres, e. g. bio- and hydrosphere, as well as with the anthroposphere. This encompasses a broad range of physical, chemical, and biological processes reaching from the Earth's surface and the planetary boundary layer (lowest about 1 km) to the troposphere (0–10 km altitude), the stratosphere (10–50 km altitude) until the mesosphere (50–80 km altitude) and the thermosphere (80–600 km altitude). Prominent examples of current research fields are related to global and regional climate change, the future of the stratospheric ozone layer, the prediction of extreme events, and the fundamental understanding of aerosol-cloud-precipitation interactions. Research in the atmospheric sciences requires high-quality, long-term observations with remote instruments but also in-situ measurements, and a strong collaboration between observational, theoretical, and numerical modelling activities.

Geosphere

The geosphere encompasses the inorganic matter from the upper lithosphere until the Earth's core. The pedosphere as one part of the lithosphere is created by the constant interaction of the lithosphere, atmosphere, cryosphere, hydrosphere, and biosphere. Central fields in the study of the solid Earth are geology, geophysics, and geochemistry. One of the most important aspects is the understanding of the Earth's lithosphere, the upper part of the solid Earth up to about 75 to 300 km in depth, and the occurring fundamental geological processes and structures. The lithosphere as a sub-sphere comprises the Earth's crust and the soil cover of the earth as well as the underlying mantle and consists of distinct plates moving on the plastic asthenosphere. Plate tectonics is a unique feature of planet Earth and is ultimately responsible for the occurrence of earthquakes, volcanic eruptions and related hazards. Moreover, understanding the structure and dynamics of the lithosphere is essential for the utilisation of soils and the finding of new natural resources, such as oil, gas, or metal deposits. Solid Earth research covers the study of Earth processes over large time and space scales (geological history), much faster geomorphological processes or even swift (bio-)chemical processes within the pedosphere. The research topics vary from the evolution of continents and oceans lasting millions of years, to the formation of soils or to sudden hazards such as rockfalls and earthquakes, which occur within periods of minutes or even seconds. The spatial scales of these events range from entire tectonic plates of thousands of kilometres to the nanometre-scale processes occurring on mineral surfaces. There are also strong interdisciplinary linkages between investigations in the geosphere and the other Earth spheres; geochemistry for instance is strongly connected to paleo atmospheric questions as well as to biochemical questions.

Hydrosphere

Water covers two thirds of the Earth's surface and is strongly interlinked with the atmosphere (e. g. water vapour is one of the most important 'greenhouse' gases), the entire biosphere and larger parts of the geosphere. Oceans (marine hydrosphere), seas and groundwater (limnosphere) as well as ice (cryosphere) have a deep impact on climate, biodiversity and ecosystem issues and are also deposits for several precious resources. Additionally, the coastal regime, i. e. the transition zone between continental (fresh) water and oceanic (salt) water requires substantial research as it is a zone of high anthropogenic impact and related change, which strongly influences its basic function and usability.

Biosphere

The biosphere covers the whole Earth in a vertical dispersion from the lower mesosphere (~60 km altitude) down to the upper lithosphere (~5 km depth) and encompasses all living organisms (biodiversity) in water and terrestrial ecosystems but also organic matter in the atmosphere. The biosphere is strongly linked with the other Earth spheres via the ecosystems, and influences (and is also influenced by) the hydro-, geo- and atmosphere. Thus, there are diverse linkages between a broad range of traditional and evolving disciplines and subfields investigating the Earth's spheres and their connections, and also the interdependencies between the biosphere and other parts of the Earth System, i. e. biogeochemistry.

II. 1.c Research infrastructure concepts in the field of Environmental and Earth System Sciences

The five infrastructures related to the Environmental and Earth System Sciences are linked to a broader range of components of the Earth System and environmental questions, but nevertheless each project is more or less focused on analyses of specific Earth spheres and phenomena. ACTRIS-D and AtmoSat are concentrated on investigations of atmospheric processes, e. g. trace-gas and aerosol distribution, clouds, atmospheric waves etc. DCOLL as a proposed infrastructure for scientific collections and BioM-D as an infrastructure for biodiversity monitoring are focused on bio- and geosphere and to a lesser extent to hydrosphere. Tandem-L is a proposal which addresses investigations of three spheres in equal measures (geo-, hydro- and biosphere).

II.2 Aerosol, Clouds and Trace gases Research InfraStructure – German contribution (ACTRIS-D)

II.2.a Scientific potential

Description

The proposal states that a deeper understanding of short-lived trace-gas concentrations and aerosol and cloud properties is highly relevant for several reasons:

_ Information on spatiotemporal distributions of aerosol particles and short-lived trace or precursor gases such as nitrogen dioxide and Volatile Organic Compounds (VOCs) as obtained in ACTRIS is needed to take measures to reduce air pollution and related adverse effects on human health and entire ecosystems.

_ Atmospheric aerosol particles influence the Earth's radiation balance. Direct effects lead to cooling (e. g. sulphates and nitrates) or warming of the atmosphere (e. g. black carbon). Indirect effects are not well described yet because of large uncertainties in the process understanding and the complexities of cloud condensation and ice nucleating particles. ACTRIS contributes considerably to this field of research.

_ Clouds are a major source of uncertainty in future climate predictions due to the question of how clouds will respond to global warming. Current climate models cannot properly deal with clouds, because of missing process understanding and the limited spatiotemporal resolution of the models. Relevant processes and trends are supposed to be identified with the help of ACTRIS data and then used for model improvement.

_ According to the concept, research on aerosol particles and clouds has also impacts for the EU economic growth, including weather services (improved weather prediction models), the green energy industry (through the influence of aerosols and clouds on the amount of solar energy reaching the ground), agriculture and forestry (through ozone damage on growing plants), and the aviation industry (regarding the impact of volcanic ash and dust storms on aircraft operations and safety).

The main operational modes of ACTRIS will be first to provide harmonised, reliable, quality assured, and fully documented long-term observational data on the chemical and physical state and the processes of the atmosphere, linking surface observations with vertical profiles, total-column observations, and cloud processes, second to provide process study results by atmospheric simulation chambers, third the establishment of a quality assurance and quality control regime for all ACTRIS activities via calibration centres, fourth to establish and utilise training capacity for field observations, simulation chamber studies, data provision, and data product usage, fifth to support research and application projects conducted at the ACTRIS research facilities (including technological innovation via instrument and service development), and sixth to provide access to national and central facilities.

According to the proposal ACTRIS and ACTRIS-D provide unique data sets which are not covered by any other RI, although several complementary RIs and research networks partly overlap with ACTRIS (e. g. the In-service Aircraft for Global Observing System (IAGOS) and the Integrated Carbon Observation System (ICOS)). One of the important features of ACTRIS, e. g. in comparison to IAGOS, is that it is not limited with respect to weight, space, power, or certification. It will be possible to deploy large and heavy instrumentation required for cloud, aerosol, and trace-gas observations and exchange these instruments easily at any time needed.

Assessment

The proposed ACTRIS-D activities will provide critical and unique data to study the coupled climate-chemistry aspect of the atmosphere. There is no doubt that successful implementation of the proposed measurements can enable science that would have profound impact on our understanding of chemistry-climate-health interactions and their societal implications. This proposal brings together most of the leading research groups in atmospheric chemistry in Germany. The RI will provide long-term measurements at sites both within and outside of Germany. Through its participation in the larger European ACTRIS framework, ACTRIS-D will be well integrated within Europe and the data will be available via the ACTRIS database. This ensures standardised quality control and free access for users from around the world. ACTRIS is the only RI focusing on ground-based observations and vertical profiles of aerosols, trace (reactive) gases and clouds. The long-term dataset of short-lived constituents would be unique and is needed by modellers and policy makers. In addition, the calibration expertise in the project will provide high quality and consistent data from not only the ACTRIS-D sites but also those of international collaborators. The proposed substantial upgrade for the RI appears to be based mainly on the newest commercially available instruments but considering the expertise of the applicants, one can also expect instrument innovations to occur. Beyond the need for accurate long-term observations for trend analyses and ground-truthing, specific research questions addressed by the RI were not clearly articulated in the proposal.

It is expected that ACTRIS-D will be a significant RI enabling science that will advance our understanding of air quality and the budgets of short lived climate forcers in Europe and globally. In addition, the linking of the chamber based process studies with the ambient observations provides unique synergy.

Because of the distributed nature of the RI, it is likely to be highly adaptable and flexible. Even if one instrument fails, or becomes obsolete, there is the potential for reorientation along a more productive path. Access to the chambers for external users will follow the successful EUROCHAMP-2020 (Integration of European Simulation Chambers for Investigating Atmospheric Processes) approach.

The RI is highly complementary to IAGOS (In-service Aircraft for a Global Observing System) which measures aerosols, trace gases and clouds in the upper troposphere and lower stratosphere and to ICOS (Integrated Carbon Observation System), which provides consistent, high precision measurements of concentrations and fluxes of carbon cycle greenhouse gases. The aspect that makes ACTRIS-D exceptional is that the proposed combination of long-term measurements does not currently exist, especially with respect to short-lived compounds and these aspects of ACTRIS-D represent a new and extremely important contribution. Thus, there is no question that these aspects of ACTRIS-D make it a unique RI worldwide. Several satellite-borne instruments that measure trace gases or aerosol optical properties are currently in orbit or planned for launch, and the ACTRIS-D RI will provide valuable ground-truthing opportunities.

II.2.b Utilisation

Description

As it is pointed out in the proposal, ACTRIS data will be used primarily by scientists in the atmospheric and neighbouring research fields worldwide as input or validation data for models and satellites, for analysing trends, and for atmospheric and air-quality studies. Furthermore, users from the public and private sectors (including meteorological services, media, and instrument developers) as well as governmental users, such as policy makers, environmental protection agencies, national weather services, and air safety organisations, can benefit from the data.

Users will have open access to the ACTRIS data centre and can apply for other services at the service access management unit in the ACTRIS head office. ACTRIS in general provides four types of direct services for the users:

_ Quality assured and harmonised observational data on the chemical and physical state and of the atmospheric processes can be accessed via an online web tool;

_ ACTRIS training will take place via instrumental workshops and summer schools organised by the calibration centres;

_ The application of projects, including technological innovation via instrument and service development, new measurement standards, and operation procedures will be supported;

_ Access to national facilities and calibration centres will be granted via a scientific evaluation process.

The ACTRIS data centre has already been established and comprises three topical data repositories: Near-surface aerosol and trace-gas data, aerosol profile data, and cloud profile data. Moreover, it is planned to implement data from the Fourier Transform Infra-Red spectroscopy (FTIR) remote sensing and the simulation chambers in the ACTRIS data centre in the future.

According to the proposal, national institutions have to follow commonly defined concepts, protocols, quality assurance, and operation procedures as well as to participate in workshops at the calibration centres to be accepted as ACTRIS national facilities. Furthermore, all ACTRIS-D institutions follow the Code of Conduct established by the German Research Foundation (DFG).

Assessment

The expected user groups have been clearly identified and they have been categorised in few categories with clear profiles. A large range of users, beyond those directly responsible for the development and operation of the RI, would benefit from the data provided. Users will primarily consist of atmospheric, climate and environmental scientists based both in Germany and globally, which made up 95.8 % of the unique users of the ACTRIS data centre. The proposal also mentions (inter-)governmental users, e. g. environmental agencies and policy makers, which only made up 2.8 % of the ACTRIS data centre users. However, despite their small number these users represent an important group.

Access management and service will be decided and regulated in ACTRIS, i. e. at the European level. Although a “terms of use” document has not been written, access to data and (legal) conditions of use as presented/outlined are largely straightforward and standard for the aerosol profile data, aerosol and trace gas near-surface data, and cloud data. They are well suited for successful research. Data access is free to all users. One open question is whether data from the chamber facilities will be archived, freely accessible, like the ambient measurements.

The overall data concept for the aerosol profile, near-surface aerosol and trace gas, and cloud profile data is strong. The ACTRIS data policy provides clear directions in terms of when instrument PIs should be contacted if an individual is using their data in an analysis, and in the event that they plan to publish the analysis. Clear language is also provided for how to acknowledge the provision of ACTRIS data in manuscripts. Because a substantial portion of the data of the form to be delivered by ACTRIS-D is already being archived at the ACTRIS Data Centre, one can be relatively confident that the strategies for data archiving and sharing are quite mature. The e-services are well developed and there is no need for significant development or upgrade. However, with respect to the chamber and calibration facility aspects more details would be useful. Similarly, it would be useful to know what types of data are proposed for the novel instruments and protocols for ensuring their long-term measurement traceability.

The institutes/institutions involved have extensive experience and high standards of quality assurance and have to follow commonly decided guidelines. It is assumed that the tendering process for the individual instruments will be competitive and transparent. There exist long term commitments for ACTRIS-D from all the partner institutes. Therefore, the ACTRIS strategy is already included in the strategies of the partners. Physical access to national and central facilities is incorporated via evaluation of requests, based on scientific excellence. Training capacity appears to be integrated into ACTRIS-D, which is important especially for some of the more complex datasets that will be obtained. Furthermore, conducting experiments at the chambers, which may have complex operational aspects, will require strong communication and training of external users. Ethical issues are dealt with both on European level at ACTRIS and also within each participating institute. The procedures follow good international standards.

II.2.c Feasibility

Description

The implementation work (e. g. instrument set-up, testing, and automation) for ACTRIS-D is straight forward, but there will be similar components at different ACTRIS-D locations, which are operated by different institutes. The individual experiences will help to increase the knowledge basis for ACTRIS-D and allow synergy effects. Thus, the risk to fail in technical development will be minimised.

The ACTRIS concept will be part of the strategies of the participating institutions in the ACTRIS-D consortium. While ACTRIS will probably assume the legal form of a European RI Consortium (ERIC) around 2020, the German ACTRIS-D consortium will stay as a national consortium of institutes (based on the joint consortium agreement). The legal connection of ACTRIS-D to ACTRIS ERIC and the question of ownership for equipment, positions, and services will be discussed and decided in the interim ACTRIS council while setting up the ACTRIS ERIC.

As the authors of the proposal pointed out, the ACTRIS-D institutes have the capacities to provide their own substantial personnel resources for all project phases. The non-university research institutes can contribute most, universities to a smaller extent, while the governmental agencies (UBA and DWD) have only personnel for the utilisation and closure phases.

According to the proposal, ACTRIS benefits from a number of former (i. e. CLOUDNET |[88], EARLINET |[89] and EUSAAR |[90], in context of the European projects FP5 and FP6) as well as on still running RI projects (e. g. EUROCHAMP and ACTRIS-2 IA |[91] in context of H2020). Moreover, the global Network for the Detection of Atmospheric Composition Change (NDACC) will be incorporated in ACTRIS. It is therefore a construction effort of more than fifteen years that will have to be secured through the transfer of ACTRIS into an operational RI.

Assessment

The risks for ACTRIS-D in the development and operational phase are low. ACTRIS-D is a distributed RI and therefore any of the components can be replaced without significant negative impact on the whole RI. Furthermore, the structure relies solidly on the expertise of each individual unit and this will ensure rapid adaptability to changing research questions or new emerging scientific issues. The technical requirements and risks are laid out well overall. More information about the system design would have been useful to understand how specific instrument types to be acquired as part of the substantial upgrade will be applied toward the overarching goals envisioned in ACTRIS-D. It is not yet clear how reliably some of the instruments, e. g. some CIMS (Chemical Ionization Mass Spectrometer) instruments currently used for process level studies, will provide long-term stable data, and it is also not clear at this point how they produce calibrated data. An important technological innovation will be achieving a calibration methodology that provides consistent, high-quality data with these instruments into context of long-term observations.

Other possible risks are not foreseen. There are no major ethical issues involved and no environmental risks are likely either.

The group of institutes/institutions involved in ACTRIS-D is perhaps uniquely suited internationally to successfully implement this very important research effort. Most of the institutions involved in ACTRIS-D already operate instrumentation similar to that included in the RI, so the technical expertise for operation and campaign-style deployment exists. The governance concept is laid

| 88 Cloudnet - A network of stations for the continuous evaluation of loud and aerosol profiles in operation NWP models

| 89 European Aerosol Research Lidar Network

| 90 European Supersites for Atmospheric Aerosol Research

| 91 ACTRIS-2 Integrated Activities

out through ACTRIS. ACTRIS-D is managed at the national level by a coordination office, a scientific steering committee, and the National Assembly. The National Assembly voting rules have yet to be laid out in the consortium agreement. It appears that there will be strong oversight for the RI, while still allowing independent science and collaborations. Although it is a challenge to coordinate the large number of institutions involved, the institutes/institutions have different tasks preventing redundancy. The integration of each unit into the overall RI is well worked out.

Overall the institutes/institutions have an excellent track record of highly qualified personnel that is suitable for all aspects of ACTRIS-D. An important aspect is that the institutions will have to change from campaign-wise to routine operation, which presents a substantial change for the personnel involved. This could affect personnel structure and retention due to the different nature of the work involved.

New personnel need to be recruited, and this procedure is clearly planned as the RI contains universities, research institutes and governmental agencies. The personnel development plan is clearly outlined. The added value of ACTRIS-D is to provide specialised training for requirements of the RI. No specific mention was made of how diversity will be enhanced through recruitment, which will be handled at the institute/university level.

It can be concluded that the ACTRIS-D is already rather mature to start with. The funding from the institutes during the operation and closure phases seems secure and the financial structure is clearly planned. ACTRIS builds on earlier efforts and research collaborations. For ACTRIS-D the same is true and thus a foundation for the strategy already exists.

II.2.d Relevance to Germany as a location of science and research

Description

Following the proposal, ACTRIS-D will strengthen German atmospheric research on the European and the broader international level. Presently, the German central facilities (calibration centers) play a significant role in ACTRIS and the national facilities (observatories and simulation chambers) are already integrated in the international landscape of atmospheric research. If ACTRIS-D is not realised, the authors of the proposal see the risk that other countries will take over the duties of the calibration centers and that Germany could lose its leading role in the context of ACTRIS.

Most of the German research institutes which are involved in experimental atmospheric research joined in ACTRIS-D. This already indicates the attractiveness of ACTRIS. According to the proposal, the German calibration centers and research facilities will be interesting for international researchers to learn about new technical developments and atmospheric data.

Knowledge and technology transfer takes place within ACTRIS and the scientific community, but is also provided to external users. Governmental organisations will be supplied with information on long-term trends or potential threats to the public, and private organisations will be provided with knowledge on environmental measurement devices.

Assessment

Germany's atmospheric observatories and chambers are already world-renowned in the atmospheric science community. ACTRIS-D funding will further support the visibility of these facilities within Europe and across the world.

Many of the partner institutes are already attractive for international scientists to work at or collaborate with, which will be further enhanced due to upgrade of infrastructure. ACTRIS-D will attract a large number of German and international researchers, both to work at the calibration centres and chambers but, probably, even more to use the data. It is not quite clear how many PhDs will be directly trained under ACTRIS-D but an even larger number of young academics would undoubtedly use the data over the extended lifetime of ACTRIS.

Transfer of knowledge and technology are key components of ACTRIS. The main route for transfer is between institutes, but additionally transfer to the rest of the society, including governmental organisations and private companies, is important and highlighted in the proposal. ACTRIS data will provide socially beneficial information on climatologies of the chemistry, physics and clouds in the atmosphere, as well as process-level information. This will inform weather and air quality predictions, climate simulations, and provide information about extreme events and atmospheric hazards. Measurements of some atmospheric constituents will also be important for evaluating emission and mitigation policies.

II.2.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Participants
	Forerunners		
ACCENT – Atmospheric Composition Change – The European Network (complementary)	Progressive and durable integration of the research capacities of the participants, enhancing at the same time the knowledge on atmospheric research topics	2004–2009	32 participating countries
EARLINET –	First aerosol lidar network which attempts to	Since 2000	IT (coordinat-

European Aerosol Research Lidar Network (complementary)	retrieve quantitative data on the vertical distribution of aerosol optical properties in a systematic and statistically significant approach and on a continental scale www.earlinet.org, last accessed 24 August 2016	Part of ACTRIS since 2011	ing) 16 participating countries
EUROCHAMP I & EUROCHAMP II – Integration of European Simulation Chambers for Investigating Atmospheric Processes (complementary)	European project which aims a better integration of simulation chambers for studying atmospheric processes. EUROCHAMP is funded within the EC 7th Framework Programme, Section "Support for Research Infrastructures - Integrated Infrastructure Initiative". www.eurochamp.org, last accessed 24 August 2016	EURO-CHAMP I (2004-2009) EURO-CHAMP II (2009-2013)	DE, ES, IE, FR, CH, UK, SE, DK
EUSAAR/ ACTRIS (complementary)	Integration of measurements of atmospheric aerosol properties performed in a distributed network of 20 high quality European ground based stations to provide reliable operational service in support of policy issues on air quality, long-range transport of pollutants and climate change ESFRI 2016 Project http://www.actris.eu/, last accessed 24 August 2016	2006–2011 Continues in ACTRIS	FR (coordinating) 16 participating countries
Existing research infrastructures			
AERONET – Aerosol Robotic Network	Global network of sun- and sky-radiometers for aerosol characterisation http://aeronet.gsfc.nasa.gov/, last accessed 24 August 2016	Since approx. 1998	Coordination: NASA, PHOTONS
ARISE – Atmospheric Dynamics Research Infrastructure in Europe	New 3D image of atmospheric disturbances in the troposphere, stratosphere and mesosphere. It includes infrasonic disturbances from volcanoes, thunderstorms, cyclones, up to large scale atmospheric waves as tides and planetary waves with unprecedented spatio-temporal resolution. http://arise-project.eu, last accessed 24 August 2016	2015–2018	Coordination: FR (CEA) 17 participating countries
ARM – Atmospheric Radiation Measurement Climate Research Facility (competing)	National user facility for the study of global climate change by the national and international research community. It consists of a network of highly instrumented ground stations; mobile and aerial facilities; and a data archive. www.arm.gov, last accessed 24 August 2016	Since 1989	US (coordinating) 10 participating countries
CALIPSO – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (complementary)	Provides new insight into the role that clouds and atmospheric aerosols (airborne particles) play in regulating Earth's weather, climate, and air quality www.calipso.larc.nasa.gov, last accessed 23 August 2016	Since 2006	Coordination: US
CLOUDSAT (complementary)	Provide observations necessary to advance our understanding of cloud abundance, distribution, structure, and radiative properties http://cloudsat.atmos.colostate.edu/, last accessed 25 August 2016	Since 2006	Coordination: US
EOS-AURA (complementary)	Aura obtains measurements of ozone, aerosols and key gases throughout the atmosphere to gain revolutionary insights into the chemistry of our atmosphere. http://aura.gsfc.nasa.gov/about.html, last	Since 2004	Coordination: US

	accessed 24 August 2016		
EUFAR/COPAL – European Fleet of Research Aircraft (complementary)	Central network for the airborne research community in Europe with the aim to support researchers by granting access to research infrastructures for in situ measurement of atmospheric properties to remote sensing with instrumented aircraft and providing professional support and training www.eufar.net, last accessed 24 August 2016	2014–2018 Continues as COPAL	Coordination: FR 11 participating countries
GOSAT - Greenhouse Gases Observing Satellite (complementary)	World's first spacecraft to measure the concentrations of carbon dioxide and methane from space www.gosat.nies.go.jp, last accessed 25 August 2016	Since 2009	Coordination: JP
IAGOS – In-service Aircraft for a Global Observing System (complementary)	Long-term observations of atmospheric composition, aerosol and cloud particles on a global scale from commercial aircraft of internationally operating airlines ESFRI 2016 Landmark www.iagos.org, last accessed 25 August 2016	2008–2035	DE, FR (coordinating) 4 participating countries
IASI – Infrared Atmospheric Sounding Interferometer (complementary)	Hyperspectral infrared sounder residing on the European Space Agencies (ESA) MetOp series of polar orbiting satellites www.eumetsat.int/website/home/Satellites/CurrentSatel tes/Metop/MetopDesign/IASI/index.html, last accessed 24 August 2016	Since 2006	EUMETSAT
ICOS – Carbon Observatory (complementary)	Harmonised and high precision data on carbon cycle and greenhouse gas budget and perturbations ESFRI 2016 Landmark www.icos-ri.eu, last accessed 24 August 2016	Since 2008	FI (coordinating) 12 participating countries
METEOSAT 2nd Generation	Two-satellite system continually returning detailed imagery of Europe, Africa and parts of the Atlantic and Indian Ocean every 15 minutes, provide operational weather observations and environmental monitoring http://www.esa.int/Our_Activities/Observing_the_Earth/Meteosat_Second_Generation/MSG_overview2, last accessed 24 August 2016	2004–2019	ESA, EUMETSAT
MODIS – Moderate Resolution Imaging Spectroradiometer (at TERRA and AQUA satellites) (complementary)	Medium resolution spaceborne imaging spectrometer, which is operated onboard of two satellites (Aqua and Terra). MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data at 36 spectral channels covering wavelengths from 0.4 to 14.4 µm. The scientific objectives include the monitoring of processes over land (e. g. land coverage, vegetation index and condition, snow coverage), ocean (e. g. surface temperature) and in the atmosphere on a variety of spatial scales ranging from local to global. Particularly in the biosphere multi-spectral measurements are highly complementary to the intended Tandem-L measurements: the information extracted from multi-spectral measurements on the vegetation type, index and condition complement the biomass and structure measurements of Tandem-L, allowing a comprehensive characterization of forest condition. This applies not only to Modis but also to the following multi-spectral missions, i. e. LANDSAT and	TERRA: Since 1999 AQUA: Since 2002	Coordination: US

	Sentinel-2. http://modis.gsfc.nasa.gov/, last accessed 24 August 2016		
NDACC – Network for the Detection of Atmospheric Composition Change (complementary)	Observing and understanding the physical and chemical state of the stratosphere and upper troposphere and for assessing the impact of stratosphere changes on the underlying troposphere and on global climate; contains data archive www.ndacc.org, last accessed 24 August 2016	Since 1991	Coordination: International
TCCON – Total Carbon Column Observing Network (complementary)	Ground-based Fourier Transform Spectrometers that record spectra of the sun in the near-infrared to monitor CO_2, CH_4, N_2O, HF, CO, H_2O, and HDO; contains data archive www.tccon.caltech.edu, last accessed 25 August 2016	Since 2004	Coordination: US, DE, AU 14 participating countries
TIMED-SABER – Sounding of the Atmosphere using Broadband Emission Radiometry (complementary)	Provides the data needed to advance our understanding of the fundamental processes governing the energetics, chemistry, dynamics, and transport in the mesosphere and lower thermosphere. http://saber.gats-inc.com/overview.php, last accessed 25 August 2016	Since 2001	Coordination: US
WMO-GAW – Global network of surface observatories (complementary)	Partnership of WMO members, contributing networks and collaborating organisations and bodies to provide data and information on the chemical composition of the atmosphere, its natural and anthropogenic change. http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html, last accessed 25 August 2016	Since 1992	More than 100 countries involved
Planned research infrastructures/under construction			
ADM-AEOLUS – Atmospheric Dynamics Mission (complementary)	Aeolus will be the first-ever satellite to directly observe wind profiles from space http://www.esa.int/Our_Activities/Operations/ADM-Aeolus_operations, last accessed 25 August 2016	Launch: 2017	ESA
EARTHCARE (complementary)	Global observations of clouds, aerosols and radiation http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/EarthCARE/Overview2, last accessed 25 August 2016	Launch: 2018	ESA, JAXA
EPS-SG – EUMETSAT Polar System – Second Generation (complementary)	EPS-SG represents Europe's contribution to the future Joint Polar System (JPS), which is planned to be established together with the National Oceanic and Atmospheric Administration (NOAA) of the United States, following on from the Initial Joint Polar System (IJPS) http://www.eumetsat.int/website/home/Satellites/FutureSatellites/EUMETSATPolarSystemSecondGeneration/index.html, last accessed 25 August 2016	2020 - 2040	EUMETSAT
EUROCHAMP – Integration of European Simulation Chambers for Investigating Atmospheric Processes (complementary)	European project which aims a better integration of simulation chambers for studying atmospheric processes. EUROCHAMP is funded within the EC 7th Framework Programme, Section "Support for Research Infrastructures - Integrated Infrastructure Initiative". http://www.eurochamp.org/eurochamp-	2020 (planned)	DE, ES, IE, FR, CH, UK, SE, DK

	2020/index.html, last accessed 25 August 2016		
ISS-MACE – Mesosphere and Climate Experiment (complementary)	Studying the climate effects in the middle atmosphere	Launch: 2017	DE, ES, JP, UK, SE, CH, US, IE, FR
MERLIN (complementary)	German-French CH4 satellite: Precise space based measurement techniques to obtain a global view on the complex processes that control the methane concentration in the atmosphere. http://www.dlr.de/rd/en/Portaldata/28/Resources/, last accessed 25 August 2016 dokumente/re/MERLIN_Datenblatt.pdf	Launch: 2019 Minimum duration: 3 years	Coordination: DE (DLR) and FR (CNES)
Sentinel 5–Precursor (complementary)	The Sentinel-5 Precursor objectives are to provide operational space-borne observations in support to the operational monitoring of Air Quality, Ozone and Surface UV, Climate. It will provide measurements of: Ozone, NO_2, SO_2, HCHO, Aerosol, CO, CH_4, Clouds https://earth.esa.int/web/guest/missions/esa-future-missions/sentinel-5P, last accessed 26 August 2016	2016–2023	NL (coordinating) EUMETSAT, ESA

II.3 AtmoSat

II.3.a Scientific potential

Description

Decadal climate fluctuations are influenced significantly by the variability of the composition and dynamics of the middle atmosphere. At the moment, there is no national or international data base with sufficient spatial and temporal resolution to quantify the underlying physical and chemical processes and to reproduce these adequately in predictive models. According to the proposal, AtmoSat will supply the necessary data basis and will additionally expand time series of important climate variables. The AtmoSat infrastructure addresses the following main atmospheric and climate research topics:

_ Variability of atmospheric trace gases and aerosols: The variability of the near-surface climate is most strongly influenced by the radiative effects of water vapour, ozone, and sulphate aerosols in the upper troposphere and stratosphere. To understand decadal climate variability it is necessary to quantify the temporal and spatial variability of these trace substances and to attribute this variability to atmospheric processes such as the Brewer-Dobson circulation, long-range transport and stratosphere-troposphere exchange.

_ Atmospheric processes: The stratospheric Brewer-Dobson circulation and stratosphere-troposphere exchange have a strong impact on the variability of water vapour, ozone and sulphate aerosols in the upper troposphere and stratosphere. By providing unique measurements of transport tracers such as sulphur hexafluoride, methane, nitrous oxides, methane and fluorocarbons, AtmoSat contributes to a significantly improved understanding of these processes, their spatial and temporal variability, and their impact on global and regional climate.

_ Dynamic couplings: The stratosphere also influences near-surface regional climate and long-term weather via dynamical coupling with the troposphere. Variations of the strength of the polar jet play a decisive role for this coupling. According to the proposal, AtmoSat will provide the necessary data basis to investigate the detailed mechanisms (e. g. the role of atmospheric waves) of these couplings and to represent these mechanisms and their effects quantitatively correctly in models.

AtmoSat relies on three main instruments. It combines infrared limb imaging (via Global Limb Radiance Imager for the Atmosphere – GLORIA) with narrowband observations in other spectral ranges (via Multiple Eye for Remote Investigation of the Atmosphere – MERIA) and GPS (Global Positioning System) radio occultation (via Triple GNSS |[92] = GPS/GLONASS/Galileo, TriG) to provide synergies at the upper and lower measurement boundary. The core instrument is GLORIA, which will be operated in two measurement modes. The landscape mode will be optimised with respect to the spatial resolution and the portrait mode enlarges the number of measurable trace species by increased spectral resolution.

Presently, there are eight limb-sounding satellite instruments in operation (e. g. ACE-FTS |[93] and MLS |[94]). According to the proposal, there will be a lack in the near future of such global satellite measurements with good spatial resolution and AtmoSat will bridge this gap. Furthermore, GLORIA/AtmoSat will be the only one which can probe the atmosphere perpendicular to their line of the sight (third spatial dimension), which is required to quantify significant climate processes like atmospheric gravity waves.

Assessment

AtmoSat is a timely and highly needed RI. It will provide much needed high resolution spatial and temporal global observations of the middle atmosphere that will contribute significantly to monitoring the Earth System. By using this observational information with Earth System Models (e. g. through validation of model output and model representation of processes, and through data assimilation) it will contribute significantly to the scientific understanding of

| 92 Global Navigation Satellite System.

| 93 Atmospheric Chemistry Experiment – Fourier Transform Spectrometer

| 94 Microwave Limb Sounder

atmospheric transport and mixing between the troposphere and middle atmosphere. It is a transformative infrastructure that will provide a three-dimensional tomography of the atmosphere. This will improve projections of long-term climate change and provide for the advancement of mid-range (7–14 days) weather forecasts.

The proposal provides an outstanding scientific rationale for this project. It is strategic and well-articulated. The proposed suite of instruments will enable a major technology advance in limb-imaging. As a result, the resolution and spatial and time coverage of the observations are unique. The three dimensional global measurements of temperature and trace gases, with high vertical resolution, would be a game-changer for the scientific field. The strategic importance of the RI to the research fields of climate change and weather forecasting is thus very high. The data that will be gathered would be crucial for advancing fundamental atmospheric dynamics and climate change research, as well as monitoring of the effects of mitigation or fundamental information required for geoengineering.

The satellite will fill an important gap in long term measurements since all previous missions have either failed, shut down or are about to shut down as they are already exceeding their planned operational period. AtmoSat will provide long term data that will complement existing observations and will extend them to the future. The advancement afforded by AtmoSat is a great leap forward and is not incremental. The research questions addressed by AtmoSat require the use of global observations, which requires low Earth orbit satellites (LEOs). A single geostationary satellite (GEO) cannot provide the global coverage required. However, the ground-based and in situ observing platforms play a key role in evaluating and complementing the satellite data. The AtmoSat proposal recognises this.

During the discussion with the reviewers, the proposers elaborated on the hierarchy of the scientific questions set by the proposal, classified as "scientific questions", "related questions", "overarching scientific questions" and "key questions". The proposal includes a comprehensive discussion of transport processes which are the most important questions addressed by the infrastructure. The proposal also addresses chemical processes and monitoring but in less detail since knowledge of transport is of higher scientific relevance to the middle atmosphere, owing to gaps in our understanding. On the same hierarchy level of scientific impact is the link of AtmoSat with air quality since long-term monitoring of more than 50 trace gases is important for following large scale pollution events and global change. The proposed measurements do not go down to the surface but constrain the air quality problem by improving the retrievals of tropospheric pollutants for the mid to upper atmosphere. The temporal resolution of the measurements in the middle troposphere (at 5 km, the lowest level sampled by AtmoSat) results in strongest impact on mid-term atmospheric processes (10–14 days). However, since parameters such as temperature and water vapour are in principle available in near real time (downloading of every orbit is possible with 4h delay) there is also a potential for improving weather forecasts.

The RI will achieve incorporation into climate and operational weather models through strong user engagement. Some of the information about this aspect of AtmoSat is contained within the supporting letters, but a more detailed understanding of how the model development and operational communities are going to be involved would be helpful.

The technical level of maturity is as high as the scientific goals. The proposal represents a very through preparation and realisation stages conducted by the proposing institutions. The satellite will use a unique instrumentation that has already been successfully tested in airborne missions. The storage and use of data has been already developed to a high level, including protocols for using the data by a few end members.

The GLORIA instrument will be operated in two modes which will be decided by the scientific steering board, which comprises representatives of the responsible institutes and their scientific partners. This provides flexibility to the AtmoSat mission, allowing prioritisation according to the scientific questions that need addressing at a given time. This provides an optimal use of the RI.

At the moment, AtmoSat is a unique infrastructure with no major competition. The uniqueness comes from the looming limb-gap and its hyperspectral imaging technology. The former means that it is likely that AtmoSat will be one of the main, if not the only, providers of limb measurements of the atmosphere after launch in the 2023 timeframe. There are no other comparable instruments operational or planned and the high resolution 3-D global averages of so many atmospheric parameters and trace gases have no equivalent. Without this infrastructure, long term observations of the parameters will not be feasible. However, it will be synergetic to other users of remote sensing (such as nadir users) that will be able to combine the AtmoSat data to improve their retrievals. The data will also be synergetic to weather and stationary satellite retrievals used by weather services.

The main technological innovations of AtmoSat are as follows:

_ The high spectral resolution of the measurements, which provide opportunities to extend the range of measurements made (e. g. daily measurements of more than 50 chemicals, water vapour and sub-visible cirrus clouds),

_ The combination of instruments (GLORIA, MERIA and TRIG) that provides simultaneous measurements across the depth of most the atmosphere (5–100 km) that link processes at the lower and upper boundaries of the measurement vertical range. This has never been done before and will provide crucial information for climate and atmospheric dynamics research.

II.3.b Utilisation

Description

The expected user group encompasses the entire community of atmospheric and climate sciences worldwide as well as the national and international weather services. The majority of users (approx. 80 %) comes from the scientific sector and is organised in international programmes and institutions (e. g. World Climate Research Programme (WCRP), International Geosphere-Biosphere Programme (IGBP), and the World Meteorological Organisation (WMO)). Other users come from the area of data assimilation (e. g. Global Climate Observing System (GCOS) and the Copernicus Atmosphere Monitoring Service (CAMS)).

Data-access will be freely available by implementation of a "wide-access"-model. |[95] Users will have to register and each version of the data will be assigned a Digital Object Identifier (DOI) to link scientific publication to the actual data. More comprehensive access (e. g. use of data processors to produce data products) will also be possible. Moreover, annual data user workshops will be organised to encourage community exchange.

The raw and secondary data delivered by AtmoSat can be broken down into raw data as sent from the instrument to the ground stations, calibration data and calibrated radiance spectra, and derived geophysical parameters (e. g. pressure, temperature, trace gas concentrations), which are generated largely in near-real time and will be made available to the users. A joint data lab will be established at FZJ and for security reasons the complete available data set will be mirrored at the KIT Steinbuch Centre for Computing (SCC). A central aim is to make the data available in standardised formats, which allow data integrity to be verified and which can be used by diverse software tools without modification.

The quality of the derived data is assured in several steps. First, non-convergent retrievals and outliers are eliminated. Second, certain control parameters, which specify the usefulness of the data, will be checked. The data are then tested for implausible values. At the end of the quality assurance process, only the data that have successfully passed all stages are made available to the user community on the data server. Important steps in this quality assurance pro-

|[95] As defined by the European Charter for Access to Research Infrastructures, https://ec.europa.eu/research/infrastructures/pdf/2015_charterforaccessto-ris.pdf, last accessed on 28/07/2016.

cedure are the proximity of the data processing personnel to the scientific users in the operating centres and the geophysical validation of the data, for instance comparison with reference measurements (e. g. from ground-stationed or balloon-borne/aircraft-borne instruments).

Assessment

Overall, there is a very impressive list of endorsements of the AtmoSat RI, including leading international scientific organisations and programmes, leading weather services, leading scientific partners in Germany and leading research scientists in Europe, USA and East Asia. The anticipated user group for this infrastructure is the international atmosphere and climate scientific community, which is interdisciplinary across chemistry, physics, and engineering. It is a community that utilises all methodologies of science – theory, observations, process studies and system science, and models (computational and physical). Given the broad range and international outlook of the supporting user groups, the proportion of international users is likely to be very high. The scientific community is several thousand people, while the assimilation community involves many governmental and international institutions. Based on previous similar missions, it is expected that the data will be fully utilised by the diverse customer groups.

The data products are to be freely and openly available, which is critical given the upcoming shortage of observations from the middle atmosphere. The proposers are perfectly aware of the need to ensure that these observations complement and augment ground-based observations and previous satellite measurements — this continuity of quality data has been acknowledged. The following aspects of AtmoSat are appropriate and likely to ensure its success:

_ Transparency and adequacy of the conditions for data access,

_ Suitability of the conditions for access for creating the best possible research conditions,

_ Training and advice services to organise qualified access to the RI,

_ Opportunities for user participation in the subsequent development of the RI. The legal conditions seem to be appropriate for a project of this nature,

_ The proposers operate one of the largest computer infrastructures in Europe and have the expertise in providing such services.

There is a detailed scheme for communicating with the community to ensure appropriate use of the current data and processing level. During the interview the proposers clarified that also free access to the source codes will be provided to researchers which clearly will enhance the community interaction.

Immense amounts of (near real time, raw and processed) data will be generated. The data concept is well articulated with recognition of various processing stages, data availability, validation, security, and timeliness. The responsible institutions have excellent computing, storage and backup capabilities. A plan for data analysis and storage with appropriate backups is proposed which is based on a joint data lab that relies on FZJ infrastructure with appropriate backup and mirroring. The "Management Concepts", the "Access Management" (e. g. the use of the Digital Object identified – DOI, and the INSPIRE |[96] directive), and the "Data Utilisation and management concept" (e. g. the processing from Level 0 data to Level 3 data) ensure the best possible use of the AtmoSat data by scientists. From a scientific perspective, the data concept formulated in AtmoSat is comprehensive, user-friendly and provides benefit to the broad scientific community.

The process integrity formulated in AtmoSat is also excellent. There is an appropriate protocol for data assurance and also a validation scheme for derived geophysical parameters, based on ground and airborne measurements which will be used as standards for comparison. A very good governance structure has been set up which will involve the global scientific community. AtmoSat has immense national and international support from leading scientists and large international organisations such as WMO, SPARC |[97], IGAC |[98], national weather services etc.

II.3.c Feasibility

Description

The core instrument GLORIA has been already successfully deployed in aircraft missions. |[99] Subsystem modifications and refinements will be necessary for the satellite-borne version. As stated in the proposal, the associated technical risks are considered low due to the wide availability of the required technologies. MERIA comprises three monolithic spatial heterodyne spectrometers (SHS) which were tested before in US-space missions. TriG is an established technology and suitable satellite receivers are commercially available.

The quantification of the influences of changes in the middle atmosphere on the surface climate necessitates an integrated utilisation of observational data, process-oriented simulations, and Earth system and climate modelling. A reduction of the uncertainties in model projections requires a data base with im-

| 96 Infrastructure for Spatial Information in Europe.

| 97 Stratosphere-troposphere Processes And their Role in Climate.

| 98 International Global Atmospheric Chemistry.

| 99 See: C. von Savigny and J. Notholt: Atmospheric limb imaging with GLORIA, in: Atmospheric Measurement Techniquies (special issue), 2013, http://www.atmos-meas-tech.net/special_issue59.html, last accessed on 28.07.2016.

proved three-dimensional resolution as provided by AtmoSat. A scientific steering committee will be set up to integrate the scientific partners into the development of the project. It will comprise one representative from each of the responsible institutions and the scientific partners listed in the concept. Moreover, three further governance instruments will be established: First, an assembly of core partners, second, a board of directors, and third a scientific advisory board.

As it is pointed out in the proposal, the responsible institutions have well-grounded scientific expertise and personnel, which is suitable to establish and operate the AtmoSat infrastructure. The aircraft-borne demonstrator of the main instrument was developed by KIT and FZJ. Additionally, FZJ is involved in a development initiative for the SHS-technology, which is the core of MERIA. GFZ has experience in installing, operating, and evaluating data from ground-based and satellite-borne GPS receivers and has worked specifically on development of the radio occultation technology.

According to the proposal, the AtmoSat concept has already reached a high level of technical and scientific maturity. The requirements of a satellite mission aiming to investigate climate processes in the atmosphere have been defined in numerous studies. A financing structure has been proposed by the responsible institutions and scientific partners declared their interest in participating in the planned cooperation.

Assessment

AtmoSat is based on proven and tested technologies, so the associated risk is not very high. The technical requirements and risks have been mitigated to a large extent by the successful development and deployment of an aircraft version of GLORIA – the main new instrument. The technology is robust enough to be launched. The consortium of the three institutions is extremely strong, and they all have experience with such projects (or the crucial components), they have the infrastructure for supporting the development, implementation and operational support for AtmoSat. There are further no risks or consequences from an ethical, legal, and environmental point of view.

From a scientific perspective, the AtmoSat proposal deals adequately with the institutional requirements. The three responsible institutions (FZJ, KIT, and GFZ) have the expertise and experience to provide the necessary technical and management competencies to make AtmoSat a success.

There is no question that the scientific and technical credibility of these institutions is of the highest standard. There is strong financial support within the institutions for data processing and data infrastructure.

During the interviews the proposers clarified some of the concerns about the project management being delegated to a “centre-overarching coordination group". The feasibility and success ultimately will depend on the people within a working structure – people with the right attitude that have a culture of support. The institutions have personnel structures that provide for the needed expertise for this project. However they also recognise the need to hire an overall project manager who will lead the overall team that will be responsible for the construction and operation of this satellite. They are also aware of the importance of this position in providing the successful system integration for this project. Working successfully across research institutions, universities, and industry is an important component of this management.

The AtmoSat proposal deals adequately with the personnel requirements. During the interview it was shown that the project is capable of ensuring a good mix of early career and senior scientists and engineers. Career paths are well established.

The proposal deals adequately with the realisation of the AtmoSat RI, and the concept has reached a high level of technical and scientific maturity. The analysis of the instrument package, data system, and the satellite platform seem to be robust and include examinations of the maturity of the technology, the sources for building the sensors and the satellite platform, and clear requirements – and all were deemed to be feasible. This will be further developed in the envisaged Phase A feasibility study as part of the implementation phase. Finally, the declarations concerning contributions to AtmoSat from the proposing institutions (KIT, FZJ, and GFZ) confirm that the infrastructure is very strong, including the financing structure.

II.3.d Relevance to Germany as a location of science and research

Description

According to the proposal, AtmoSat will expand Germany's leading international position in the atmospheric and climate sciences substantially and a high international visibility of the infrastructure will be ensured. The data basis has a unique character and will make AtmoSat attractive for large scaled international research programmes like the World Climate Research Programme (WRCP) or the International Geosphere-Biosphere Programme (IGBP).

It is emphasised in the proposal, that the high visibility promotes the attractiveness of Germany as a location of science and research for both, established researchers worldwide and young academics working in the atmospheric and climate sciences. The diversity of related activities of the German research community and the distinguished integration of German institutions in international programmes also provides an incentive, and creates attractive opportunities for research and funding.

In addition to scientific publications in high-impact journals, numerous contributions are expected to reports by WMO, International Panel on Climate Change (IPCC), and WCRP, which not only transfer knowledge to the public but are also consulted by policy makers. Moreover, the responsible institutions will exploit their involvement in the Earth System Knowledge Platform (ESKP), which aims to coordinate the transfer of knowledge on system Earth (e. g. climate change). Furthermore, a close connection to the Climate Service Center Germany (GERICS) and national climate offices is intended by the institutions participating in AtmoSat.

Assessment

There is absolutely no doubt that AtmoSat will lead to high visibility and impact in various fields. The realisation of the RI will reinforce the strong tradition of the German science community in modelling, data assimilation and earth observation and will place it in a leading role. Germany is internationally recognised as a scientific leader in atmospheric and climate science. The nation has also politically taken a leading role in Europe (if not the world) in developing strategies and policies for responding to climate change – and research support is one of those strategies. AtmoSat will contribute significantly to the implementation of the German climate strategy. The RI will put German geophysical sciences in the forefront of atmospheric dynamics and climate research and will attract the next generation of scientists globally. The high quality of the data, the availability of the near real time data to all users and the relevance to several important science questions and important weather services, would clearly place this infrastructure and Germany in an international leading position.

Overall, the AtmoSat RI will provide ground-breaking and much needed contribution to the long-term scientific research in Germany on Earth Climate System that is linked to the key societal challenges of the 21st Century. It will make a very strong contribution toward making Germany an attractive place to do scientific research in Earth System Science, consolidating the strengths of the German research landscape. In particular, the AtmoSat RI will ensure the appropriate training and career positioning of the next generation of scientists. There is no currently known alternative to AtmoSat, so the RI will be a unique platform that will attract national and international interest. This will put Germany at a leadership position in the field and will enhance and increase its international scientific connections.

AtmoSat is a timely and highly needed project and will have a huge scientific impact nationally and internationally. If the RI could not be realised, there would be a gap in limb-viewing observations of the middle atmosphere (most current missions are old, and currently there is little prospect of renewal). AtmoSat will bring together the main players in Earth System Science, including academia, weather forecasting agencies, climate scientists and international organisations. Hence AtmoSat provides a very high societal gain in many dimensions and the overall output from such infrastructure can be immense with great impacts on many fronts.

II.3.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Participants
Forerunners			
GOMOS/Envisat – Global Ozone Monitoring by. Occultation of Stars	GOMOS is a medium resolution spectrometer covering the wavelength range from 250 nm to 950 nm. The high sensitivity requirement down to 250 nm has been a significant design driver leading to an all-reflective optical system design for the UVVIS part of the spectrum and to functional pupil separation between the UVVIS and the NIR spectral regions (thus no dichroic separation of UV). Due to the requirement of operating on very faint stars (down to magnitude 4 to 5), the sensitivity requirement to the instrument is very high. Consequently, a large telescope (30 cm × 20 cm aperture) had to be used to collect sufficient signal, and detectors with high quantum efficiency and very low noise had to be developed to achieve the required signal to noise ratios. https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/gomos, last accessed 28 July 2016	2002–2012	ESA
HiRDLS/Aura – High Resolution Dynamics Limb Sounder	Infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $ClONO_2$, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models. http://www.nasa.gov/mission_pages/aura/spacecraft/hirdls.html, last accessed 28 July 2016	2004 –2008	US (NASA)
MIPAS/Envisat – Michelson Interferometer for Passive Atmospheric Sounding	Fourier transform spectrometer for the detection of limb emission spectra in the middle and upper atmosphere. It observes a wide spectral interval throughout the mid infrared with high spectral resolution. Operating in a wavelength range from 4.15 microns to 14.6 microns, MIPAS detects and spectrally re-	2002–2012	ESA

	solves a large number of emission features of atmospheric minor constituents playing a major role in atmospheric chemistry. https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/mipas, last accessed 28 July 2016		
SCIAMACHY/ Envisat – Scanning Imaging Absorption Spectrometer for Atmospheric Chartography	Imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere. The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 0.5 nm) over the range 240 nm to 1,700 nm, and in selected regions between 2,000 nm and 2,400 nm. The high resolution and the wide wavelength range make it possible to detect many different trace gases despite low concentrations (The mixing ratios of most constituents are of the order of 10-6 or less). The large wavelength range is also ideally suited for the detection of clouds and aerosols. SCIAMACHY has three different viewing geometries: nadir, limb, and sun/moon occultations which yield total column values as well as distribution profiles for trace gases and aerosols in the stratosphere and partly the troposphere. https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/sciamachy, last accessed 28 July 2016	2002–2012	ESA
SMILES/ISS – Superconducting Submillimeter-Wave Limb-Emission Sounder	SMILES is a sensitive submillimetre-wave sounder. The objective of SMILES is to monitor global distributions of stratospheric trace gases which contribute ozone depletion. SMILES is the first approach to use a superconductive low-noise receiver with a mechanical 4-K refrigerator in space to realize a high sensitive observation. http://www.nasa.gov/mission_pages/station/research/experiments/638.html#description, last accessed 28 July 2016	2009–2010	US (NASA)
Existing research infrastructures			
ACE-FTS/ SciSat-1 – Atmospheric Chemistry Experiment–Fourier Transform Spectrometer	ACE-FTS is the prime instrument of the SciSat mission. ACE has been built by ABB Bomem Inc. of Quebec City, Quebec. The objective is to measure the vertical distribution of atmospheric trace gases, in particular of the regional polar O_3 budget, as well as pressure and temperature (derived from CO_2 lines). The instrument is an adapted version of the classical sweeping Michelson interferometer, using an optimized optical layout. ACE consists of the following components: the FTS, a VNIR (Visible Near Infrared) imager, a sun tracker, the instrument electronics, and a power supply. An SNR > 100 is achieved; IFOV (FTS) = 1.25 mrad; a telescope aperture diam-	Since 2003	CA

	eter of 100 mm and a measurement period of 2 s. The instrument includes a suntracker, which provides fine pointing toward the radiometric centre of the sun with a stability better than 15 µrad, to both the infrared spectrometer and the imager during solar occultation of the Earth's atmosphere (there are about 30 sun occultation periods per day). Measurements can be made in the altitude range 5 – 150 km. The FTS is coupled with an auxiliary 2-channel VNIR imager. https://directory.eoportal.org/web/eoportal/satellite-missions/s/scisat-1, last accessed 28 July 2016		
CrIS/Suomi NPP – Cross-track Infrared Sounder (complementary)	CrIS, an advanced spectrometer with 1,305 infrared spectral channels, is designed to provide high vertical resolution information on the atmosphere's three-dimensional structure of temperature and water vapour. CrIS will continue this data record and provide data for use in NOAA's numerical weather prediction models to forecast severe weather days in advance. https://jointmission.gsfc.nasa.gov/instruments.html, last accessed 28 July 2016	Since 2011	US (NASA; NOAA, DMSP)
GOME-2 – Global Ozone Monitoring Experiment–2 / MetOP-A MetOp-B MetOp-C (complementary)	Optical spectrometer, fed by a scan mirror which enables across-track scanning in nadir, as well as sideways viewing for polar coverage and instrument characterisation measurements using the Moon. It is used to get a detailed picture of the total atmospheric content of ozone and its vertical profile in the atmosphere. It also provides accurate information on the total column amount of NO_2, SO_2, H_2O, O_2/O_2 dimer, BrO and other trace gases, as well as aerosols. http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/GOME2/index.html, last accessed 28 July 2016	MetOp-A: Since 2006 MetOp-B: Since 2012 Metop-C: Launch: 2018	Coordination: EUMETSAT FR (CNES), ESA
IASI – Infrared Atmospheric Sounding Interferometer / MetOP-A MetOp-B MetOp-C(complementary)	IASI measures in the infrared part of the electromagnetic spectrum at a horizontal resolution of 12 km over a swath width of about 2,200 km. With 14 orbits in a sun-synchronous mid-morning orbit (9:30 Local Solar Time equator crossing, descending node) global observations can be provided twice a day. http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/IASI/index.html, last accessed 28 July 2016	MetOp-A: Since 2006 MetOp-B: Since 2012 MetOp-C: Launch: 2018	Coordination: EUMETSAT FR (CNES), ESA
MAESTRO/ Scisat-1 – Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation	Dual-channel optical spectrometer in the spectral region of 285–1030 nm. The objective is to measure ozone, nitrogen dioxide and aerosol/cloud extinction (solar occultation measurements of atmospheric attenuation during satellite sunrise and sunset with the primary objective of assessing the stratospheric ozone budget). Solar occultation spectra are being used for retrieving vertical profiles of temperature and pressure, aero-	Since 2003	CA

	sols, and trace gases (O_3, NO_2, H_2O) involved in middle atmosphere ozone distribution. The use of two overlapping spectrometers (280–550 nm, 500–1030 nm) improves the stray-light performance. The spectral resolution is about 1–2 nm. https://directory.eoportal.org/web/eoportal/satellite-missions/s/scisat-1, last accessed 28 July 2016		
MLS/Aura – Microwave Limb Sounder	Measurements of atmospheric composition, temperature, humidity and cloud ice that are needed to (1) track stability of the stratospheric ozone layer, (2) help improve predictions of climate change and variability, and (3) help improve understanding of global air quality. MLS observes thermal microwave emission from Earth's 'limb' (the edge of the atmosphere) viewing forward along the Aura spacecraft flight direction, scanning its view from the ground to ~90 km every ~25 seconds. Aura is in a near-polar 705 km altitude orbit. As Earth rotates underneath it, the Aura orbit stays fixed relative to the sun; to give daily global coverage with ~15 orbits per day. Aura is part of NASA's A-train group of Earth observing satellites. These satellites fly in formation with the different satellites making measurements within a short time of each other. The MLS measurements are made globally day and night. A feature of the MLS technique is that its measurements can be obtained in the presence of ice clouds and aerosol that prevent measurements by shorter-wavelength infrared, visible and ultraviolet techniques. http://mls.jpl.nasa.gov/index-eos-mls.php, last accessed 28 July 2016	Since 2004	US (NASA)
OMPS/Suomi NPP – Ozone Mapping Profiler Suite	OMPS measures the global distribution of the total atmospheric ozone column on a daily basis. It also measures the vertical distribution of ozone from about 15 km to 60 km, though somewhat less frequently. The Nadir instrument looks directly below the satellite while the Limb instrument looks at an angle to the Earth's surface. The instruments measure ozone by collecting light from the sun that has been reflected off of the atmosphere. Ozone molecules absorb some of this light and these absorption features are used to calculate the amount of ozone present over the entire globe. https://jointmission.gsfc.nasa.gov/omps.html, last accessed 03 August 2016	Since 2011	US (NASA)
OSIRIS/Odin – Optical Spectrograph and InfraRed Imaging System	UV/VIS/IR limb sounder, in effect a double instrument, mounted in a common optical housing and supported by common electronics. The UV/VIS imaging spectrograph uses compact reflective optics (off-axis system, folded design, aperture = 36 mm x 36 mm)	Since 2001	CA

	and an aspherical ruled grating along with UV-enhanced CCD arrays. OSIRIS has a dual-purpose objective of detecting aerosol layers and to detect abundances of species such as O_3, NO_2, OClO, and BrO (retrieval of altitude profiles of terrestrial atmospheric minor species by observing limb-radiance profiles). https://directory.eoportal.org/web/eoportal/satellite-missions/o/odin, last accessed 28 July 2016		
SABER/ **TIMED** – Sounding of the Atmosphere using Broadband Emission Radiometry	Provides the data needed to advance our understanding of the fundamental processes governing the energetics, chemistry, dynamics, and transport in the mesosphere and lower thermosphere. http://saber.gats-inc.com/overview.php, last accessed 28 July 2016	Since 2001	US
SAGE III/ISS – Stratospheric Aerosol and Gas Experiment III	The SAGE III instrument is used to study ozone. More specifically, SAGE III – ISS will provide global, long-term measurements of key components of the Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE III also provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases such as water vapour and nitrogen dioxide that play significant roles in atmospheric radiative and chemical processes. SAGE III, like its predecessors, is a grating spectrometer that measures ultraviolet/visible energy. However, SAGE III has a few upgrades. The new design incorporates Charge Coupled Device (CCD) array detectors and a 16-bit A/D converter. Combined, these devices allow for wavelength calibration, a self-consistent determination of the viewing geometry, lunar occultation measurements and expanded wavelength coverage. http://science.nasa.gov/missions/sage-3-iss/, last accessed 28 July 2016	Since 2016	US (NASA)
SMR/ODIN – Sub-Millimetre Radiometer	Passive microwave limb sounder with one receiver at a wavelength of 3 mm and additional four bands within the submillimetre range (0.5–1.0 mm) corresponding to a frequency range of 486–580 GHz. Antenna reflector type: offset Gregorian telescope [off-axis system, 1.1 m diameter, surface roughness: 10 µm rms, material: carbon fibre reinforced plastic (CFRP)]. SMR is used in the astronomy as well as in the atmospheric research mission to detect molecular transitions. https://directory.eoportal.org/web/eoportal/satellite-missions/o/odin, last accessed 28 July 2016	Since 2001	SE (coordinating), FR, FI
SOFIE/AIM – Solar Occultation for Ice Experiment	SOFIE is one of three instruments onboard the Aeronomy of Ice in the Mesosphere (AIM) satellite. The objective of AIM is to study polar	Since 2007	US, UK

	mesospheric clouds (PMCs) and the environment in which they form. SOFIE uses the technique of solar occultation to measure solar energy passing through the limb of the earth's atmosphere as the sun rises or sets relative to the spacecraft. http://sofie.gats-inc.com/sofie/index.php, last accessed 28 July 2016		
Planned research infrastructures/under construction			
CrIS/JPSS-1 – Cross-track Infrared Sounder (complementary)	CrIS, an advanced spectrometer with 1,305 infrared spectral channels, is designed to provide high vertical resolution information on the atmosphere's three-dimensional structure of temperature and water vapour. CrIS will continue this data record and provide data for use in NOAA's numerical weather prediction models to forecast severe weather days in advance. https://jointmission.gsfc.nasa.gov/jpss_mission.html, last accessed 28 July 2016	From 2017	US (NASA; NOAA)
IASI-NG/ MetOp-SG A – Infrared Atmospheric Sounding Interferometer (complementary)	Will provide hyper-spectral infrared soundings of temperature, water vapour, and trace gases with a spectral resolution of 0.25 cm^{-1} within the spectral range from 645 to 2,760 cm^{-1} at an average spatial sampling distance of 25 km. http://www.eumetsat.int/website/home/Satellites/FutureSatellites/EUMETSATPolarSystemSecondGeneration/EPSSGDesign/index.html, last accessed 28 July 2016	From 2021	EUMETSAT, ESA
IRS/MTG-S – Infrared Sounder (complementary)	The Infrared Sounder (IRS) on MTG-S will be able to provide unprecedented information on horizontally, vertically, and temporally (4-dimensional) resolved water vapour and temperature structures of the atmosphere. Retrieving highly resolved vertical structures of humidity (~2 km resolution with 10 % accuracy) and temperature (~1 km with 0.5°–1.5° accuracy) by remote sensing techniques does require measurements within the water vapour and CO_2 absorption bands with extremely high spectral resolution and accuracy. The IRS is based on an imaging Fourier-interferometer with a hyperspectral resolution of 0.625 cm^{-1} wave-number, taking measurements in two bands, the Long-Wave InfraRed (LWIR) and the Mid-Wave InfraRed (MWIR), with a spatial resolution of 4 km. The IRS will deliver over the Full Disk in the LWIR (700–1,210 cm –1 or 14.3–8.3 μm) 800 spectral channels and in the MWIR (1600–2175 cm^{-1} or 6.25–4.6 μm) 920 channels with a basic repeat cycle of 60 min. The IRS includes the ozone band within LWIR and the carbon monoxide band within MWIR. This will allow measurement within the free	From 2019	EUMETSAT, ESA

	troposphere, leading to information on enhanced levels of pollution in the boundary layer below. By providing operational measurements of carbon monoxide and ozone, IRS will also make a significant contribution to the space segment of the Copernicus initiative. http://www.eumetsat.int/website/home/Satellites/FutureSatellites/MeteosatThirdGeneration/MTGDesign/index.html, last accessed 28 July 2016		
OMPS/JPSS-2 – Ozone Mapping Profiler Suite	OMPS measures the global distribution of the total atmospheric ozone column on a daily basis. It also measures the vertical distribution of ozone from about 15 km to 60 km, though somewhat less frequently. The Nadir instrument looks directly below the satellite while the Limb instrument looks at an angle to the Earth's surface. The instruments measure ozone by collecting light from the sun that has been reflected off of the atmosphere. Ozone molecules absorb some of this light and these absorption features are used to calculate the amount of ozone present over the entire globe. https://jointmission.gsfc.nasa.gov/omps.html, last accessed 03 August 2016	From 2021	US (NASA)
Sentinel-4	The Sentinel-4 mission covers the needs for continuous monitoring from a geostationary orbit of the atmospheric chemistry in order to support air quality monitoring and forecast over the skies of Europe. The main data products will be O_3, NO_2, SO_2, HCHO and aerosol optical depth, which will be generated about every hour at a high spatial resolution. The Sentinel-4 UVN instrument is a high resolution spectrometer covering the ultraviolet (305–400 nm), visible (400–500 nm) near-infrared (750–775 nm) bands. The spatial resolution is 8 km while the spectral resolution in the three wavelength bands ranges between 0.12 and 0.50 nm. http://esamultimedia.esa.int/docs/EarthObservation/Sentinel4_facts_2015.pdf, last accessed 16 August 2016	2019 (Follow-up mission: 2027)	EUMETSAT, ESA
Sentinel-5/ MetOp-SG A (complementary)	Instrument to provide ozone profiles, monitor various trace gases, as well as air quality and support climate monitoring by means of hyper-spectral soundings with a spectral resolution from 0.065–1 nm in the wavelength range from 0.27–2.4385 µm, at a spatial sampling of 7 km for channels above 0.3 µm. http://www.eumetsat.int/website/home/Satellites/FutureSatellites/EUMETSATPolarSystemSecondGeneration/EPSSGDesign/index.html, last accessed 28 July 2016	From 2021	EUMETSAT, ESA
Sentinel-5P	The Sentinel-5 Precursor objectives are to provide operational space-borne observations in support to the operational monitoring of Air Quality, Ozone and Surface UV, Climate. It will provide measurements of: Ozone, NO_2, SO_2, HCHO, Aerosol, CO, CH_4, Clouds https://earth.esa.int/web/guest/missions/	2016–2023	EUMETSAT, ESA

	esa-future-missions/sentinel-5P, last accessed 28 July 2016		
TEMPO – Tropospheric Emissions: Monitoring of Pollution	After being deployed on a geostationary satellite, TEMPO will observe Earth's atmosphere in ultraviolet and visible wavelengths to determine concentrations of many key atmospheric pollutants. It will be launched to an orbit about 22,000 miles above Earth's equator. The investigation will for the first time make accurate observations of tropospheric pollution concentrations of O_3, NO_2, SO_2, HCHO, and aerosols with high resolution and frequency over the U.S, Canada and Mexico www.nasa.gov/centers/langley/science/TEMPO.html, last accessed 16 August 2016	2017–2019	US (NASA)

II.4 German Center for Biodiversity Monitoring (BioM-D)

II.4.a Description

Basic data on the research infrastructure

The German Center for Biodiversity Monitoring is planned as a decentralised and coordinated facility for the monitoring and monitoring research of biodiversity. It will support, advice and inform research institutions, authorities, planning offices, politics and society in the area of ecosystem research, conservation biology, biodiversity usage, population ecology and sustainability research. According to the proposal the infrastructure will be established as non-profit-organisation and includes "weather stations for species diversity", evaluation stations for satellite data, data and computing centres, specialised research laboratories. It develops monitoring methods for users, will organise, harmonise and save data, offer innovative analyses and provide tools and instruments for causal research.

The facility is designed as national infrastructure with participation of eleven member institutions. Leading responsible institutions are the Zoological Research Museum Alexander Koenig–Leibniz Institute for Animal Biodiversity (ZFMK), Bonn, accompanied by: Federal Agency for Nature Conservation (BfN), Bonn; Free University of Berlin, Botanic Garden and Botanical Museum Berlin (BGBM); State Natural History Collections of Bavaria (SNSB), München; Leibniz Institute – German Collection of Microorganisms and Cell Cultures (DSMZ), Braunschweig; Senckenberg Research Institute/German Centre for Marine Biodiversity Research (DZMB), Wilhelmshaven; German Federation for Biological Data (GFBio), Bremen; German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig/Leipzig University; Leibniz Institute for Baltic Sea Research (IOW), Warnemünde; Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin; Leibniz Institute for Evolution and Biodiversity Science (MfN), Berlin.

The development phase is planned as lasting ten years. Investment costs without administrative overhead costs and without own contributions are estimated to a total of EUR 419 million. BioM-D has no limited lifetime. The operating phase is estimated to start in 2029/2030. According to the proposal by now no more precise estimations for the operating costs of BioM-D can be given. Except where laboratory work or fieldwork is being carried out, running costs and maintenance costs will be borne by the member institutions.

Scientific potential according to the proposal

Central scientific issues of BioM-D are:

_ Development and optimisation of techniques and methods. These are e. g. reference databases, monitoring strategies, genetic and genomic monitoring techniques, various analysis tools, standardisation, data transmission and data integration.

_ Modelling, theory development, syntheses, and development of scenarios.

_ Analyses of impacts on Biodiversity at the landscape level, e. g. review of forecasts, impacts of climate change, land use, water use and pollution, effectiveness of management measures.

_ Analyses of impacts on biodiversity at species level, e. g. analysis of the value of indicator species, population development of endangered and non-endangered species, rootcause analysis, establishment of early warning systems, observations of phenology, analysis of mechanisms of dispersal and evolution.

According to the proposal the infrastructure will mobilise and provide reference data, innovative methods and information (e. g. for ecological synthesis). It will help to harmonise the currently fragmented research landscape, to increase the efficiency of existing resources, and to provide information on the long-term development of biodiversity, on the basis of a broad data base. BioM-D will encourage networking between practical nature conservation and basic ecological research. Furthermore, the facility will make an important contribution bridging the gap between taxonomy and ecology.

After the set-up phase, the new infrastructure could be used simultaneously by many users. With the accumulation to a large extent fully automated workflows and techniques applications will be easier and more efficient. Additionally new Biodiversity-Information will be provided.

According to the proposal there is neither in Germany nor in Europe a coordinated research infrastructure for biodiversity monitoring so far. Complementary to BioM-D are:

- _ Observatories, e. g. LTER-observations |[100], the DFG-exploratories, the TERENO Program by Helmholtz institutes |[101], which in part serve experimental ecology and environmental observation, but without focus on a comprehensive “monitoring of biodiversity”,
- _ the planned DCOLL project, a decentralised infrastructure in which collection data from museums is digitised, and
- _ monitoring activities and programmes for monitoring of species, habitats and ecosystems in federal states and at federal level.

Utilisation according to the proposal

BioM-D will be open to all user groups and stakeholders. The centre provides users with the data, results, methods, provide IT-tools (information technology) and workflows, use cases and instructions for use and will carry out research and development. Potential users for BioM-D might be scientists, civil service, societies, and citizen scientists at university and non-university research institutes, natural history museums, botanical gardens, observatories and exploratories, the media, early warning services, decision-makers, Federal State Offices for Nature Conservation/regional authorities. Also BioM-D will contribute to international networks, projects, and conferences. Techniques developed by BioM-D will be made available to small and medium enterprises for further distribution.

According to the proposal all data, methods, software tools, analyses and findings should be free of charge and freely available, unless security concerns, species and data protection speak against it and no additional operating costs are involved. They should basically be distributed via an internet portal, but also at conferences and workshops, as well as through the international networks. Users of BioM-D will have different options for access: online via the BioM-D internet portal or by contacting the central administrative office or the responsible BioM-D member institutions. Costs must only be repaid if running expenses, wear and tear or additional staffing is incurred. Data of users should be accepted at no cost and integrated into the datasets, as long as the data is valuable and quality-controlled. Commercial use is expressly permitted. Citizen scientists who provide data must agree that the information will be published for further use.

According to the proposal many partner institutions of BioM-D have the necessary expertise in compiling and archiving data (which take into account the complexity of huge data volumes and integration of different data types). Data

|[100] LTER: Long Term Ecological Research.

|[101] TERENO: Terrestrial Environmental Observatories.

and meta-data standards as well as protocols for exchange are mostly established at an international level. Data systems and standards can be used by BioM-D. [102] Also the set by the DFG guidelines for the handling of research data in biodiversity research and the recommendations for safeguarding good scientific practice will apply for the work of BioM-D. The access and benefit-sharing-rules apply for research abroad. Furthermore, information that could endanger species will not to be made public.

The quality of the stored data is ensured through continuous quality control and ring tests. All data that is stored in the BioM-D databases must satisfy standardised assessment procedures. Observational data are checked by experts. Mutual self-correction of species experts is achieved by the disclosure of observational data. Automated monitoring is controlled with regular testing using standardised methods. Samples stored in biobanks are checked by sequencing genetic markers.

Feasibility according to the proposal

The infrastructure will develop new monitoring techniques to maturation for applications. Complex technical constructions with unknown risks are not required for BioM-D. Technical concepts, synthesis of data and methodology have already been developed and tested in other projects and case studies and can be used or adapted to monitoring purposes, strengthened, continued and improved by BioM-D. For this purpose all BioM-D member institutions have clearly defined tasks. They are responsible for the overall operation, take the lead for their thematic focuses and for infrastructure development at the respective site locations. The work packages are derived from their expertise and research focus (e. g. conservation, monitoring, software, databases, methodology, theory, synthesis, collections).

The work of BioM-D is directed by a Board of Directors, which consists of the representatives of BioM-D member institutions, as well as the scientific and administrative management of the Centre. It will be accompanied by a Scientific Advisory Committee and a Supervising Board. Scientific head at BioM-D is a Director who is supported by an administration office headed by a business manager of BioM-D. During the set-up phase, a large number of PhD-students and Postdocs are taught and trained for development projects. BioM-D requires funds for staff for approx. 300 employees in all areas outside of the Board of Directors for scientific, administrative and technical tasks.

[102] GFBio – German Federation for Biological Data or Lakebase – Database Infrastructure for Long-Term Data of German Lakes.

The implementing institutions, the large number of actors, as well as many partners in research and development projects, have been planning improvements to the analysis of biodiversity changes, the harmonisation, archiving and integration of biodiversity data in Germany for many years. This also comes true for the development of new technologies and processes for biodiversity monitoring carried out at the individual institutes. A long planning process and several round table discussions were held for BioM-D. Additionally various foundational projects that were financed via third-party funds in recent years, led to the development of new technologies (including for example bioacoustics and barcoding) as well as data and data portals relevant to BioM-D.

Relevance to Germany as a location of science and research according to the proposal

The proposal points out that so far a large research infrastructure for biodiversity monitoring is lacking which combines and secures data, further develops techniques, performs modelling, develops new analysis options and makes all available for users. The losses of habitats and species are increasing as the proposal points out, but there are too few data and coordinated research projects to increase public awareness. BioM-D will assume these tasks. The centre will supply scientific data relevant for the implementation of the National Biodiversity Strategy and thus help in achieving social and political objectives and raise science-based awareness of society and policy makers in the field of biodiversity losses. The societal and economic impact of BioM-D will be relevant for the following areas:

_ Conservation of landscapes valuable for the quality of life,

_ Forestry, agriculture, fisheries, availability of drinking water, conservation of ecosystem functions, of genetic resources, biological pest control,

_ Support of public administrations in their responsibilities for nature conservation and reporting,

_ Support of non-profit-organisations, citizen scientists and consultancies with expertise in native species,

_ Development of science-based options for actions for policy makers and economy,

_ Societal development: means a greater certainty in dealing with biological environment and increase awareness for sustainability.

According to the proposal BioM-D can assume a leadership role in technologies like bioacoustics and automatic classification through image recognition (as only pilot studies exist) with innovations that complement the global development of ecological experimental areas in Germany. As soon as BioM-D is set in motion, as the founders intend it, a higher attention on the insights into trends and predictions about biodiversity should be perceived by the media and decisions in politics and business will be able to rely on strong scientific arguments.

II.4.b Assessment and recommendations

An infrastructure that allows for continuous monitoring of biodiversity could be enormously relevant for approaching important scientific issues as well as for Germany as a location of science and research. The importance of BioM-D as an ambitious and visionary concept inter alia aiming at monitoring large numbers of species and data analysis as well as at the provision of evaluation services and research laboratories could be substantial to efficient, sustainable and evidence-based research and monitoring of biodiversity.

Furthermore, BioM-D aims at making the enormous treasure of biodiversity data hidden in the grey literature and elsewhere available to both science and public. It thereby could attract top scientists, policy makers and other stakeholders and holds a great potential for filling critical gaps in the knowledge on changes in species richness and habitat conditions.

A clear strength of BioM-D is its involvement of many science disciplines and topics. BioM-D will consist of many diverse project modules being implemented by a consortium of renowned and outstanding German institutions. The proposed RI comprises a High-Tech approach that has the appealing feature of bringing the latest technology to bear on pressing environmental issues. It could expand opportunities to integrate basic laboratory and field research with actual conservation efforts.

The need to preserve biodiversity and sustainably manage for agriculture and energy increasingly relies on an understanding of how the ecological pieces fit together. Besides the high scientific potential and attractiveness that BioM-D could develop, some essential concerns and weaknesses arise. BioM-D combines a huge diversity and complexity of important tasks, activities and products but would benefit from more focus and clear priorities. Therefore, the committee recommends determining the connection between project modules to specific scientific goals in biodiversity research in more detail. Only by formulating those goals it might be possible to clarify what data and infrastructure would be required. Otherwise, the risk is that things will be developed, stored and measured that will not find an application, while many others that are unstudied could become crucial later on. Without a more focused approach to the scientific questions and problems that will be addressed, it is difficult to assess if the RI is adequate and necessary.

Furthermore, the proposal aims to cover a lot of product development and fundamental research as a basis for the further development of the RI. The biggest uncertainty in BioM-D is a lack of a clear sense of how much the effort relies on the success of the highly ambitious R&D |[103] accomplishments. With heavy reliance on methods that are not yet developed, it is not clear how the operation phase can proceed. The committee recommends developing the technology and erecting the infrastructure that will depend on that technology one after another. The vision for efficient species monitoring assumes that solutions to difficult problems will be found. The monitoring programme that follows the technology development will have to adapt to what works and what doesn't. It cannot be verified how well the new innovations would perform and how useful the data would be. The planned RI would profit from a clear evaluation cycle of the components being developed and a more agile design process. In addition, a timeline for evaluating each component would be fundamental (i. e. goals along the way to test feasibility of the approaches, instrumentation, and data production).

The idea of installing an infrastructure for monitoring biodiversity which presents and delivers essential information to a broad range of user groups is intriguing. Having an active community with top scientists is a key to the success of an RI. BioM-D should actively involve different users outside the consortium (and their interests). Otherwise, there is the risk of underutilisation. This also applies to other groups of national and international users (e. g. stakeholders, external users not for profit, commercial users). In this sense, also the access to data, data sharing, data authentication, interoperability as well as authorisation of users, especially for accessing and combining data from different sources with different owners and rights, is not an easy task in such a huge project and should be clearly defined.

For such a complex project like BioM-D, fast decision making and providing information to all participating partners involved is needed. This poses a major challenge to the organisational structure and coordination of the proposed RI. The general management cannot be taken up by a single scientific director who also has to do research. The committee recommends that the organisational structure as well as the specific tasks and authorisations of a highly qualified executive team (a CTO (Chief Technology Officer), a director general and a professional team assisting the director) are worked out in more detail.

The project is defined for Germany, at least initially with few international connections. As such, there is probably little competition from related efforts. The definition as a strictly German initiative also means that a lot of work co-

| [103] Research & Development

incides with work done elsewhere, such as monitoring networks in other regions. To take advantage of expertise developed elsewhere the committee recommends building up connections in particular with EU initiatives, for instance with LifeWatch | [104].

II.4.c Summary

BioM-D could develop a high potential and could raise the scientific visibility of Germany in the area of biodiversity. Besides the scientific potential, many concerns about the specific feasibility of the concept exist. The project lacks a clear focus on its scientific goals, has no clear evaluation cycle so far and shows weaknesses in its organisational structure. At this moment, the implementation seems very problematic as it is hard to assess how many of the proposed approaches, methods and stations can be developed within a 10-year time span, and how much of the new automatised technology under development will work sufficiently. Under consideration of these uncertainties and risks, the concept BioM-D could not be included in the comparative assessment of all proposals. The project in this form is not mature enough.

Taking into account the high potential BioM-D holds, the responsible scientists should reconsider the conceptualisation of their proposal, the handling of the high R&D proportion, and the match between scientific goals and data needs for an appropriate and successful implementation of the concept.

II.4.d Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
	Existing research infrastructures		
Biodiversity Exploratories (complementary)	The Biodiversity Exploratories serve as open research platform for all biodiversity and ecosystem research groups of Germany. Study objectives are the understanding of the relationship between biodiversity of different taxa and levels, the role of land use and management for biodiversity, and the role of biodiversity for ecosystem processes. http://www.biodiversity-exploratories.de, last accessed 7 September 2016	Start of first phase: 2006	DE
LifeWatch – E-Science European Infrastructure for Biodiversity and Ecosystem	The mission of LifeWatch is to advance biodiversity research and to provide major contributions to addressing the big environmental challenges, including knowledge-based solutions to environmental managers for its	Operation start 2016	Coordination: ES; committed countries: BE, IT, RO, ES, GR, PT, NL;

| [104] LifeWatch – E-Science European Infrastructure for Biodiversity and Ecosystem Research.

Research	preservation. To achieve this mission LifeWatch provides access through a single infrastructure to a multitude of sets of data, services and tools enabling the construction and operation of Virtual Research Environments (VREs) linked to LifeWatch, and where specific issues related with biodiversity research and preservation are addressed. LifeWatch entered the ESFRI Roadmap in 2006 and is a Landmark on the ESFRI Roadmap 2016. http://www.lifewatch.eu/, last accessed 7 October 2016		observer countries: FI, FR, HU, SK, SE; stakeholders from other countries: Norwegian Institute for Nature Research
LTER-D – German Long-Term Ecosystem Research Network (complementary)	LTER-D is a platform for communication, documentation and collaboration of scientists in long-term, system-oriented and interdisciplinary environmental research in Germany. Currently, it covers 17 sites and platforms all over Germany performing long-term ecological research in all relevant ecosystem types from the high mountains to the Wadden Sea. http://www.ufz.de/lter-d, last accessed 14 September 2016	Founded in 2004	DE
TERENO – Terrestrial Environmental Observatories (complementary)	TERENO spans an Earth observation network across Germany that extends from the North German lowlands to the Bavarian Alps. This large-scale project aims to catalogue the long-term ecological, social and economic impact of global change at regional level. Scientists and researchers want to use their findings to show how humankind can best respond to these changes. http://teodoor.icg.kfa-juelich.de/, last accessed 14 September 2016	Since 2008	DE
UFZ – Centre for Environmental Research (complementary)	Research work at the UFZ is concentrated on the terrestrial environment – on densely-populated urban and industrial areas, on agricultural landscapes and natural landscapes. Scientists at the UFZ are investigating future land-use scenarios, the conservation of biodiversity and ecosystem services, the sustainable management of soil and water resources and the impact of chemicals on humans and the environment. https://www.ufz.de, last accessed 14 September 2016 http://www.helmholtz.de/en/about_us/helmholtz_centres_networks/zentrum/detailansicht/helmholtz_centre_for_environmental_research_ufz/, last accessed 20 October 2016	Founded in 1991	Leipzig, Halle and Magdeburg, DE
Planned research infrastructures/under construction			
DCOLL – German Natural Science Collections Infrastructure (complementary)	For detailed information please see the concept proposal of DCOLL.	Operation from 2026/2027	DE
NEON – National Ecological Observa-	NEON is a continental-scale ecological observation facility, sponsored by the National Science Foundation and operated by Battelle,	Full operation from	Headquarters: Boulder, US

tory Network	that gathers and synthesizes data on the impacts of climate change, land use change and invasive species on natural resources and biodiversity. http://www.neonscience.org, last accessed 7 October 2016	2018	

II.5 German Natural Science Collections Infrastructure (DCOLL)

II.5.a Scientific potential

Description

DCOLL will integrate numerous geographically and organisationally heterogeneous collections to safely store, digitise, and preserve physical records and information for decades, to make them and their data accessible for future research and society at large. According to the proposal DCOLL will offer a novel level of accessibility and interlinking of collections, and an innovative research platform and virtual research space for trans- and interdisciplinary work within and between natural, social and cultural sciences. It will provide the basis for basic sciences like biological, geological, medical, and technical research and for applied research fields, such as bio-economy, climate research, agriculture, or protection of genetic and other organic and inorganic natural resources.

Following a comprehensive digitisation of the collections in DCOLL, details of rare and unique specimens or objects and large data volumes can be made accessible globally without handling or endangering the precious objects themselves. This enhances the research and collaboration process by allowing a more efficient and hence more economic access to data and information. According to the concept economic advantages can be derived from the storage and preservation of digital research data to avoid repetition of experiments, to recognise new connections, and to preserve the scientific and cultural heritage. The network proposed by DCOLL and the long-term digitisation of the collections lay the foundation for novel research horizons in the natural and social sciences, new research programmes and intensive new collaborations.

According to the proposal DCOLL will establish a globally unique infrastructure with respect to its extent as well as its scientific and cultural significance, especially in conjunction with further European EUCOLL and CETAF-partners. DCOLL will neither duplicate nor compete with existing, mostly disciplinarily, regionally or geographically shaped infrastructures and information systems. |[105] Existing infrastructures reach neither a geographically nor histori-

|[105] Like national programs for digitisation or improvement of natural history collections.

cally comparable depth and coverage (e. g. Netherlands - NCB Naturalis, France - RECOLNAT |[106], Australia - Atlas of Living Australia, United States - iDigBio). |[107] Somewhat related collections in terms of numbers and global orientation are only found in the EUCOLL- and CETAF-consortia, and in the USA (Smithsonian Institution, Washington, D.C.; American Museum of Natural History, New York; Field Museum, Chicago; California Academy, San Francisco).

Assessment

A successful DCOLL will significantly enlarge collection-based research in the natural sciences, making it considerably more hypothesis-driven, data-intensive, standardised and inter-connected. This RI will have a substantial impact on biodiversity discovery and monitoring, analysis of large-scale patterns in biological and geological diversity, and predictive models of environmental change. It will generate and make available a major new source of environmental data that offer the prospect of integrating geological and biological processes, as well as of comparing historical and contemporary patterns of diversity. It will reform research in the field by making specimens and associated information openly available to the global research community for the first time, whereas currently access requires the physical loan of individual specimens or physical visits to the participating institutions.

The scientific impact will be worldwide: sharing and inclusion are clear goals of the proposal, researchers and citizens worldwide will be able to make use of the vast amounts of data generated.

The strategic cooperation of the major natural science collections in Germany will be a major achievement and will lead to the better use of these collections in research, avoidance of unnecessary duplications in scientific work, and alignment of scientific activities among institutions. The member institutions of this proposal represent the largest and scientifically most important scientific collections of their type in Germany. Taken together, these institutions outweigh any other scientific collection within this field in the world. A concerted effort among institutions is a necessity in order to achieve a common standard for examination, documentation, analysis and dissemination of data and specimens, which will directly benefit the international scientific community. The proposed network will not only stimulate cooperation between the present member organisations but should also act as a strategic nucleus to attract further collections. The proposed network should also take the lead to

| 106 *Réseau des Collections Naturalistes.*

| 107 NCB NATURALIS – *Nederlands Centrum voor Biodiversiteit*, e-ReColNAT – *Récolement des Collections Naturalistes*, iDigBio – Integrated Digitized Biocollections.

develop and extend technical strategies in digitisation of specimens and the corresponding data management from which institutions inside and outside the planned network could profit. Since individual specimens will be directly associated with multiple kinds of data – e. g. X-ray images, photographs, DNA sequences (Deoxyribonucleic Acid) – it is very likely that scientists and students will reach out to other disciplines beyond their own, in order to interpret aspects not previously envisaged in their research. This should result in a boost of collaborations across fields in the natural sciences.

The proposed RI will likely be open-ended. It is envisaged that the infrastructure once established will permanently operate for all involved institutions and that the established infrastructure will also provide service to institutions outside the network. This requires intensive cooperation. The proposal acknowledges that technological improvements move fast and the design of the RI must allow for both planned and 'unknown' future exploitation, especially with respect to informatics and omics approaches, digitisation, electronic data handling and maintenance. DCOLL is supposed to be flexible throughout its lifetime and has to adapt to changing needs in the future. DCOLL will maximise the chances of this by seeking to improve the environmental conditions under which specimens are stored, improving the conservation of the collections, and employing internationally-recognised data standards. The applicants also expect and welcome novel analytical procedures along the way, in order to better serve developing research questions. The participating institutions have excellent experience in this type of planning.

A considerable number of related initiatives worldwide aims at digitising and analysing its specimens, but DCOLL will set a new standard for existing and planned infrastructures in this area, including linking with key existing data aggregators (e. g. the Global Biodiversity Information Facility (GBIF or GenBank)) and a potential application for an ESFRI Project in this area. The proposed RI will constitute a major national component of internationally operating infrastructures and could become a model for current and future initiatives. The network planned in DCOLL will be an excellent nucleus that will ensure a leading position for the German collections in an international setting.

There are no directly competing RIs in Germany or other countries. This set of applicants represents all major science collection-based institutions in Germany so collaboration across this group would constitute a new key national infrastructure. Institutions in other countries, such as France, the Netherlands, Australia and the United States, have started to digitise their collections but differ in quantity by an order of magnitude.

The core mission of DCOLL is to create an information platform to make Germany's world-famous natural science collections available to the global research community and carry out the digitisation and other analyses required to make this possible. Supporting these elements of the project is therefore clearly integral to the success of DCOLL. Other aspects of work described in the proposal, such as the further collecting and broader infrastructure requirements, appear less fundamental to DCOLL itself and are instead the fundamental task of these institutions. DCOLL should therefore focus on the facilitation of data and not include new collections or infrastructure such as a research vessel.

II.5.b Utilisation

Description

DCOLL will provide access and use for:

_ data/media objects/information;

_ physical samples/objects;

_ equipment, labs, analytic infrastructure.

The use of individual collections varies substantially according to the nature of the collection objects. DCOLL's focus is on internationally oriented scientific use (approx. 75-80 %) for various discipline-specific basic research (e. g. biodiversity research, taxonomy, palaeontology, biotechnology, ecology, climate research, medicine, or history). Education and public outreach use is primarily at the national or local level (15-20 %). Use by other groups, e. g. commercial, societal and governmental use, is currently comparatively minor. A major shift from the use of physical objects to the use of digital data and media is expected.

According to the proposal DCOLL will create the prerequisites for uniform and precise citability of physical and digital objects in scientific publications and provide direct, complete, free and public access to data, information, collections and media. Unified approaches will be developed for extended services including provision of workspaces with collection access, and the loan of collection objects for research and exhibitions.

DCOLL will implement and maintain information and knowledge management systems, databases and media repositories for the long-term storage of research data and metadata, while at the same time ensuring their availability and use. The essential components of the DCOLL data concept are: handling of an increased quantity/data volume, continuous quality management, sustainability, and flexibility issues. Ethical, ownership, data access and protection principles will be observed during data collection, documentation and access provision. Research data management by DCOLL, including security and sustainable access, will use common guidelines that are conformable with established cross-disciplinary standards and practices (e. g. DFG: Recommendations to Insure

Good Scientific Practice, Principles for Handling Research Data). All DCOLL members have already agreed to be subject to a large number of guidelines (e. g. DFG, Leibniz Association). The yet to be established association DCOLL e. V. will strive to fully adopt these obligations. With the establishment of DCOLL a Code of Conduct shall be finalised and bindingly adopted.

Assessment

DCOLL attracts an extensive community, with the applicant institutions currently serving approximately 10,000 scientific queries and 3,000 scientific visitors. The proposed RI will multiply this number, as reflected by the multiple-billion downloads of comparable existing data through, e. g. GBIF. Researchers and students from Germany and other countries, from diverse career levels, disciplines and science fields working in the classical "collection" fields like taxonomy and systematics, mineralogy, palaeontology and organismal biology but also in climate research, biotechnology, history, archaeology are all likely to profit from the open and integrated resources made available by DCOLL. Costs will only be charged when necessary, for instance, on particularly time-consuming or intellectually demanding requests, which should be well accepted by the community. It is anticipated that the DCOLL network will raise the general scientific and non-scientific interest in the collection items dramatically; the digitisation will provide information on scientific research objects around the world while avoiding damage to the objects.

The participating institutions have a long record of providing research 'open access' to collections and associated data. As a result there is an established policy to make as much as possible of the enormous amount of data and specimens available to as many people as possible inside and outside science. The proposed RI will substantially extend the traditional access model used by collections-based institutions not only by providing coordinated access to physical specimens across sites, but also by facilitating much more extensive and secure access to digital and genomic surrogates and meta-data associated with specimens, as well as substantially improved on-site analytical facilities. Taken together, this represents an almost complete change in the intellectual business model that underlies these institutions and will put German infrastructure in a leading international position with respect to open science and innovation. To extend the principles and processes established under a series of EU collaborations, the new RI will adopt the access framework established under the SYNTHESYS (Synthesis of Systematic Resources) programmes, in which the applicants have participated for more than a decade.

DCOLL has a well-developed and highly integrated strategy for creating, maintaining, and making data available. It proposes (1) the adoption of a fully open data policy across the new RI, with all resources made available through a common data portal as well as being served to the relevant data aggregators and (2) the adoption of the existing well-established international data standards with respect to biological records, which ensure inter-operability with other systems, as well as unique identifiers for digital assets. DCOLL will follow standards and established practices in the field, not creating isolated solutions (databases, software). The proposal acknowledges the need for the careful handling of sensitive data (e. g. geographical data on threatened species) and the various levels of access depending on the end-user.

It can be expected that DCOLL will manage their project with all necessary needs towards quality and reliability. The participating research institutions have agreed to subscribe to a large number of guidelines with respect to ethics and best practice. These appear appropriate for a RI of this type. The main institutions benefit from the fact that they already share a common regulatory framework.

II.5.c Feasibility

Description

All DCOLL members have relevant technical knowledge and are experienced in handling samples and voucher specimens as well as the digital development of the collection inventories and the accessibility of relevant data. In the development and operation of DCOLL, tried-and-true technologies and procedures are available that can be used for the physical collections to a large extent. This applies in particular to the structural housing, proper storage and maintenance of the collections as well as to test procedures, the corresponding equipment, the requirements of a scientifically demanding digitisation of the inventories, and to database systems and portals. According to DCOLL the data volume accrued in the context of the intended mass digitisation and data collection and the corresponding storage and processing of these data is one of the biggest challenges.

The DCOLL association will contain three organs: an Executive Committee, a General Meeting and a Governing Board. It will be supported by a Scientific Advisory Board. An Executive Office will be established for the working tasks and the project coordination, which will be given additional support by an Administrative Management and a Steering Committee. The project goals will be ensured through the establishment of a controlling on the basis of a cost and performance accounting system.

All DCOLL members command their own personnel capacities. During the construction phase DCOLL will engage approximately 220 qualified scientific, technical and administrative personnel. For each DCOLL member the executive office will be supported by two locally established positions for coordination and execution.

The strategic development of the collections requires new construction and structural renovation measures at the sites in Berlin, Bonn, Frankfurt and Munich. |[108] The individual buildings, research collection and laboratory structures are in varying states of fundamental assessment and target planning. For the preparatory phase of DCOLL (2016–2018), the establishment of a comprehensive national collection strategy is planned, under consideration of all essential natural history collection inventories under public ownership in Germany. This review will enable a clear prioritisation of the digitisation measures and at the same time allow specifying additional needs regarding the development and upgrading of collections.

Assessment

The technological innovations of DCOLL are relatively moderate for a new scientific infrastructure because most of the technical approaches can be imported from other disciplines. The applicants therefore suggest the use of existing state-of-the-art technologies rather than promising to develop totally new - and yet unverified - solutions. This is a sensible approach for such a large proposal.

Due to these circumstances the technical risks associated with this RI are low for a scientific infrastructure of this scale. DCOLL is largely based on established technologies and will profit from well-documented experiences around the world, at the partner institutions or their international collaborators, where the key technologies have already been implemented or tested at smaller scales. This applies to the collection storage and curation facilities that make up a significant proportion of the capital infrastructure, the proposed imaging and genomic analytical facilities, the digitisation pipelines for different types of specimens and even most aspects of the informatics pipelines, the transcription of information from large volumes of specimen labels and registers, and the creation of a common data platform across all seven institutions. All points are discussed in dedicated work packages at DCOLL, so the risk area is well recognised.

The infrastructure DCOLL appears to be well-planned and the foundations of the collaboration underlying the proposed RI appear robust, the partnership and synergy created by the establishment of DCOLL is outstanding. As a coordinated group they would be the world's largest research consortium in this area, probably comprising the world's largest integration of natural science specimens. The partner institutions of DCOLL are already very well-established and already participate in a series of national and international networks.

|108 The respective state governments were informed about the structural measures or are involved in the corresponding planning and negotiations regarding the required development of the collection infrastructure.

There appears to be extensive ongoing collaboration among the institutions, albeit at a lesser level. The expertise of the DSMZ is essential for the sequencing part of the project.

The partner institutions are organised and built on solid institutional, financial, and physical elements. Many of the activities proposed are already being developed at smaller scales and can serve as pilot studies providing a solid basis for the integration envisioned.

The proposed infrastructure is intimately linked with the existing partner institutions as the majority of activities take place at the individual institutions, but it is coordinated through a central office with respect to overall strategy, project management and information systems. Given the physical distribution and ownership of the collections this appears to be a practical approach. The work programme is clearly described and organised around four main fields: collection management; informatics; digitisation and physical infrastructure. The governance and management strategies appear well developed. The activities carried out by DCOLL complement, rather than replace or compete with, those currently in place by its partners. The Scientific Advisory Board that is made up of national and international experts from outside the DCOLL network will serve a valuable function to DCOLL at different stages and for different tasks.

DCOLL will need a large number of new personnel to fulfil all planned tasks within the planned timeframe. The key risk here is the recruitment and/or training of a relatively large number of staff with digital and genomic skills, as reflected by the substantial proportion of staff costs that are dedicated to these areas. Since IT-specialists, in particular, but also specialists in the various fields of curating collection specimens of organisms are rare it will not be easy to recruit personnel in sufficient numbers. The participating institutions in DCOLL should therefore seriously consider how to work with organisations, such as universities and technology companies, to recruit, train and support such large intake of staff.

The proposed RI will require a substantial shift in the skill base of the participating institutions, with significant capacity improvements in digital and genomic technologies while at the same time modernising core curatorial and systematic skills. This vision is matched by extensive plans for training and recruitment across the RI network and the establishment of a training school to share best practice across institutions and to create a centre-of-excellence in modern curation. The planned training centre has the potential to raise international visibility and will have a tangible impact on the research area itself and the scientific output of the research infrastructure in particular. The proposal for such a ‘School of Collections’ is excellent, but the traditional distinction between ‘curators’ and ‘scientists’ might change in the future. There is much to be gained by involving individuals in both fields, e. g. half time each.

Therefore, the proposed training could perhaps not only cover physical handling and classification of specimens (which are in themselves very worthwhile and important skills, and generally diminishing), but also cover, e. g. chemical/physical analysis, taxonomy, evolution, biogeography, as well as general scientific methodology, statistics, scientific writing, etc. The proposal indicates that training and recruitment will be done in collaboration with Universities and Technical Colleges, which potentially provide a larger pool of recruits as well as providing additional career opportunities. It is important that the new RI does not end up in a zero-sum competition with university and industry groups in recruiting talent. Hence, it may be worth extending the 'School of Collections' concept to these areas.

II.5.d Relevance to Germany as a location of science and research

Description

According to the proposal DCOLL will bring Germany a competitive advantage in the medium and long term particularly in three science policy areas:

_ Bio-economy: The mobilisation and expansion of data and knowledge about natural objects and phenomena will greatly enhance research on sustainable use of natural resources, especially in biological and geological fields.

_ Digital Agenda of the German (Federal) Government: The digitised collection created by DCOLL provides a platform for the further development of high-resolution scanning methods and techniques, the analysis, the handling and the liberation of available digital data and media to other users and the general public.

_ Internationalisation: DCOLL offers potential for the targeted initiation and support of bilateral and multilateral research collaborations with nearly all regions and countries of the world.

The proposal points out that DCOLL represents an important opportunity for Germany as a science hub to overcome the scattered organisation and structural weaknesses of its scientific collections and take a nationally-coordinated approach. It will help Germany to secure a leading position in scientific and social research on natural resources and natural history collections internationally and particularly at European level. The provisioning of digital data and information via DCOLL will increase the level of awareness, visibility, and potential applications and will strengthen the profile of the natural science collections in Germany. DCOLL will provide the national and international young academics with improved educational, research and career opportunities in all fields of geo-biodiversity. |[109] DCOLL will further develop and deepen existing links with universities. The infrastructure will contribute to knowledge and technology transfer by allowing an accelerated, open, virtual access to the documents and samples contained in the natural history collections and their metadata, images and measured variables. Most DCOLL members will increasingly act as a bridge between science and society and fulfil tasks in knowledge transfer, scientific communication and public education by operating e. g. exhibitions, botanical gardens, school labs, and citizen science formats.

Assessment

Given the high profile and enormous value of the collections cooperating in the DCOLL initiative, there is no doubt that the planned network and especially the planned digitisation of collection specimens will dramatically increase the visibility of German science institutions in Europe and worldwide. The proposed RI will have a profound impact on Germany's research landscape and on its international visibility and competitiveness, and German research in the natural sciences has long played a prominent role internationally. German institutions house some of the most important natural science collections in the world, but these collections are scattered across a series of different institutions and are currently relatively difficult to access. This negatively affects the international visibility and scientific use of the German collections. Additionally, there has been little investment in either the physical care for the collections or the exploitation of digital and genomic technologies to make the collections available to modern science. In contrast, a number of other countries have invested heavily in natural science collections and have created either central collections or coordinated collection networks complemented by large-scale specimen digitisation. The proposed RI can reverse this situation, creating modern storage and analytical facilities, providing a coordinated national infrastructure, and putting Germany in a globally leading position.

The proposed RI will also make a very significant contribution to European and global scientific infrastructures and the international visibility of European natural science research in this area. The German collections are among the most extensive and important in Europe and globally but at present only a small proportion of the material is digitally available. The proposed RI will lead to the digitisation of a large fraction of the collections, will intensify national and international cooperation and will create an informatics framework that could potentially be extended to the broader European environment.

|[109] DCOLL members already actively train junior scientists.

As the proposal states DCOLL is open for additional members and smaller collections. This would further expand the visibility and impact of the RI.

The infrastructure is of key strategic significance for strengthening Germany's role as a leading nation in research in fields from biodiversity to geology and would re-design the core scientific disciplines of taxonomy, systematics and mineralogy by providing coordinated digital access to German natural science collections, and by linking these collections with other sources of environmental data.

The expected increase in visibility and improved conditions for geo-biodiversity research offered by DCOLL will make German research collections and the associated German research institutions more attractive for research stays. It will also most likely increase the chances of DCOLL partners to participate in international consortia and projects, such as those funded by the EU, NSF, and other large funding bodies in other countries. The RI will create an integrated platform for the study of the earth and its environment, with a network of collaborating institutions, facilities and supporting expertise. Given the scale and importance of the German collections, this will put Germany at the very highest level in terms of international competitiveness and certainly at the forefront of European research infrastructures and science. Thus this unique initiative has the potential to set an international standard.

DCOLL will attract students and scientists around the world and will provide an excellent opportunity to train the next generation of collection-based scientists, especially given the focus on digital and genomic technologies. This will in turn increase the possibilities for new generations of scientists, create jobs in the area of curation, IT-management around collections, as well as in the respected conservation fields.

The societal and scientific impact of the proposed RI is likely to be extremely high, in part because of the broad use of the collections and in part because of the high public profile of the institutions themselves. The applicants are aware of this important aspect and have taken appropriate measures for knowledge and technology transfer and their documentation, improved representation of collection items by digitisation and improved communication. There is already extensive use of natural science collections in education and public outreach activities. Thus, it is likely that digitisation will stimulate further innovation, particularly in the field of citizen science. The collections are also widely acknowledged in the cultural sector and it is likely that the resources generated by the RI will also form the basis for research and public engagement in this area. Since DCOLL will create transparent, open-source platforms for the handling and analysis of specimens to the maximum possible extent, it seems straightforward for other organisations to follow the good example and thus draw scientific and societal profit from other collections.

Reaching out to citizens and industry may also have a large beneficial impact, but it may become a harder task than reaching out to scientists. The proposal briefly lists some ways in which interactions could take place, e. g. through open portals, citizen science and social media. Similarly there is some mention of potential commercial partnerships. These plans for commercial exploitation of the data and public engagement with DCOLL via citizen science should be further developed, but will probably become more important during later phases of the DCOLL implementation.

II.5.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
Existing and planned research infrastructures			
ALA – Atlas of Living Australia (complementary)	ALA is a web portal with information about species in Australia (pictures, species occurrence records, taxonomic information, literature, DNA sequences). It brings together field records, observational data and collection data. ALA contains 55.6 million occurrence datasets from animal species for more than 12,000 users (as of December 2015). http://www.ala.org.au/, last accessed 10 August 2016	Since 2010	AU
AmphibiaWeb (complementary)	AmphibiaWeb is an information system on extant amphibian species of the world with focus on geographical distribution, ecology and taxonomy as well as conservation status. AmphibiaWeb contains 7,571 species. It has 3,145 species accounts for 2,495 species, 6,819 literature references, 675 sound files, 120 video files, and 33,562 photos of 4,217 different amphibian species (as of 7 October 2016). http://amphibiaweb.org/, last accessed 7 October 2016	Launched in 2000	Management: US; global partners from AU, CU, MG, Pacific Region, ES
AnaEE – Infrastructure for the Analysis and Experimentation on Ecosystems (complementary)	AnaEE is a research infrastructure for experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems. AnaEE is a project on the ESFRI Roadmap 2016. http://www.anaee.com/, last accessed 7 October 2016	Implementation from 2018 onwards	Project coordination: FR; further consortium members: UK, NO, DK, TR, IT, CZ, BE, FI, SE, IL, EE
ARIADNE – Advanced Research Infrastructure for Archaeological Datasets Networking in Europe (complementary)	ARIADNE sits within DARIAH (Digital Research Infrastructure for the Arts and Humanities) as a digital infrastructure focussed on the archaeological and heritage sector. The network aims to bring together and integrate the existing archaeological research data infrastructures so that researchers can use the various distributed datasets. http://www.ariadne-infrastructure.eu/,	Project start 2013; runtime 48 months	Coordination: IT; further consortium members: UK, NL, DE, GR, AT, IE, SE, ES, SI, HU, CY, CZ, BG, RO, FR

	last accessed 7 October 2016		
BFB – Barcoding Fauna Bavarica (complementary)	BFB aims at generating a DNA barcode for each animal species in Bavaria, Germany. After 5 years, BFB contains more than 30,000 DNA barcodes from more than 10,000 Bavarian animal species. In total, nearly 200,000 samples have been delivered to the International Barcode of Life (iBOL). http://www.faunabavarica.de/, last accessed 11 October 2016	Since 2009	Munich, DE
BHL – Biodiversity Heritage Library (complementary)	BHL is a digitalisation programme and data portal which provides digitalized, mainly older, freely available biodiversity literature. The portal allows users to search for and download selected publications. It contains 109,955 titles, 185,835 volumes and 49,860,840 pages (as of August 2016). http://biodiversitylibrary.org/, last accessed 3 August 2016	Portal launch in 2007	Administration: US; further members from: MX, AU, SG, UK
BHL Europe – Biodiversity Heritage Library for Europe (complementary)	BHL Europe is a web database, originating from an EU project on digitalization of biodiversity literature, and is the local project of the Biodiversity Heritage Library (BHL). In February 2011, it contained close to 33 million pages from about 88,000 books. http://www.bhl-europe.eu/, last accessed 11 October 2016	Project duration: 2009 to 2012	Project coordination: DE; in all, 26 European and 2 US institutions
BiNHum – Biodiversity Network of the Humboldt-Ring (complementary)	BiNHUM was a joint project of the several natural history museums in Germany for object-related collection digitalisation and (further) development of data standards. The project resulted in a portal that provides access to the collections of six natural history museums in Germany. The portal contains approx. 1.9 million searchable collection items (as of October 2016). http://www.binhum.net/, last accessed 11 October 2016	Project duration 2012 to 2015	DE
BioCASe – Biological Collection Access Service (complementary)	BioCASe is a transnational network of primary biodiversity repositories. It links together specimen data from natural history collections, botanical/zoological gardens and research institutions worldwide with information from huge observation databases. It provides data standards and software for collection-based biodiversity data for numerous projects and networks. http://www.biocase.org/, last accessed 11 October 2016	Construction of the network from 2001 to 2004	Coordination: DE; established by partners from 31 countries
Biodiversity Exploratories (complementary)	The Biodiversity Exploratories serve as open research platform for all biodiversity and ecosystem research groups of Germany. Study objectives are the understanding of the relationship between biodiversity of different taxa and levels, the role of land use and management for biodiversity, and the role of biodiversity for ecosystem processes. http://www.biodiversity-exploratories.de, last accessed 7 September 2016 Data platform BExIS (Biodiversity Exploratories Information System):	Start of first phase: 2006	DE

	https://www.bexis.uni-jena.de/Login/Account.aspx, last accessed 11 October 2016		
Bio[M] (complementary)	Bio[M] is a networking agency for the biotechnology sector, mainly in Bavaria, Germany. It supports biotechnology companies and start-ups by offering consulting, events etc. http://www.bio-m.org, last accessed 18 August 2016	Since 1997	Martinsried, DE
Canadian Museum of Nature – Collections online (complementary)	Canadian Museum of Nature – Collections online is a web portal giving access to collection objects and metadata. The database provides access to data for more than 700,000 specimens. http://collections.nature.ca/en/Search, last accessed 12 October 2016	Launched in 2014	Ottawa, CA
ChemSpider (complementary)	ChemSpider is a free database, owned by the Royal Society of Chemistry, providing fast text and structure search access to chemical structures. It contains over 57 million chemical structures with further information from 532 data sources. http://www.chemspider.com/, last accessed 12 October 2016	Released in 2008	UK
CoL – Catalogue of Life (complementary)	CoL is a global index of the world's species, consisting of a single integrated species checklist and taxonomic hierarchy. The Catalogue holds essential information on the names, relationships and distributions of over 1.6 million species. CoL is led by Species 2000, an autonomous federation of taxonomic database custodians, working in partnership with the Integrated Taxonomic Information System (ITIS), a partnership of federal agencies and other organisations from the United States, Canada, and Mexico, with data stewards and experts from around the world. http://www.catalogueoflife.org/, last accessed 12 October 2016	Start of the project in 2001	Species 2000; ITIS
CONABIO - National Commission for the Knowledge and Use of Biodiversity (complementary)	The web databases of CONABIO contain information about the biodiversity and biological resources of Mexico. CONABIO operates the National Information System on Biodiversity (SNIB), which, by 2012, contained 761 digitised projects with 811 databases and a "Repatriation Programme" for more than 5 million collection specimens (2012). http://www.conabio.gob.mx/, last accessed 14 October 2016	Since 1992	Mexico City, MX
DARIAH – Digital Research Infrastructure for the Arts and Humanities (complementary)	DARIAH is a pan-European infrastructure for arts and humanities scholars working with computational methods. It supports digital research as well as the teaching of digital research methods. DARIAH-EU entered the ESFRI Roadmap in 2006 and is currently an ESFRI-Landmark on the Roadmap 2016. DARIAH-EU: http://dariah.eu/, last accessed 14 October 2016 German regional partner DARIAH-DE:	Operation start in 2019	Coordination: FR; further members: AT, BE, CY, DE, DK, EL, HR, IE, IT, LU, MT, NL, RS, PL, PT, SI

	https://de.dariah.eu/, last accessed 14 October 2016		
DataONE – Data Observation Network for Earth (complementary)	DataONE is an IT infrastructure and portal for the storage, preservation and the provision of access of scientific data and metadata for environmental research. Through its member nodes, DataONE contains121,911 datasets, 225,007 metadata, 401,736 data objects and 1,043,205 individual objects in total (as of summer 2016). https://www.dataone.org/, last accessed 14 October 2016	Since 2009	Coordination: US; member nodes worldwide
DBpedia German (complementary)	DBpedia German provides and extracts structured information from the German Wikipedia. It is part of the international DBPedia project. DBPedia German describes in total about 3 billion individual data (Version 2014). http://de.dbpedia.org/, last accessed 14 October 2016	Not specified	DE
de.NBI – German Network for Bioinformatics Infrastructure (complementary)	De.NBI is a national infrastructure providing comprehensive, high-quality bioinformatics services to users in life sciences research and biomedicine. The partners organize training events, courses and summer schools on tools, standards and compute services provided by de.NBI to assist researchers to more effectively exploit their data. https://www.denbi.de/, last accessed 14 October 2016	Since 2015	DE
digiCULT (complementary)	digiCULT is a web portal for museum collections in Schleswig-Holstein, Hamburg, Thuringia and Saarland, encompassing collections from history of art and cultural history as well as Natural History collections, archaeological findings and items from the history of medicine and technology. https://www.digicult-verbund.de/, last accessed 18 August 2016	Project start in 2003	Kiel, DE
Digimorph – Digital Morphology (complementary)	Digimorph is an online repository for CT and morphological data (pictures, films) from extant and fossil animal species. It contains data of more than 1,000 specimens/objects, based on the contributions of almost 300 participating scientists. http://digimorph.org/, last accessed 14 October 2016	Not specified	US; contributors worldwide
Dryad – The Dryad Digital Repository (complementary)	Dryad is a curated resource that makes the data underlying scientific publications discoverable, freely reusable, and citable. It provides a general-purpose home for a wide diversity of datatypes. It contains more than 10,000 data packages (Annual Report 2015). http://datadryad.org/, last accessed 14 October 2016	Found in 2009	Durham, US
Edaphobase – GBIF Database on Soil Zoology (complementary)	The soil-zoological information System Edaphobase is a taxonomic-ecological database system, which combines existing taxonomical primary data on soil organisms from collections, scientific literature and reports etc. originating from many research institutes and persons involved in soil zoology. The data-	Project start 2009	DE

	base system is part of the GBIF data systems. Edaphobase contains approx. 325,000 datasets from 25,000 localities (as of December 2015). http://www.senckenberg.de/root/index.php?page_id=11082, last accessed 14 October 2016		
EDIT Platform for Cybertaxonomy (complementary)	The EDIT Platform for Cybertaxonomy is a collection of open source tools and services which together cover all aspects of the taxonomic workflow, from taxonomic editing to (online) publishing. http://cybertaxonomy.eu/ , last accessed 14 October 2016	Not specified	DE
ELIXIR – A distributed infrastructure for life-science information (complementary)	ELIXIR is a distributed data infrastructure for the Life Sciences, in particular for molecular and genetic data. ELIXIR entered the ESFRI Roadmap in 2006 and is a ESFRI-Landmark on the Roadmap 2016. https://www.elixir-europe.org/, last accessed 16 August 2016	Start of operations in 2014	Members: EMBL, UK, SE, CH, CZ, EE, NO, NL, DK, IL, PT, FI, BE, IT, SI, LU, IE and 2 provisional members: ES, FR
EMBL-EBI – The European Molecular Biology Laboratory - The Bioinformatics Institute (complementary)	EMBL-EBI is a global hub for big data in biology. It promotes scientific progress by providing freely available data to the life-science research community, and by conducting exceptional research in computational biology. EBI is part of EMBL, an international non-profit organisation with 21 member states and 2 partners. http://www.ebi.ac.uk/, last accessed 14 October 2016 http://www.ebi.ac.uk/sites/ebi.ac.uk/files/groups/external_relations/Documents/EMBL_EBI_Overview_LowRez.pdf, last accessed 20 October 2016	Established in 1994	Hinxton, UK
EMBRC – European Marine Biodiversity Resource Centre (complementary)	EMBRC is a planned European distributed research infrastructure for marine research, with focus on marine research stations and analytical laboratories. EMBRC entered the ESFRI Roadmap in 2010 and is currently an ESFRI project on the Roadmap 2016. http://www.embrc.eu/, last accessed 16 August 2016	Start of operation envisioned for 2016	Coordination: FR; further participants: BE, GR, IL, IT, NO, PT, ES, UK
EMSO – The European Multidisciplinary Seafloor and water-column Observatory (complementary)	EMSO is a large scale, distributed, marine Research Infrastructure. It consists of ocean observation systems for long-term, high-resolution, (near) real-time monitoring of environmental processes including natural hazards, climate change, and marine ecosystems. EMSO entered the ESFRI Roadmap in 2006 and is an ESFRI-Landmark on the Roadmap 2016. http://www.emso-eu.org/, last accessed 14 October 2016	Not specified	IT, FR, IE, ES, GR, UK, PT, RO
EOL – Encyclopedia of Life (complementary)	EOL is a free, online collaborative encyclopaedia intended to document all of the 1.9 million living species known to science. EOL contains 1,341,098 EOL pages with information (as of October 2016).	Website went life in 2008	Coordination: US; partners worldwide

	http://eol.org/, last accessed 14 October 2016		
EoS – Erschließung objektreicher Spezialsammlungen (complementary)	EoS is a project for mass digitalization, visualisation and long-term archiving of entomological collections and Natural History collections at the Museum für Naturkunde Berlin (MfN). As part of the project 10,000 insect drawers and 10,000 selected insects are digitalized. http://eos.naturkundemuseum-berlin.de/, last accessed 14 October 2016	Project completed: 2012 to 2015	Berlin, DE
e-ReColNat	e-ReColNat is a digital platform for the environment and society which intends to make accessible French natural history collections from 350 years. https://recolnat.org/, last accessed 20 October 2016	Project start in 2013	FR
EU BON – European Biodiversity Observation Network (complementary)	EU BON follows an integrated approach to aggregate biodiversity data. A new open access web platform will provide the aggregated biodiversity and Earth observation data. http://eubon.eu/, last accessed 17 August 2016 Data portal (beta version): http://beta.eubon.ebd.csic.es/home, last accessed 18 October 2016	Project duration: December 2012 to May 2017	Project coordination: DE; further partners: EE, FI, DK, UK, ES, FR, BG, PH, GR, BE, CH, IL, BR, SE, SK, NO, IT
Euro+Med PlantBase (complementary)	Euro+Med PlantBase is an online registry and taxonomic reference list of all plant species in Europe and the Mediterranean region. It is part of the Pan-European Species directories Infrastructure (PESI). Euro+Med PlantBase provides access to 194 plant families (approx. 95 % of European Vascular plants) (as of May 2016). http://ww2.bgbm.org/EuroPlusMed/query.asp, last accessed 14 October 2016	Not specified	Management: DE; Institutions in UK, ES, IT, DE, CH, SK, BG, FI, GR
Europeana Collections (complementary)	Europeana is a web database/virtual library for cultural heritage and science, i. e. cultural and scientific objects from prehistory and protohistory up to the present, such as picture, texts, sound and video files. Europeana contains 53,606,838 objects/entities (works of art, items, books, videos, sound files; as of October 2016). http://www.europeana.eu/portal/en, last accessed 14 October 2016	Europeana version 1.0 launched in 2009	More than 2,000 contributing European institutions (Museums and local Archives)
Fauna Europaea (complementary)	Fauna Europaea is a European project with information on extant European animal species, with focus on terrestrial and limnic habitats. A web portal provides taxonomic data, scientific names, information on geographic distribution, data on taxonomic experts and literature. The technological basis is the EDIT Platform for Cybertaxonomy. Fauna Europaea is part of the Pan-European Species directories Infrastructure (PESI). It contains 235,708 taxonomic names (180,712 accepted taxonomic designations), including 132,097 accepted species names. http://www.fauna-eu.org/, last accessed 14	Project start in 2000; Fauna Europaea Version 1.0 in 2004	Host: DE; network of national partner institutes throughout Europe

	October 2016		
FishBase (complementary)	FishBase is an online database with multiple information on the extant fish species of the world, their ecology, morphology, physiology, and taxonomy, as well as information about their use and conservation status. FishBase contains information on more than 33,200 species, 306,300 common names and 56,500 pictures (as of December 2015). http://www.fishbase.org/, last accessed 14 October 2016	Not specified (web launch in1996)	Coordination: DE; international consortium
Flora von Bayern (complementary)	Flora von Bayern is a long-term initiative for the floristic mapping and description of the vascular plants of Bavaria, Germany. It contains checklists and Red Lists of plants in Bavaria (approx. 12,500 names, as of April 2015), about 2,500 species descriptions, data about the distribution collected by AG Flora von Bayern and the Bayerischen Landesamt für Umwelt (approx. 7 million). http://www.bayernflora.de/, last accessed 18 August 2016	Initiative Flora of Bavaria exists for more than 100 years; AG Flora von Bayern since 2011	DE
FloraWeb – Daten und Informationen zu Wildpflanzen und zur Vegetation Deutschlands (complementary)	FloraWeb is an online platform of the German Federal Agency for Nature Conservation (BfN) providing information about wild plant species, plant communities and Germany's natural vegetation. It contains about 3,500 species descriptions with up to 55 specific details concerning taxonomy, systematics, biology, ecology, natural habitat, distribution and conservation status as well as pictures, vegetation maps and information about the plant communities. http://www.floraweb.de/, last accessed 14 October 2016	Since 2007	Bonn, DE
Freshwater Information Platform (complementary)	The Freshwater Information Platform is an online information platform for limnological data and metadata. It is a web portal with biodiversity data, a Global Freshwater Biodiversity Atlas, data to the geographical distribution of animal species etc. It contains various data and metadata, e. g. Freshwater Biodiversity Data Portal 91,774 species, 16,047,940 data to geographical distribution (georeferenced 13,156,607). http://www.freshwaterplatform.eu/, last accessed 14 October 2016	Since 2015	DE, AT, BE
GBIF – Global Biodiversity Information Facility (complementary)	GBIF and the GBIF portal make biological data and information on biodiversity digitally available via the Internet using web services. It provides access to more than 630 million datasets of more than 1.6 million animal species. The 29,286 data sets are provided by 822 data publishers. http://www.gbif.org/, last accessed 14 October 2016	Since 2001	Copenhagen, DK; in all 37 voting participants, 17 associate country participants, 39 other associate participants
GBIF-D – Global Biodiversity Information Facility	The main objective of GBIF-D is the focussed collection and mobilisation of suitable data within Germany's research community and	GBIF member since 2001	DE

Germany (complementary)	natural history collections as well as the available observation data to fulfil the aims of GBIF's MoU. GBIF-D is a founding member of GBIF. http://www.gbif.de/, last accessed 14 October 2016		
GBOL - German Barcode of Life (complementary)	GBOL provides an inventory and genetic characterisation of animals, plants and fungi from Germany by means of DNA barcoding. The GBOL project strives to record the diversity of German animal, fungus and plant species based on their DNA Barcodes (genetic fingerprints). https://www.bolgermany.de/, last accessed 18 August 2016	First phase from 2012	DE
GenBank (complementary)	GenBank is an international, open access database of publicly available nucleotide sequences. Approx.194.4 million sequences containing approx. 213.2 million bases are available (as of June 2016). GenBank is part of the International Nucleotide Sequence Database Collaboration. http://www.ncbi.nlm.nih.gov/genbank/, last accessed 8 August 2016	Since 1982	US
GEO/GEOSS – Group on Earth Observation / Global Earth Observation System of Systems (complementary)	GEO and the online portal GEOSS provide free access to global and regional remote sensing data and insitu data on the fields of agriculture, biodiversity, ecosystems, climate, catastrophic events, energy, health, water and weather. It contains 7 million aggregated data (i. e. a mix of data collections, datasets and individual pictures, of which around 1.2 million are available in GEOSS Data Core). GEO: http://www.earthobservations.org/, last accessed 8 August 2016 and GEOSS Portal: http://www.geoportal.org/web/guest/geo_home_stp, last accessed 14 October 2016	Since 2005 (GEO)	102 nations and the European Commission; 103 participating organisations
GFBio - German Federation for Biological Data (complementary)	GFBio is a sustainable, service oriented, national data infrastructure facilitating data sharing for biological and environmental research. http://www.gfbio.org/, last accessed 14 October 2016	Project duration 2013 to 2015	DE
GGBN – Global Genome Biodiversity Network (complementary)	GGNB is an international network of institutions that share an interest in long-term preservation of genomic samples representing the diversity of non-human life on Earth. GGBN provides a platform for biodiversity biobanks from across the world to. One of GGBN's founders is the DNA Bank Network, which linked all DNA bank databases of its partners and made them accessible via a central web portal. The DNA Bank Network is fully merged with GGBN. GGBN contains 125,483 DNA samples and 252,074 tissue samples from 32,193 species out of 2,194 families (as of August 2016).	Formed in 2011	Secretariat: Washington, D.C., US; 41 member institutions from 20 countries

	http://www.ggbn.org/, last accessed 14 October 2016		
GRBio – Global Registry of Biodiversity Repositories (complementary)	GRBio is an online registry and metadata database for biological collections and repositories worldwide. It contains 7,003 Biorepository Records and 690 Institutional Collection Records (as of August 2016). http://grbio.org/, last accessed 8 August 2016	Not specified	Merger of: Index Herbariorum, Biodiversity Collection Index and Biorepositories .org; contributors worldwide
iBOL – International Barcode of Life (complementary)	iBOL is an international initiative dedicated to gather and provide DNA Barcodes of all organisms. Its main mission is extending the geographic and taxonomic coverage of the barcode reference library – Barcode of Life Data Systems (BOLD) – storing the resulting barcode records, providing community access to the knowledge they represent and creating new devices to ensure global access to this information. BOLD contains 5,191,084 DNA barcodes and 259,811 species (as of October 2106). iBOL: http://ibol.org/, last accessed 17 October 2016 and BOLD: http://www.boldsystems.org/, last accessed 17 October 2016	iBOL: since 2010	Scientific Hub: Guelph, CA; nodes in 28 countries
IDES – Integrated data management for mobilisation and digitalisation of zoological and palaeontological collections (complementary)	The project IDES aims to set up a high performing information infrastructure which will be commonly used by four research collections belonging to the Staatliche Naturwissenschaftliche Sammlungen Bayerns (SNSB). IDES will mobilise and digitalise the data and metadata of Actinopterygii from Europe and adjacent seas, starting from the Mesozoic era (Trias) until collections of extant fishes. At the end of the project, the data for more than 50,000 objects with 10,000 images will be accessible via the relational database system Diversity Workbench (DWB). http://ides.snsb.info/wiki/, last accessed 18 October 2016	Project start in 2012	DE
iDigBio – Integrated Digitized Biocollections (complementary)	iDigBio is a web portal for digital data and pictures of extant and paleontological species, mainly from natural history collections in the USA. It operates as a coordination centre for the digitalisation of biodiversity data. iDigBio contains several million data and pictures of collection specimens. https://www.idigbio.org/, last accessed 17 October 2016	Since 2011	US
iDiv - German Centre for Integrative Biodiversity Research (complementary)	iDiv is a national research centre with the aim of capturing biodiversity in its complexity as well as providing and using scientific data on a global scale to generate strategies, solutions and utilization concepts suitable for policy makers. https://www.idiv.de, last accessed 19 August 2016	Since 2012	DE

	iDiv biodiversity data portal: https://idata.idiv.de/, last accessed 17 October 2016		
IESB – International Environmental Specimen Bank Group (complementary)	IESB promotes the world-wide development of techniques and strategies of environmental specimen banking. http://www.inter-esb.org/, last accessed 17 October 2016	Launched in 2008	Website coordination: DE; cooperation of specimen banks worldwide
iMicrobe – Building a Cyberinfrastructure for Microbes (complementary)	iMicrobe is a data portal for metagenomics and genomics with annotated metadata for microbial datasets. Project data, -omics data, metadata, and other related data are provided. http://imicrobe.us/, last accessed 17 October 2016	Project initiated in 2013	US
The Israeli National Natural History Collections (complementary)	The Israeli National Natural History Collections of Hebrew University of Jerusalem comprise the herbarium and various animal groups. The website provides information on the collections and their databases. It contains 61,235 zoological and 15,540 botanical entries. http://nnhc.huji.ac.il/, last accessed 17 October 2016	First collections date back to the beginning of the 20th century	Jerusalem, IL
The IUCN Red List of Threatened Species (complementary)	The IUCN (International Union for Conservation of Nature) Red List delivers information about the global conservation status of biological species. The specific data of each species are published via a web portal. More than 80,000 species have been assessed (as of 2016). http://www.iucnredlist.org/, last accessed 17 October 2016	Since 1964	Red List Partnership of several organisations, e. g. IUCN, BirdLife International, Royal Botanic Gardens, Kew etc.
JSTOR Global Plants (complementary)	JSTOR Global Plants is a database with digitalized type specimens of plants and fungi. It is a platform for research and international cooperation in Botany. Global Plants was made possible by the Global Plants Initiative (GPI), an international undertaking by leading herbaria. The GPI seeks to digitise and make available plant type specimens and other holdings used by botanists every day. Partners of GPI include more than 300 institutions in more than 70 countries. https://plants.jstor.org/, last accessed 17 October 2016	Not specified	JSTOR (US)
KultSam - Kulturhistorische Sammlungen als Wissensspeicher in Museen und Archiven (complementary)	The research infrastructure KultSam plans to digitally bring together different information originating from cultural and historical research museums, collections, archives and libraries. The purpose is the opening of the collections as knowledge repositories for interdisciplinary and transdisciplinary research by digitizing, making accessible and linking various collections. The concept of the infrastructure is currently in the planning phase.	Planning phase: 2016 to 2018; Operation start planned for 2029	DE
LIAS Light – A Database for Rapid	LIAS light aims at optimizing online identification of lichens of the world by using an easily	Initiated in 2001	Editorial management: DE;

Identification of Lichens (complementary)	working interactive multi-access key which is based on a subset of 70 diagnostically relevant characters from the LIAS main set. LIAS light delivers data for the Species2000 initiative and acts as the Global Species Database for Lichens. http://liaslight.lias.net/, last accessed 17 October 2016		further editors from, AU, RU, CH, US
LIAS Names – A Database with Names of Lichens, Lichenicolous Fungi and Non-Lichenized Ascomycetes (complementary)	LIAS names is a global thesaurus of names and checklist of lichens, lichenicolous fungi and non-lichenized ascomycetes. LIAS names delivers data for the Species 2000 initiative and acts as the Global Species Database for Lichens. http://liasnames.lias.net/, last accessed 17 October 2016	Initiated in 2003	Editorial management: DE; further contributors from AU, SE, UK, US
LifeWatch – E-Science European Infrastructure for Biodiversity and Ecosystem Research (complementary)	LifeWatch in an EU-wide distributed e-research infrastructure linking and analysing data from biodiversity and ecosystem research. LifeWatch entered the ESFRI Roadmap in 2006 and is currently an ESFRI-Landmark on the Roadmap 2016. http://www.lifewatch.eu/, last accessed 18 October 2016	Operation start planned for 2016	Committed countries: BE, GR, IT, PT, RO, NL, ES; observer countries: FI, FR, HU, SK, SI, SE; stakeholder from NO
LOD2 - Creating Knowledge out of Interlinked Data (complementary)	LOD2 is an EU project about „Linked-Open Data" and research on new and innovating semantic data and web technologies. http://lod2.eu/, last accessed 17 October 2016	Project duration: 2010 to 2014	Coordination: DE; in all 15 partners from 11 European Countries (and one associated partner from Korea)
LTER in Europe – Long-Term Ecosystem and Socio-Ecological Research in Europe (complementary)	LTER capitalizes on research infrastructures such as the *in-situ* network of sites and information technology. Thousands of research projects have been carried out taking advantage of this infrastructure. The increasing complexity of ecosystem research led to the networking and global organization of LTER. LTER in Europe comprises three components: _ LTER-Europe: The umbrella network for LTER in Europe and regional network of ILTER (International Long-Term Ecological Research) _ eLTER H2020: A cooperation project of the European LTER and critical zone research, developing network level Research Infrastructure services alongside exemplary research questions and analyses of data from 162 sites across Europe. _ eLTER ESFRI: The initiative to progress towards a formal eLTER ESFRI research infrastructure for multiple use by user groups such as the LTER and Critical Zone research community. eLTER was recognised as an emerging projects on the ESFRI Roadmap 2016. http://www.lter-europe.net/, last accessed	LTER-Europe launched in 2003 eLTER H2020: project duration 2015 to 2019	LTER-Europe network: national networks of 25 European countries (one, LT, inactive); eLTER H2020: coordination AT; 28 partners from 22 countries in all

	21 October 2016		
Meteoritical Bulletin Database (complementary)	The Meteoritical Bulletin Database is a worldwide database of the International Society for Meteoritics and Planetary Science, listing all identified meteorites worldwide. It contains 54,926 valid meteorite names and 8,068 provisional names (as of October 2016). http://www.lpi.usra.edu/meteor/, last accessed 17 October 2016	Not specified	The Meteoritical Society has members from over 40 countries
MIRRI - Microbial Resource Research Infrastructure (complementary)	MIRRI is a distributed European research infrastructure for research on microorganisms and the corresponding collection management. MIRRI entered the ESFRI Roadmap in 2010 and is currently an ESFRI project on the Roadmap 2016. http://www.mirri.org, last accessed 18 August 2016	Construction and operation envisioned for 2017	Coordination: DE; further partners: UK, NL, ES, FR, PL, PT, IT, BE, SE, SE, RU
Morphbank Biological Imaging (complementary)	MorphBank is an open web repository of biological images documenting specimen-based research in comparative anatomy, morphological phylogenetics etc. It holds more than 216,000 public images of more than 4500 different species. http://www.morphbank.net/, last accessed 17 October 2016	Established in 1998	Host: US; international team of scientists, originally from SE, US and ES
Morph-D-Base (complementary)	Morph-D-Base is a web portal for the storage and free access to morphological datasets, pictures and other metadata. https://www.morphdbase.de/, last accessed 19 August 2016	Since 2006	DE
MorphoBank (complementary)	MorphoBank is an online database for morphological data (e. g. phylogenetic matrices for phylogenetic analysis, pictures of morphological structures). There are 467 publicly accessible projects with 62,462 images and 317 matrices available (as of October 2016). http://www.morphobank.org/, last accessed 17 October 2016	Development of version 1.0 started in 2001	US
NBC Naturalis – Netherlands Biodiversity Center Naturalis	NBC's scientific research aims to understand the development of biodiversity and the interaction between species. Its natural history collection is the 5th largest in the world with 37 million objects. http://www.naturalis.nl/en/, last accessed 20 October 2016	Launched in 2010	Leiden, NL
PaleoBioDB – Paleobiology Database (complementary)	PaleoBioGb is a databank for paleontological data. Its purpose is to provide global, collection-based occurrence and taxonomic data for organisms of all geological ages, as well data services to allow easy access to data for independent development of analytical tools, visualization software, and applications of all types. It contains 1,309,186 data on occurrences and 345,609 taxa (as of August 2016). https://paleobiodb.org/, last accessed 10 August 2016	Originated in the Phanerozoic Marine Paleofaunal Database initiative (1998 to 2000)	Hosted by University of Wisconsin-Madison, US; operated by an international group of researchers
Pangaea – Data Publisher for Earth	Pangaea is an IT infrastructure and web portal to store, archive and make accessible georef-	Not specified	DE

& Environmental Science (complementary)	erenced datasets from Earth and environmental sciences. It contains more than 350,000 datasets based on approx. 10 billion individual measurements from 235 European and international projects (as of October 2016). https://www.pangaea.de/, last accessed 17 October 2016		
PESI – Pan-European Species directories Infrastructure (complementary)	PESI is an e-infrastructure for taxonomic information on species occurring in Europe. The portal integrates data from Fauna Europaea (terrestrial and limnic animals; see "Fauna Europaea"), the Euro+Med Plantbase (vascular plants from Europe and the Mediterranean region; see "Euro+Med Plantbase"), the European Register of Marine Species (marine species) and the European part of Index Fungorum (Fungi). It contains almost 450,000 scientific names and 240,000 valid names of (sub)species. http://www.eu-nomen.eu/, last accessed 18 August 2016	Portal launch v.1.0 in 2011	Project management: NL; in all 40 partner organisations from 26 countries
Phenoscape (complementary)	Phenoscape is a genomic database linked to phenotype data across various fields in Biology (e. g. Anatomy, Palaeontology, EvoDevo). It contains, through the Phenoscape Knowledgebase (KB), 20,969 genetic, developmental, morphological and evolutionary datasets; genes with at least one phenotype: more than 15.000 (zebrafish, mouse, man); gene expression profiles: more than1.2 million (zebrafish, mouse, man) (as of July 2015). http://phenoscape.org/, last accessed 17 October 2016	Not specified	US
The Plant List (complementary)	The Plant List is a working list of all known plant species. It aims to be comprehensive for species of Vascular plants and of Bryophytes. It contains 1,064,035 scientific plant names of species rank; of these 350,699 are accepted species names (as of October 2016). http://www.theplantlist.org/, last accessed 17 October 2016	Since 2010	Consortium on US and UK institutions and other collaborators
PRELIDA – Preserving Linked Data (complementary)	The PRELIDA project targets the particular stakeholders of the Linked Data community, including data providers and end user communities to make the best use possible from the existing digital archiving opportunities. http://www.prelida.eu/, last accessed 17 October 2016	Project completed: January 2013 to December 2014	APA and institutions from IT, UK, AT
Reptile Database (complementary)	The Reptile Database provides a catalogue of all living reptile species, including data on their names and synonyms, distribution, taxonomy, morphology, ecology, and corresponding literature. It contains 10,391 species, 38,902 literature references, and 9,191 pictures (as of August 2016). http://www.reptile-database.org/, last accessed 10 August 2016	Founded in 1995	CZ
SiB Colombia – Sistema de Información sobre Bio-	SiB is a network giving access to Colombian collection specimens. It gives access to more than 2.2 million Co-	Since 2000	CO

diversidad de Colombia (complementary)	lombian collection specimens and almost 50,000 species. http://www.sibcolombia.net/web/sib/, last accessed 18 October 2016		
SILVA – High quality ribosomal RNA databases (complementary)	SILVA is an online database for quality checked and aligned ribosomal RNA sequence data. It contains more than 5,300,000 SSU/LSU sequences (as of July 2015). https://www.arb-silva.de/, last accessed 19 August 2016	Implementation of the SILVA system in 2007	DE
SpeciesLink (complementary)	SpeciesLink is a network giving access to Brazilian collection specimens. It contains almost 7.5 million Brazilian collection specimens. http://splink.cria.org.br/, last accessed 18 October 2016	Conception in 2001	BR
StrainInfo (complementary)	StrainInfo provides information about the use and research history of bacterial strains from different research centres. It contains information about the repositories of bacterial strains, changes observed in these bacterial strains and their nomenclature. It contains 696,914 strain numbers from 299,254 strains with 13,878,482 accession numbers (bacterial, archaeal and fungi strains) (as of December 2015). http://www.straininfo.net/, last accessed 18 October 2016	First implementation of the web application in 2007	BE
UMAC Database – UMAC Worldwide Database of University Museums & Collections (complementary)	UMAC, the International Committee for University Museums and Collections, is one of the specialised committees of the International Council of Museums (ICOM). Its database is a global online directory and database of university museums and collections from various fields. It contains metadata from 1,288 collections, 1,359 Museums etc. (as of December 2015). http://publicus.culture.hu-berlin.de/umac/, last accessed 18 October 2016	Development of the database started in 2003	Coordination: ICOM; international network with 312 members in 56 countries and regions
University Collections in Germany (complementary)	The information system University Collections in Germany documents collections at German universities encompassing collections from the Humanities as well as from Natural Sciences. It includes information about the history of the collections. It contains 1,149 collections, 2,620 material models, 5,096 publications (as of August 2016). http://www.universitaetssammlungen.de/, last accessed 19 August 2016	Project start 2004	DE
UPB - Environmental Specimen Bank (complementary)	UPB is an archive for samples that can be used to document and assess the quality of the environment and the pollutant load in Germany. Specimens from representative ecosystems throughout Germany are collected at regular intervals. Besides specimens representing various levels of the food chain – such as algae, mussels, fish, herring gulls – human specimens (blood and urine) are also collected from student volunteers at four different sites. https://www.umweltprobenbank.de/de, last	Since 1994	DE

	accessed 18 October 2016		
VH/de – German Virtual Herbarium (complementary)	VH/de is an online resource that provides access to information obtained from collections held in German herbaria using the BioCASe infrastructure (see "BioCASe"). http://vh.gbif.de/vh/index, last accessed 18 October 2016	Since 2015	DE
WISIA - Information System on International Species Conservation (complementary)	WISIA is a species conservation database from the German Federal Agency for Nature Conservation with information on the legal status of both animal and plant species under national or international protection. http://www.wisia.de/index.html, last accessed 18 October 2016	Since 2001	Bonn, DE

II.6 Tandem-L

II.6.a Scientific potential

Description

The Earth system consists of a wide variety of components and processes that are intrinsically linked by complex interactions in and between the Earth's spheres. Until now, many of these interactions have not been sufficiently researched and understood. In this context, Tandem-L addresses a broad range of scientific questions and topics concerning the Earth's spheres:

- Biosphere: Tandem-L will deliver information about the amount, structure, and spatial distribution of forest biomass, the change of forests over time, and the impact of the climate change as well as anthropogenic activities on the structure and stability of forests.
- Geosphere: Tandem-L will contribute to the improvement of forecast models for natural hazards as well as to hazard assessment of earthquakes and volcanoes activities, and in particular to a better understanding of how volcanoes are connected to their environment.
- Cryosphere: The project aims to deliver new results concerning the impact of the global climate change on glaciers, ice caps, and the question of how global climate change alters the ice mass motion and balance in the Arctic and Antarctic. The project also addresses the question, which processes in general are driving the current mass depletion in the major ice sheets.
- Hydrosphere: Tandem-L will also help to understand the spatial and temporal dynamics of soil moisture's contribution to soil and plant transpiration, the exchange of water and energy between the soil and the atmosphere, the influence of soil moisture patterns on the formation of new ground water, surface run-off and soil water storage in large river basins, and the linkage between spatiotemporal changes in soil moisture and changes in regional climate (and weather).

Two complementary measurement modes were developed for Tandem-L. The 3D-structure mode will permit, for the first time, large scale tomographic data acquisitions of vegetation, ice, sand, and dry soil from space, and the three-dimensional imaging of these structures in all polarisations. The deformation mode will allow precise measurements of topographic changes in the Earth's surface in the millimetre range. This mode will be used primarily in geo- and lithosphere research but has also a significant potential for other scopes (e. g. measurements of glacier flow velocities and the observation of subsidence phenomena in cities and permafrost regions). According to the proposal, Tandem-L features a high degree of innovation with regards to both methodology and technology. Examples include polarimetric SAR interferometry for the estimation of forest height, multi-pass coherence tomography for imaging the vertical structure of vegetation and ice, the use of novel digital beam-forming techniques to extend the swath width and resolution, as well as the close-formation flight of two radar satellites.

Including the predecessor missions TerraSAR-X and TanDEM-X |[110] there are seventeen complementary and competing RI, whose capabilities overlap at singular points but complement the extensive scope of applications of Tandem-L. Among them is the US mission NISAR and the ESA (European Space Agency) mission BIOMASS. According to the proposal none of them – in existence or in planning – achieves a spatial and temporal resolution and quality of higher-level information products comparable to Tandem-L.

Assessment

Overall, the scientific potential of the Tandem-L proposal is high. Tandem-L is highly relevant and of great strategic importance for filling key observational gaps regarding many processes occurring at the Earth's surface, which are currently mostly mapped regionally or globally at insufficient spatial and/or temporal resolution. The mission is technically highly innovative with high potential to generate observations for enhanced insights into a number of processes. Currently, such observations can't be obtained (e. g. forest biomass, ice mass, or surface deformation). There is a high likelihood that the retrieved backscatter fields will be superior to existing products. There are still some open issues concerning the algorithms and the higher level products.

Tandem-L allows an expansion of applications to areas where surface penetration is important for measuring (depth-averaged) conditions such as ice/snow conditions, soils and soil moisture, and vegetation cover. For example, Tan-

| [110] TerraSAR-X add-on for Digital Elevation Measurement

dem-L is expected to provide unique data to address forest diversity, structure and biomass in ways that current missions can't.

Tandem-L data will sharpen the questions about the fundamental functions of the Earth system, thereby allowing quantification of the processes involved leading to an improved understanding of the shortcomings in current knowledge. For example, the data from the mission are expected to contribute to more accurate estimates of ice mass (ice caps, glaciers) their inter-annual variations and secular changes, either with Tandem-L measurements alone or together with ICESat-2 (Ice, Cloud and land Elevation Satellite-2).

More specific examples of contributions of Tandem-L to the understanding of the Earth system include more accurate observations of surface deformation that can be used as early warning indicator for hazards such as earthquakes, as well as better determinations of biomass inventories that are important for monitoring of changes in the biosphere due to, for example, migration of vegetation zones caused by climate change or deforestation/afforestation. Understanding the processes that govern the form and mass of ice sheets is essential for estimates of sea level rise and of the impact of changes in glacial ice budgets on the stratification and circulation of adjacent oceans. Tandem-L will improve our capability to understand the near-surface processes that determine the dynamics and mass balance of ice sheets. Such insights are critical for projections of the expected changes of ice sheet mass and their contribution to sea level rise in a warming world. Tandem-L will also contribute to a better understanding of soil moisture. Operation in the L-Band will achieve deeper penetration, thereby allowing observation of a larger portion of the unsaturated soil zone. Observation of soil moisture is critical for understanding vegetation and its changes and feedbacks to climate change.

Some of the listed goals such as studies of permafrost, land-atmosphere coupling and ocean circulation are seen as more problematic. There will be contributions of Tandem-L to these fields but the primary knowledge will most likely be derived from other observations. There is also some room for strengthening of the higher-level products.

The Tandem-L data acquisition concept comprises two complementary measurement modes that can be adapted flexibly to accommodate changing requirements. Mode (I) can provide multiple essential 3D data sets for bio-, hydro- and cryosphere research. Mode (II) can be used to map swaths with a width of 350 kilometres, facilitating repeated imaging within short intervals that is judged to be primarily useful for geo- and lithosphere research but also has significant potential for use in other research areas. There is also a capability of focusing the mission on areas where extreme events are suspected to develop.

The proposed satellite/sensor system will offer innovative measurements that are expected to address the listed science questions with a new perspective. The imaging technologies and high mapping capacity of Tandem-L make it a unique radar observatory of dynamic processes at the Earth's surface. Complementary satellite missions designed for individual applications include, for example, the Sentinel-1 satellites, which can record large areas in weekly cycles at the higher sensor frequency of the C-band. Tandem-L differs from these by its longer wavelength, allowing for greater penetration depth and improved temporal stability (coherence), its higher azimuth resolution, supporting fully polarimetric data acquisition, and its use of two satellites in a tight formation providing bistatic imaging capability and facilitating generation of three-dimensional, tomographic image products at high spatial and temporal resolution. Furthermore, the formation flight also distinguishes Tandem-L from other L-band SAR missions (e. g. ALOS-2 PALSAR |[111] with a very narrow swath).

There are complementary missions but there is no directly competing mission in terms of sensor configuration given the unique observational system of two-satellite sensors flying in close formation. These are quite well reviewed in the proposal. The complementary missions are those whose data products overlap with potential Tandem-L data products and can be used synergistically.

Tandem-L expands the data acquisition capacity by almost two orders of magnitude compared to that of TanDEM-X, and the Tandem-L ability to acquire systematic three-dimensional data regardless of weather conditions is an overall key improvement for global change observations. Tandem-L will further complement and extend the global high-resolution elevation model produced by TanDEM-X, currently the only bistatic radar mission, by including and resolving both terrain elevation (e. g. forest soil) and surface elevation (e. g. treetops).

To some degree, the proposal overstates the importance of Tandem-L in addressing some of the listed science questions, and minimizes the contributions of existing and planned missions, which are also mentioned in the proposal. For example, it is claimed that there is a lack of regular and comprehensive observation of fundamental processes such as changes in the global biomass, glacier dynamics, volcanic activity, tectonic displacements, global ocean currents, freezing and thawing cycles in permafrost, local variations in soil moisture, and so on. At the same time, there are many current and planned missions listed that address these areas. Complementary missions using quite different technologies (e. g. integration with high-density – high precision geodetic location programmes, with high resolution gravity missions and with altimeter missions for ice and ocean studies) are not adequately recognised. Recognition of these complementarities is important in determining the priorities of competing science objectives and in designing the acquisition plan. It

| [111] Advanced Land Observing Satellite-2 Phased Array type L-band Synthetic Aperture Radar.

does not take away from the importance of the proposed project. Rather it places it more solidly into the context of multiple missions required for adequate global Earth surface observations and studies of global environmental processes and their changes.

II.6.b Utilisation

Description

The users of Tandem-L come from all fields of the environmental sciences, including geophysical, hydrological, glaciological, geological, and ecological disciplines and climate research, as well as from different areas of the technical sciences. They can be divided into scientists from the responsible and cooperating institutions and a group of users from the wider scientific community. According to the proposal, users from government agencies and institutions with sovereign tasks as well as commercial users are also expected.

The data are accessed via the web-based “Tandem-L science server” interface, which will be managed by the science and user segment. The radar raw data from the satellites will be processed in the ground segment to derive images or higher-level information products as needed. These data will be distributed via a web portal. While basic products will be freely available to all users, higher-level information products (e. g. elevation models or surface deformation maps) will be freely available only to the research community. Other users will have to pay licensing fees that are an integral part of the Tandem-L business plan.

The overall Tandem-L system is designed to allow the satellites to record up to 8 terabytes of radar raw data per day. The data will be transmitted by a Ka-band datalink |[112] to the processing and archiving centre via a global network of ground stations. The principal elements of the data centre (processing and exploitation platform, long-term archive, and the data interface) will be designed around the use of virtual machines according to the cloud computing approach. On the one hand, products will be generated systematically and globally on the exploitation platform; on the other hand, the platform will be made available to the users to generate custom products on local and regional scales, using standardised algorithms.

The space and ground segment of Tandem-L will be developed in compliance with the specifications of the European Cooperation for Space Standardisation (ECSS), which provides a uniform set of standards for all European space activities. Accordingly, product assurance plans will be defined for both segments at

|[112] The Ka-band is defined as the 26-40 GHz range of the radio spectrum.

the start of the project. Moreover, the ground segment, procedures for data delivery, data storage, and long-term archive are certified according to International Certificate for Quality Management (ISO | [113]) 9001:2008. All participants involved in data evaluation are requested to notify the scientific and user coordinator within the Tandem-L project if they submit publications, and to acknowledge the body responsible for funding the research infrastructure. Guidelines to the handling of publications of the Helmholtz Centre and the DFG are also implemented.

Assessment

Tandem-L implies 100 % instrument utilisation. A systematic acquisition plan has been developed to ensure that this 100 % utilisation can be useful in supporting a broad community of users, expected to represent a wide range of research fields.

A discussion of specific legal conditions for access management and service in this section of the application could not be identified. A process to allow simple access to the scientific data has already been established for TerraSAR-X and TanDEM-X and an equivalent process will be used for Tandem-L, which should be adequate. The record of the TanDEM-X mission appears to be outstanding and provides a good guide as to what may be anticipated from Tandem-L. The free availability of the data to the non-commercial user is a very strong point.

An image of an inclusive set of diverse users, across broad disciplines, with access to the data and data products without charge (if science related) is presented in the proposal.

The Tandem-L mission is expected to generate a broad range of radar raw data and higher-level information products, and these will be made available free of charge to scientific users in Germany and to the international community. A data management and utilisation concept has been developed to ensure that the data are systematically acquired, processed to create higher-level products, securely archived, and made available to the users. Overall, the application describes a clear data strategy and an adequate data management plan.

In view of the data plans, raw radar measurements will be processed by the mission into higher level products only for the forest biomass and surface deformation requirements, with other products expected to be developed by a smaller group within the Helmholtz Alliance core team. There is discussion of the downlink from the satellite to ground stations to DLR, but the data product

| [113] International Organization for Standardization.

archiving and distribution by the back-end data producers (the smaller group producing the higher level products) within the Helmholtz Alliance is not well described.

Overall, quality is assured through extensive measures to be implemented in both the initiation and the utilisation phases of Tandem-L. An integrated quality management concept conforming to ECSS aerospace standards will be applied to Tandem-L to ensure successful project execution.

II.6.c Feasibility

Description

Tandem-L was included in the Helmholtz-Roadmap for RIs in 2011 and is a key element of the strategy for the research field "Earth and Environment" of the Helmholtz Association as well as the core DLR fields in the space programme. The principal strategic goals are to expand and connect observation and knowledge systems alongside integrated model approaches to improve predictions and to make the results available as quickly as possible. As it is stated in the proposal, the implementation of Tandem-L will create a globally unique Earth observatory, surpassing the performance of existing systems.

According to the proposal, Tandem-L builds partly on the TerraSAR-X/TanDEM-X satellite missions and the SARah satellites of the German Federal Armed Forces, which will be launched approx. three years before Tandem-L. Thus, the SAR technology will be sufficiently tested. Tandem-L has, nevertheless, to be significantly modified to enhance the recording capacity by almost two orders of magnitude in comparison to TanDEM-X. Therefore, there are several possible risks, primarily concerning the new developments which are necessary for both, the two satellites and their payload as well as the ground segment. Further risks are the failure of facilities, delivery delays due to project partners, and changes in external regulations and laws. The risk assessment provided in the proposal quantifies a risk amounting to 18.7 % of the total cost of the development phase.

Satellite missions require a broad range of expertise, ranging from mission design and specification to space technology, systems engineering, satellite operation, data processing and archive in addition to the determination of bio-/geophysical parameters as well as Earth system modelling. According to the proposal, the participating institutions have sufficient experience in radar missions and possess all of the necessary personnel requirements to build and successfully operate Tandem-L within the budgeted costs and intended schedule.

The Tandem-L proposal dates back to 2007. Two preliminary phase A studies were completed between January 2008 and August 2014 to prepare a detailed mission concept and to establish the technical feasibility. Preparation for Tandem-L continues at present with the launch of a phase B1 study, which will seek to further elaborate the designs for the ground and space segments on a subsystem level. Additionally, preparations to ensure scientific utilisation of the Tandem-L data in a large number of applications in the bio-, geo-, cryo- and hydrosphere have been ongoing within the Helmholtz Alliance ‘Remote Sensing and Earth System Dynamics’ since 2012.

Assessment

The development and use of novel techniques and technologies and the large volume of data, which also requires processing, present various challenges and risks for Tandem-L. Overall the mission proposal has a strong heritage and a risk analysis has been carried out for the hardware and ground segments. Using an equivalent process for simple access to the scientific data as that already established for TerraSAR-X and TanDEM-X is expected to ensure legal certainty for the operator and the users. No other risks relating to ethics or environmental policies are expected. Together with the scientific rationale, these attributes of the mission add up to a strong proposal, the successful execution of which would provide significantly enhanced, novel opportunities for monitoring and understanding the Earth System.

The Helmholtz Alliance and cooperating organisations are well recognised nationally and internationally. Overall, the capacities of the participating Helmholtz centres will be pooled as joint research portfolios for advancement of Earth observation and knowledge systems alongside integrated model approaches, and Tandem-L is of fundamental importance for achieving their joint strategic objectives. Close collaboration between the participating research fields has been established in 2009 within the framework of significant Helmholtz Association research investments for TERENO (TERrestrial ENvironmental Observatories) and during the activities of the Tandem-L Science Team. Furthermore, the Tandem-L governance and project management concept builds on relevant experience gained during the TerraSAR-X and TanDEM-X missions. Overall, the participating institutes should have the capacity to carry out the proposed project.

The institutions participating in Tandem-L have experience from five radar missions completed during the last 25 years, and have developed adequate personnel concepts for the development, implementation and operation of also this RI. This includes established leading expertise across the involved research fields and in project management for ensuring successful implementation of Tandem-L. An extensive course programme and a job exchange programme between the centres will be organised to particularly support young scientists. A specific recruiting measure plan for personnel groups other than young scientists and for diversity management could not be identified in this application section. The availability of personnel for the mission hardware and ground segment design seems to be appropriate. The Helmholtz Alliance and cooperating organisations need to assess their personnel needs regarding the development of higher level products, outreach activities, user interaction, and data centre needs (for the higher level products.)

There is strong heritage of the mission concept and sensor technology at DLR. The financing of the mission through launch (space hardware, ground segment, radar processing) seems solid. Algorithm development is rooted in existing algorithms and focused on refinement. Algorithm development will continue throughout the test phases of the mission.

II.6.d Relevance to Germany as a location of science and research

Description

According to the proposal, Tandem-L will affirm Germany's position in forefront of international, high-resolution radar remote sensing beyond 2020 and will lay the foundation for future generations of synthetic aperture radar satellites. Publications in high quality journals based on Tandem-L data are expected and the large number of international users will further enhance the worldwide visibility of this RI. Moreover, the social relevance of Tandem-L supports visibility in scientific as well as in societal and political contexts.

The authors emphasise that Tandem-L will enhance Germany's attractiveness as a hub of science and research across several areas and disciplines (e. g. climate and environmental research, radar techniques and radar data analysis). According to the proposal, the unique technology and data as well as the societal relevance of the underlying scientific enquiries make Tandem-L strongly attractive, especially to young, but also to senior scientists and researchers globally.

As it is pointed out in the proposal, Tandem-L will have a far-reaching impact not only for scientific, but also for societal and economic implications, including the creation of new high skill jobs in the space industry and in connection with data analysis as well as the establishment of new geo-information services within the tertiary sector. Moreover, spin-off effects are expected, e. g. for the automotive industry and the monitoring of critical infrastructures using ground based radar systems. Beside the export of radar satellite technology and an expected impetus to big data management, Tandem-L also offers new opportunities for scientific and technological collaboration with developing countries, i. e. safeguard natural resources, in environmental monitoring or in climate protection. The project plan also contains a dedicated work package for the planning and coordination of public outreach activities (e. g. articles in mass media and the organisation of exhibitions).

By the breadth of its objectives and scientific applications, a successful Tandem-L mission will secure a leading position and increased international visibility and impact of Germany and German scientists in high-resolution, large-scale observation and interpretation of the Earth System and its change. Increased collaborations across the participating Helmholtz centres and with other national and international partners related to and facilitated by Tandem-L have the potential to establish this RI as a major global radar observatory, contributing considerably to meeting key challenges in Earth System and global change science. The societal relevance of geo-data and information products will also lead to visibility for Tandem-L outside academia, as well as impact on the ability of the private sector to utilise remote sensing data for a variety of practical applications.

Tandem-L has the potential to substantially enhance Germany's attractiveness as an international hub of research across several research areas and disciplines. The mission would strengthen the technological expertise of DLR in microwave radar systems. If the mission is operated as expected, it will provide a technologically innovative observation platform for Earth observations.

The imaging technology in Tandem-L is expected to yield innovative geo-information products and services, which can lay the foundation for future national and international observation and continuous monitoring of the Earth System and its changes. Targeted national action plans are developed to ensure knowledge transfer to a wider audience, and commercial and technological extensions. Commercial exploitation of new applications and products will be guided by the Technology Marketing of the Helmholtz centres. These centres are expected to provide advice concerning market potential and financial promotion, help in developing innovative ideas for translating business concepts to market maturity, and technical support for company start-ups. Tandem-L imaging and higher-level data products will be useful across many scientific areas, as well as in commercial and government applications and services. Examples provided in the proposal include precision farming, cartography, urban infrastructure planning, land utilisation, natural resource monitoring, ensuring mobility, monitoring adherence to climate treaties, early detection of environmental risks and hazards, and other security applications such as maritime safety.

II.6.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Participants
Existing research infrastructures			
ALOS-2 –	Spaceborne SAR mission operating at L-band	2014-2021	JP

Advanced Land Observing Satellite	(λ=24cm). The main mission objective is to provide (data) continuity to ALOS-1, the precursor mission. The main application areas are in mapping, regional monitoring, environmental surveillance, as well as the support in disaster management. The scientific focus of ALOS-2 is in four areas: forest, wetland, and glacier (polar regions) monitoring on a continuous regional, continental and/or global basis and in the generation of global radar reflectivity maps. Despite the systematic acquisition plan providing global consistent data, no higher level products (apart from annual forest/no-forest maps) are intended. http://global.jaxa.jp/projects/sat/alos2/, last accessed 18 October 2016		
LANDSAT	A series of optical multi-spectral satellites first launched in 1972. The last satellite of the series, LS-8, was launched in 2013 and acquires data in 13 spectral channels covering wavelengths from 0.4 to 12.5 μm. The scientific objectives of the mission include the monitoring of processes over land (e. g. land coverage, vegetation index and condition, snow coverage), and coastal waters on a local to global scale. An important feature of Landsat is the unique time series of acquisitions, which allow tracing changes on the land surface back to the year 1972. http://landsat.gsfc.nasa.gov/, last accessed 18 October 2016	LS8: 2013-2018	US
MODIS – Moderate-resolution Imaging Spectroradiometer (complementary)	Medium resolution spaceborne imaging spectrometer, which is operated onboard of two satellites (Aqua and Terra). MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data at 36 spectral channels covering wavelengths from 0.4 to 14.4 μm. The scientific objectives include the monitoring of processes over land (e. g. land coverage, vegetation index and condition, snow coverage), ocean (e. g. surface temperature) and in the atmosphere on a variety of spatial scales ranging from local to global. Particularly in the biosphere multi-spectral measurements are highly complementary to the intended Tandem-L measurements: the information extracted from multi-spectral measurements on the vegetation type, index and condition complement the biomass and structure measurements of Tandem-L, allowing a comprehensive characterization of forest condition. This applies not only to Modis but also to the following multi-spectral missions, i. e. LANDSAT and Sentinel-2. http://modis.gsfc.nasa.gov/, last accessed 18 October 2016	Terra: Since 1999 Aqua: Since 2002	US
Sentinel-1 (complementary)	Spaceborne SAR mission operating at C-band (λ=6cm) consisting of two satellites (Sentinel-1A and -1B): Both satellites circle the Earth on the same orbit shifted by 180° in order to reduce the revisit time (temporal resolution) from 12 to 6 days. Sentinel-1 is part of ESA's	A: 2014-2021 B: 2016-2023	ESA

	Copernicus program ensuring continuity of C-band Earth remote sensing data and products. The scientific objectives of the mission are in the long term sea- and land-ice monitoring in the polar regions, the monitoring of volcanic and tectonic activities and the associated Earth surface deformations, as well as in measuring ocean currents and wind fields over the oceans. The commercial and operational goals include the generation of sea-ice maps and the monitoring of icebergs, both for ship navigation, maritime surveillance and security, as well as measuring of terrain deformation and subsidence primarily in urban areas. In addition, Sentinel-1 is intended to support disaster management for help and rescue operations. Apart from the ocean products (wind fields and radial velocity component of ocean currents) no systematic higher-level products are generated. There are no global higher-level products generated systematically. https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1, last accessed 18 October 2016		
Sentinel-2	Multi-spectral Earth observation spaceborne mission consisting of a pair (Sentinel-2A and Sentinel-2B) of optical satellites acquiring data in 13 spectral channels covering wavelengths from 443 to 2190 nm. Both satellites use the same orbit, shifted by 180° to increase the temporal resolution. Sentinel-2 is part of ESA's Copernicus program aiming at providing continuity of multi-spectral Earth observation data. The scientific focus of the mission is the thematic mapping and classification of the Earth surface and in monitoring changes, such as vegetation changes and growth phase. https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2, last accessed 18 October 2016	A: 2015-2023 B: 2016-2024	ESA
SMAP – Soil Moisture Active Passive	Combined microwave radiometer and radar spaceborne mission operating at L-band (λ=24cm). The main scientific objectives are in measuring soil moisture and monitoring freeze and thaw processes over land. Similar to SMOS, SMAP achieves the high temporal resolution at the cost of a degraded spatial resolution. Tandem-L closes this spatial resolution gap in soil moisture measurements. http://smap.jpl.nasa.gov/	2015-2018	US
SMOS – Soil Moisture and Ocean Salinity	L-band (λ=24cm) microwave radiometer spaceborne mission with two main scientific objectives: The measurement of soil moisture over land, and the estimation of ocean (surface) salinity. SMOS achieves the high temporal resolution (revisit time) at the cost of a degraded spatial resolution. Tandem-L closes this spatial resolution gap in soil moisture measurements. SMOS is part of ESA's Earth Explorer program. http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS, last accessed 19 October	Since 2009	ESA

	2016		
TerraSAR-X **TanDEM-X** – TerraSAR-X-Add-on for Digital Elevation Measurements (complementary)	Spaceborne SAR mission operating at X-band (λ=3cm) providing multimode (in terms of swath width, temporal and spatial resolution) SAR data appropriate for a wide variety of scientific and commercial applications. The main application areas include local and regional thematic mapping, vegetation, waterbodies, sea and polar monitoring, as well as disaster management and security. However, TerraSAR-X does not follow a systematic product generation plan and no global higher-level products are systematically generated. http://dlr.de/terrasar-x, last accessed 19 October 2016	TerraSAR-X: Since 2007 TanDEM-X: Since 2010	DE
Planned research infrastructures/under construction			
BIOMASS	Spaceborne SAR mission operating at P-band (λ=75cm). The main scientific objectives of the mission are to determine the global forest biomass, its spatial distribution and its annual change, to estimate forest height and to monitor the change in forested areas due to reforestation and deforestation. A secondary mission goal is the measurement of flow velocity of fast flowing glaciers in the cryosphere. BIOMASS is part of ESA's Earth Explorer program. www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Future_missions/Biomass, last accessed 18 October 2016	2021-2026	ESA
EnMAP – Environmental Mapping and Analysis Program (complementary)	Hyperspectral Earth observation spaceborne mission acquires data in 232 spectral channels covering wavelengths from 420 to 2450 nm, with high spatial and temporal resolutions. The scientific objectives of the mission are to measure and monitor parameters of vital processes in agriculture, forestry, soil and geological environments, as well as coastal zones and inland waters. The hyperspectral EnMAP measurements are highly complementary to the Tandem-L measurements. However, the limited data acquisition capacity of EnMAP (5000 km with 30 km swath width per day) restricts its capacity to monitor the dynamics of large scale (i. e. spatially extended) processes. Accordingly, the synergy with Tandem-L can be exploited only on smaller scales (i. e. local and regional). http://www.enmap.org/, last accessed 18 October 2016	2018	DE
FLEX – Fluorescence Explorer (complementary)	Spaceborne implementation of a high resolution imaging spectrometer. It measures the fluorescent radiation of vegetation in order to extract photosynthesis activity on a global scale. FLEX is part of ESA's Earth Explorer program. FLEX and Tandem-L are highly complementary, since both gather different processes of the biosphere (vegetation) enabling an improved quantification of its contribution to global carbon cycle.	2022	ESA

	http://esamultimedia.esa.int/docs/EarthObservation/SP1330-2_FLEX.pdf, last accessed 19 October 2016		
GEDI – Global Ecosystem Dynamics Investigation Lidar (complementary)	Lidar altimeter (full waveform) mission implemented on the International Space Station (ISS). GEDI's main science objectives are: to quantify forest biomass, its spatial distribution and change caused by disturbances and deforestation; to measure the 3D forest structure with respect to biodiversity, and to assess the potential of forest carbon sequestration under different land use and climate conditions. GEDI and Tandem-L are highly complementary missions, since both measure the vertical vegetation structure but at different wavelengths. A common mission phase is not planned, since GEDI's life time is limited to one year. Nevertheless, GEDI data can play an important role in the calibration & validation phase of Tandem-L. http://eospso.nasa.gov/missions/global-ecosystem-dynamics-investigation-lidar, last accessed 19 October 2016	2018	US
ICESat-2 – Ice, Cloud and land Elevation Satellite-2 (complementary)	Satellite Lidar altimeter mission (λ=532 nm). The primary scientific mission goals are within the cryosphere: To measure height differences of polar ice sheets and glaciers in order to quantify their contribution to current and future sea level change; to measure changes in sea-ice thickness in order to examine exchanges of energy, mass and moisture between the ice, the ocean and the atmosphere. The determination of forest height for biomass estimation is a secondary mission goal. The high complementarity between ICESAT-2 and Tandem-L is based on the operation at largely different spectral windows. While ICESat-2 measurements ice surfaces with a high accuracy, Tandem-L covers the volume structure of the ice mass. Combining both measurements allows the accurate reconstruction of the mass balance. http://icesat.gsfc.nasa.gov/icesat2/, last accessed 19 October 2016	2017	US
NISAR – NASA-ISRO Synthetic Aperture Radar	Spaceborne SAR mission operating at L- and S-band (λ=12 and 24cm). The main science objectives are the accurate measurements of surface deformation due to volcanic, tectonic or subsidence processes, glacier flow velocity measurements in the cryosphere, and in determining the drift velocity of sea ice in the polar regions. Secondary mission objectives are the mapping of vegetation biomass and its change in low biomass biomes (up to 100t/ha) and the classification of agricultural cover. http://nisar.jpl.nasa.gov/, last accessed 19 October 2016	2020-2023	US, IN
SAOCOM - Argentine Microwaves Observation Satellite	Spaceborne SAR mission operating at L-band (λ=24cm). The main scientific goal is to measure soil moisture over Argentina's agricultural areas (Pampa). To increase the temporal resolution two satellites (SAOCOM-A and SA-	A 2017–2022 B 2018–2022	AR, IT

	OCOM-B) phased by 180° are foreseen. http://www.conae.gov.ar/index.php/english/satellite-missions/saocom/introduction, last accessed 19 October 2016		
SAOCOM-cs – Argentine Microwaves Observation Satellite – Companion Satellite	Spaceborne SAR mission operating at L-band (λ=24cm) utilizing a passive small satellite flying in close formation to SAOCOM-B (see previous mission above) and receiving its echo signals. SAOCOM-cs is a demonstrator mission aiming at testing and validating a number of new SAR techniques (such as tomography for 3D imaging of forest areas, and bistatic polarimetry for soil moisture measurements). An intended large-scale product is the forest structure in boreal zones. The mission concept does not provide global coverage. http://seom.esa.int/polarimetrycourse2015/files/SAOCOM_MDavidson.pdf, last accessed 19 October 2016	2017-2020	ESA

D.III BIOLOGICAL AND MEDICAL SCIENCES

III.1 Scientific landscape in Biological and Medical Sciences

Biological and Medical Sciences encompass a multitude of scientific disciplines that deal with life processes, living organisms and their organisation, and relationships between organisms and the environment.

III.1.a Scientific landscape for research infrastructures in Biological and Medical Sciences

Research objectives in Biological and Medical Sciences include the elucidation of the structural and functional basis of biological phenomena, knowledge transfer between basic science and clinical applications, the principles of health maintenance, and the prevention and treatment of diseases. The rapid development of new technologies in biomedical research (such as genome sequencing, high-throughput microarray and imaging technologies) makes it increasingly possible to study issues of complex systems. Biological and Medical Sciences have developed from data-poor into data-rich disciplines with increasing use of sophisticated bioinformatics tools and databases. This is changing the character of biomedical research towards large-scale, technology-driven studies that critically rely on the availability of appropriate research infrastructures. So far, the new omics technologies have not been fully exploited for translation into health science, pharmacology and medicine. One key challenge of the next decades will be to bridge the gap between basic science and applications in health sciences, pharmacology, and medicine.

The focus of the research infrastructures of the current Roadmap Process is on biomedical imaging ranging from non-invasive macroscopic to highest resolution microscopic techniques.

The field of bioimaging is situated at the forefront of interdisciplinary biomedical research, and can be expected to advance Biological and Medical Sciences towards a deeper understanding of biological processes. Biomedical imaging is the technique and process of creating visual representations of the interior of a body for clinical analysis and medical intervention, as well as visual representation of the function of specific organs, tissues or cells. The choice for a specific imaging technique depends on the medical research question.

Modern imaging technologies, e. g. advanced light microscopy (ALM), MRI, PET, and spectroscopic imaging can be used to study biological functions in contexts of physiological and pathological conditions all the way up from single molecules and single cells to whole-body imaging of animals and humans. These new approaches in biomedical and life sciences require technically and logistically demanding screening facilities that provide appropriate cutting-edge methods and databases. Access to bioimaging facilities is nowadays essential in biomedical sciences, due to the rapid advancement of imaging methods, the development of novel high resolution techniques and the increasing requirement of expertise in technologies and data management.

Biological and molecular imaging methods enable the visualisation of biological processes, and the combination with functional analyses can reveal physiological and pathophysiological mechanisms in living cells in real-time and at high spatial resolution. Compared to so-called "omics" technologies like genomics, proteomics and metabolomics, these functional imaging approaches more accurately reflect the dynamics, interactions, and status of a particular molecule in its natural environment over time. Therefore, they can contribute to the identification and validation of biomarkers and to the diagnosis of various disease states, including neurological disorders, infectious diseases and cancer. The interdisciplinary collaboration of basic, translational, and clinical researchers using a common imaging infrastructure in research and healthcare affords prompt translation of basic biological discoveries in cells into animal models of human disease and clinical application.

Microscopy

Microscopy is the technical field of using microscopes to view objects and areas of objects that are not within the resolution range of the human eye. There are three well-known branches of microscopy: optical, electron, and scanning probe microscopy. Optical and electron microscopy involve the diffraction, reflection, or refraction of electromagnetic radiation/electron beams interacting with the specimen, and the collection of the scattered radiation or another signal in order to create an image. Scanning probe microscopy involves the interaction of a scanning probe with the surface of the object of interest. The development of microscopy revolutionised biology, gave rise to the field of histology and is an essential technique in the life and physical sciences.

Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lenses to allow a magnified view of the sample. The resulting image can be detected directly by the eye, imaged on a photographic plate or captured digitally. The single lens with its attachments, or the system of lenses and imaging equipment, along with the appropriate lighting equipment, sample stage and support, makes up the basic light microscope. The development of super-resolved fluorescence microscopy allowed optical microscopy to get into the nanodimension.

Electron microscopy works with microscopes that use a beam of accelerated electrons as a source of illumination. As the wavelength of an electron can be up to 100,000 times shorter than that of visible light photons, the electron microscope has a higher resolving power than a light microscope and can reveal the structure of smaller objects. Electron microscopes are used to investigate the ultrastructure of a wide range of biological and inorganic specimens including microorganisms, large molecules and biopsy samples.

Scanning probe microscopy (SPM) is a branch of microscopy that forms images of surfaces using a physical probe that scans the specimen. SPM was founded with the invention of the scanning tunneling microscope, an instrument for imaging surfaces at the atomic level.

Macroscopy

On the macroscopic scale, objects or phenomena are large enough to be visible practically with the naked eye without magnifying devices. The most frequently used macroscopic imaging techniques are ultrasound, x-ray and nuclear diagnostic as well as endoscopy, MRI and computer tomography.

Medical ultrasound (also known as diagnostic sonography or ultrasonography) is a diagnostic imaging technique. It is used to see internal body structures such as tendons, muscles, joints, vessels and internal organs. Its aim is often to find a source of a disease or to exclude any pathology. Ultrasonic images also known as sonograms are made by sending pulses of ultrasound into tissue using a probe. The sound echoes off the tissue; with different tissues reflecting varying degrees of sound. These echoes are recorded and displayed as an image.

X-ray is an imaging technique where the rays are projected through the body onto a detector. The image is formed based on which rays pass through (and are detected) versus those that are absorbed or scattered in the patient (and thus are not detected).

Nuclear medicine is a medical specialty involving the application of radioactive substances in the diagnosis and treatment of disease. It records radiation emitting from within the body. Radiopharmaceuticals are taken internally. Then, external detectors capture and form images from the radiation emitted by the radiopharmaceuticals. Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) scans are the two most common imaging modalities in nuclear medicine.

Endoscopy uses an instrument, called endoscope to examine the interior of a hollow organ or cavity of the body. Unlike most other medical imaging techniques, endoscopes are inserted directly into the organ.

Magnetic Resonance Imaging (MRI) is a medical imaging technique used to image the anatomy and the physiological processes of the body in both health and disease. MRI scanners use strong magnetic fields, radio waves, and field gradients to form images of the body. Most MRI scans essentially map the location of water and fat in the body.

A computed tomography (CT) scan makes use of computer-processed combinations of many X-ray images taken from different angles to produce cross-sectional (tomographic) images (virtual "slices") of specific areas of a scanned object. A three-dimensional image of the inside of the object from a large series of two-dimensional radiographic images taken around a single axis of rotation is generated.

Biophotonics

Biophotonics can be described as "the development and application of optical techniques, particularly imaging, to the study of biological molecules, cells and tissue". |[114] The applications range from fundamental research in cell biology to a diagnostically approach in medicine. One of the main benefits of using optical techniques which make up biophotonics is that they preserve the integrity of the biological cells being examined. Biophotonics can be used to study biological materials or materials with properties similar to biological material, i. e. scattering material, on a microscopic or macroscopic scale. Biophotonics are featuring multidisciplinary approaches to research in the life sciences. Infection research will be developed as a field of application for photonics. In this way the use and combination of photonic technologies represents a significant and cross-disciplinary way to increase diagnostic and therapeutic approaches of infectious diseases.

III.1.b Important existing research infrastructures in the field of biomedical imaging

In view of the steadily increasing demands for the use of these technologies by biomedical sciences, there is a need for research infrastructures to provide access to high-end instrumentation and to maximally leverage infrastructure investments. Appropriate e-infrastructures for handling and storing vast

|[114] King's College London Centre for Biophotonics.

amounts of data are an essential part of research infrastructures in biomedical sciences. A list of important research infrastructures competing with and complementary to the RIs related to the bioimaging/biomedical field of research that is in the focus of this Roadmap Process is included in the appendix. Some complementary RIs, relevant for all research infrastructures having applied in the National Roadmap Process are already named here:

BioMedBridges

BioMedBridges is a joint effort of twelve biomedical sciences research infrastructures on the ESFRI roadmap. Together, the project partners develop the shared e-infrastructure – the technical bridges – to allow data integration in the biological, medical, translational and clinical domains and thus strengthen biomedical resources in Europe. |[115]

EU-Openscreen

The European Infrastructure of Open Screening Platforms for Chemical Biology (EU-OPENSCREEN) is a distributed RI that aims to develop novel small chemical compounds which elicit specific biological responses on organisms, cells or cellular components. EU-OPENSCREEN enables scientists to use compound screening methods to validate novel therapeutic targets and also support basic mechanistic studies addressing fundamental questions in cellular physiology (across human, animal and plant systems) using the methods of chemical biology. |[116]

Janelia Advanced Imaging Center (AIC)

AIC aims at making imaging technologies developed at Janelia widely accessible, and at no cost, to scientists before the instruments are commercially available. Operating strategically at the interface of engineering and biological applications, the AIC is positioned to reduce the time between instrument development and widespread use in the increasingly technology-intensive field of biology. |[117]

Euro-BioImaging

The European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences (Euro-BioImaging, EuBI) will provide open physical user access to a broad range of state-of-the-art technologies in biological and

|115 BiomedBridges Building data bridges from biology to medicine in Europe. http://www.biomedbridges.eu/, last accessed on 09/02/2017.

116 ESFRI Strategy Report on Research Infrastructures, Roadmap 2016. https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/esfri_roadmap_2016_full.pdf, last accessed on 09/02/2017.

|117 https://www.janelia.org/, last accessed on 09/02/2017.

medical imaging for life scientists in Europe and beyond. It will offer image data support and training for infrastructure users and providers and continuously evaluate and include new imaging technologies to ensure cutting-edge services in a sustainable manner. The EuBI will consist of a set of complementary, strongly interlinked and geographically distributed nodes – specialised imaging facilities – to reach European scientists in all member states. The infrastructure will be empowered by a strong supporting and coordinating entity, the EuBI hub. The hub will provide the virtual access entry point from which users will be directed to their desired imaging technology as served by the respective EuBI nodes. Within the hub, dedicated data management and training activities tailored to the needs of users of the imaging infrastructure will be coordinated. |[118]

III.1.c Research infrastructure concepts in the field of biomedical sciences

Currently there are four research infrastructure concepts in the National Roadmap Process which are related to the research area and the named research infrastructures.

The **German BioImaging Research Infrastructure (GerBI-RI)** is a distributed research infrastructure for biological imaging. The five imaging nodes are supposed to provide access to the newest technical advances in biological imaging on a microscopic level in Advanced Light Microscopy Core Facilities (ALM-CF), before they become commercially available. The fundamental idea is to bring together excellent developers of instrumentation and methods of biological imaging technologies with application-oriented scientists from the life and biomedical sciences and grant the latter access to unique equipment and expertise. For a list of competing and complementary infrastructures in materials research such as synchrotrons see D.III.2.e.

The **Leibniz Center for Photonics in Infection Research (LPI)** aims at establishing a user-oriented open centre for photonics and optics for the development of fundamentally new solutions for the diagnosis, monitoring and experimental treatment of infections as well as at transferring these solutions into routine applications. According to the proposal, LPI's central approach is the pursuit of innovative photonics-based diagnostic and treatment methods to tackle infectious diseases. The applicant intends to implement novel diagnostic technology and treatment approaches along the entire innovation pipeline from the idea to the validated method in a single research infrastructure. For a list of competing and complementary infrastructures in materials research such as synchrotrons see D.III.3.e.

|[118] ESFRI Strategy Report on Research Infrastructures, Roadmap 2016. https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/esfri_roadmap_2016_full.pdf, last accessed on 09/02/2017.

The **National Biomedical Imaging Facility (NIF)** plans to house important diagnostic imaging technologies such as Magnetic Resonance Imaging (MRI), PET, Magnetoencephalography (MEG), EEG and hybrid imaging technology (hybrid MR-PET). NIF aims to establish the world's first human 14 T scanner. Nine research infrastructures for biomedical imaging exist, e. g. 10.5 T whole-body system at the University of Minnesota, and four are currently under construction, e. g. 11.7 T whole-body system at NeuroSpin research facility in Paris. For a list of competing and complementary infrastructures in materials research such as synchrotrons see D.III.4.e.

The **National Imaging Science Center (NISC)** wants to integrate microscopic technologies with macroscopic imaging modalities under one roof. NISC will unite experts from different fields of imaging sciences and integrate imaging modalities that yield complementary information with different time and spatial scales. For a list of competing and complementary infrastructures in materials research such as synchrotrons see D.III.5.e.

III.2 German BioImaging Research Infrastructure (GerBI-RI)

III.2.a Scientific potential

Description

Imaging technologies are nowadays essential for understanding the basic principles of disease and to test new therapies in model systems before applying them to patients. State-of-the-art imaging is key to unravelling the underlying complex spatiotemporal dynamics of cellular processes. In fact, light microscopy enables researchers to observe how cells in an intact organism grow, divide and react to environmental stimuli. In combination with electron microscopic techniques, advanced light microscopy (ALM) makes it possible to study these processes within the structural context of the cell and to correlate them to the architecture and location of single proteins and protein complexes.

GerBI-RI wants to offer pioneering biological imaging technologies and integrate them into a functional, user-oriented platform which will act as a national resource for research in life sciences and biomedicine. The RI aims to provide the structural, operative and technical pre-requisites necessary to achieve this goal. Through GerBI-RI scientists from Germany and abroad will access novel microscopes at an early stage of development, well before they become commercially available. Insights and knowledge acquired in the RI can in turn inform instrument development and contribute to its further optimisation and thus promote the innovation process.

The infrastructure will be set up in direct collaboration with developers of optical technologies. Its aim is to give developers the possibility to provide a larger group of users from life sciences and biomedicine with access to their latest instruments in appropriately equipped ALM core facilities (CFs). This early exposure to a broad spectrum of applications will quickly reveal which methods are best suited for a particular application. By keeping close contact and exchanging information with industrial manufacturers this approach will in turn contribute to streamlining the realisation of commercial microscopes that are specifically tailored to the users' needs.

According to the proposal, GerBI-RI will take up one of the main challenges of future imaging technology – handling, analysing and quantifying vast amounts of imaging data. Existing capacities and expertise available at the different nodes will be consolidated into an overarching 'virtual' node. Thus, the entire scientific community will have access to the latest algorithms and software developments for imaging by a central online portal.

The concept of GerBI-RI is based on the model of the renowned Janelia Advanced Imaging Center (AIC) |[119] of the Howard Hughes Medical Institute in the USA and will be unique in Europe. The RI complementary to GerBI-RI on the European level is called Euro-BioImaging (EuBI). In December 2015 a similar, world-wide project was started, Global BioImaging. It is financed by "Horizon 2020" and will lead to further collaborations between EuBI and imaging infrastructures in Australia, Argentina, South Africa, India, Japan and the US. A cooperation of GerBI-RI with other national RIs is envisaged with EU-OPENSCREEN, an infrastructure for the systematic testing of chemical compounds with regard to their biological activity. In addition, synergies between GerBI-RI and the planned Leibniz Center for Photonics in Infection Research (LPI) are expected.

Assessment

The planned RI in the field of biomedical imaging is of high strategic importance and relevance for both Germany and Europe and is very timely.

The RI is distributed in terms of imaging technologies and locations. The concept allows the RI to react fast to changing requirements in the field of biological imaging by the inclusion/exclusion of technologies in the future and minimises the risk of underperforming nodes.

Today most core facilities cannot provide state-of-the-art methods before they become commercially available. The RI will enable close collaboration between developers of advanced imaging technologies and researchers that use them to answer important biological and biomedical questions. Bringing new and ad-

|[119] https://www.janelia.org, last accessed on 09/02/2017.

vanced imaging technologies to biology is of utmost importance for the advancement of the biosciences and is expected to lead to significant new technological innovations and to help brain-gain, especially of starting applicants who may have limited access to infrastructure.

The RI has wide-spread support from the German biological imaging community as well as from industry partners and embarks on strong commitment of the participating institutions and the willingness of developers, users and industrial partners to collaborate in the frame of GerBI-RI.

Operation of the various RI components has been carefully planned. The RI will create nodes centred at institutions that have proven expertise in developing and operating new imaging technologies. All five nodes and the hub with a virtual node are geographically distributed over Germany and have well-established international links. Established ALM-CFs add the infrastructure and expertise to support the needs of users, i. e. from the biological field. The structure of the RI is capable for self-organising, namely to have the possibility to establish new links thanks to the close contact between nodes, including contacts of the software engineers with the scientists developing and operating the microscopes. The aim of the RI, to provide access as soon as possible to as many applicants as possible while constantly revising needs based on use, is considered a strength.

Modes of operation of GerBI-RI are flexible and adaptive to provide timely change of technologies in response to the appearance of new technologies and corresponding hardware and software.

There is no similar approach, world-wide, with ambitious goals as outlined by the authors. GerBI-RI takes the successful concept of the AIC to the next level in Germany by building a decentralised network of research nodes that mimic the AIC approach.

Funding GerBI-RI is expected to facilitate the participation of Germany to Euro-BioImaging. Implementation of the RI will be significantly facilitated by prior experience from the participating institutions both through the German Euro-BioImaging (GEBI) |[120] proposal and through Euro-BioImaging.

|[120] German Euro-BioImaging – GEBI (German Research Infrastructure for Imaging Technologies in Biology and Medical Sciences) is a proposal submitted in the pilot phase of the National Roadmap Process. http://www.wissenschaftsrat.de/download/archiv/2841-13_engl.pdf, last accessed on 09/02/2016.

Description

According to an estimate of the proposers, about 5,500 scientists per year will be interested in using the services offered by GerBI-RI. The proportion of international users for these commercial imaging technologies amounts to about 20–30 %. One of the software platforms which is to be offered as a cloud-based service as part of GerBI-RI has 25,000 active users worldwide already. The majority of the users of imaging core facilities (CF) will presumably belong to the life and biomedical sciences and will mainly come from both universities and German research organisations. In future, GerBI-RI expects to increasingly attract users from industry.

Access to the imaging technologies provided at the individual GerBI-RI nodes will be organised in a transparent process coordinated by the central hub at the University of Konstanz. The access concept will be in line with the guidelines drawn up in the frame of ESFRI Projects, especially by EuBI. Following the example of the AIC there are also plans to start a fund for providing fellowships for users of GerBI-RI. Fellowships will be awarded upon application and depending on the scientific quality of the projects.

According to the proposal, a well-defined data management concept for experimental raw data and the development of a central, user-friendly access portal for image analysis are supposed to be main components of GerBI-RI. Data storage is to be set up as a hybrid system in which raw data is kept at the generating node until publication. Thereafter, reference data sets will be stored in a central database, where they will be accessible to the scientific community under the terms of the access control regulations as outlined in the proposal. To warrant the qualitative and quantitative analysis of the ever increasing large amount of image data, GerBI-RI will bring together the competencies of the participating software developers in the virtual node. The GerBI-RI is committed to implementing an open access strategy.

The quality of the hub and nodes will be appraised on a regular basis. The governance will rule how new members are integrated and how existing ones can be excluded. The scientific advisory board will continuously advise the GerBI-RI board. GerBI-RI users have to commit themselves to complying with the "rule of good scientific practice" released by the DFG.

Assessment

The users are expected to be from the fields of life sciences, fundamental medicine, photonics, biophotonics and nanobiophotonics at universities and research institutions across Germany and abroad. Another group of users should come from companies, especially small start-up companies. The estimate of around 5,000 potential users provided by the applicants is conservative and would far surpass the RI's capacity. The RI's strong training and data analysis components (virtual hub) are likely to be able to accommodate an even larger number of users. Still, the number of users will also depend on the ease of access to the node's infrastructure, the pricing model, and the type of available technologies. User orientation of this RI is considered a strength.

All aspects of management and service, such as transparency and adequacy of the conditions for access, centralised application process, scientific merit-based allocation of research slots, supporting facilities to prepare samples at the site of a node, accessibility, quality assurance, data storage and analysis, responsibilities, suitability of the conditions for access for creating the best possible research conditions, training services for users, opportunities for user participation in the subsequent development of the RI, and legal conditions, are well addressed by the applicants. The RI's strong training component with dedicated training events organised by the hub is a strength. Inclusion of new users as the RI develops is inherent in the access scheme. It will be important to keep the barrier of entrance as low as possible, ensuring low user fees and adequate user support from national and international funding schemes. The applicants are well aware of this challenge and have appropriate plans to address it.

The RI addresses the challenges of large data sets, their communal mining, and data stewardship requirements in an exemplary manner through close collaborations with German and European infrastructure projects. The data concept is well appropriate for state-of-the-art imaging technologies that produce enormous amounts of data. The dedicated virtual node for data storage, handling and analysis, including a central, user-friendly access portal for image analysis is a strong point of the application. The plan to integrate developers of widely used open-source software (Fiji, ilastik, KNIME) as the centre of the Virtual Software Node is well thought out and is likely to have a large impact in the bioimaging community, even independently of the other RI components. The issues of data protection and security, training services for professional data management, sustainable utilisation and reuse of data, and open data strategy are adequately addressed. The RI will set-up long-term storage (minimum ten years) of published data at the central hub. The goal to work towards standards for required metadata is well appreciated.

The processes for project evaluation, resource allocation, and governance are transparent, democratic and follow the standards set by the DFG and similar entities to ensure high ethical standards. All parties of the project are well experienced and educated to provide a high level of integrity, including the adequacy of the measures envisaged to ensure the quality, ethics, and good scientific practice in the work with research data and publications.

Description

GerBI-RI's responsible institutions have the necessary technical and personnel capacities for implementing the RI. According to the proposal, there are no technical obstacles or risks that may interfere with the cooperation between the developer teams and ALM-CFs as planned. During implementation, a pilot phase is planned to gain experiences from still limited utilisation and incorporate them in the implementation process.

During the planning of the GerBI-RI, all stakeholder groups, especially the heads of CFs and microscopy researchers, were involved. From a scientific point of view, the most important objective of GerBI-RI governance is to ensure that all participating institutions and universities can contribute their scientific expertise according to their respective qualifications. Participation in decision-making and cooperation are key elements.

The management structure will be divided into three levels. The uppermost level will consist of the general assembly, in which all institutes and universities belonging to GerBI-RI are represented. They will be responsible for defining the statutes, rules and norms within GerBI-RI and elect members of the supervisory board, the GerBI-RI board, among its members. The board will be composed of one scientist for each node and the hub, respectively. The supervisory board is supposed to appoint, advise and supervise the management, which executes the GerBI-RI operations. The management will be based at the hub. The legal form of GerBI-RI will be probably a non-profit GmbH |[121]. The management will be supported by a scientific and an economic advisory board.

At all sites comprehensive administrative and organisational expertise is supposed to be available for establishing and operating the RI. Each node will nominate a responsible scientist and a contact person who will coordinate the collaboration between the participating research groups and the imaging CFs thus enabling high-level and efficient services at the respective sites in accordance with the goals of the GerBI-RI. All responsible institutions have declared their intent to provide personnel resources and have tried-and-tested processes for recruiting competent staff and for personnel development in place. The University of Konstanz as hub-hosting institution and coordinating institution of German BioImaging has longstanding experience in the quality assurance of the qualification of young scientists and will develop a programme specifically tailored to the needs of the scientists working in the GerBI-RI.

|[121] Company with limited liability.

Implementing the technologies carries a very low risk, because all involved institutions have the essential components of technologies, a proven track record in developing cutting-edge optical equipment and qualified personnel to implement planned infrastructure, excellent experience of cooperation between the teams and good expertise in ethical and legal problems. Used equipment and technologies do not carry environmental risks. The allocation of modalities to nodes with prior relevant experience ensures that the implementation is likely to proceed as planned. Technical modalities are independent, over 30 individual microscopes will be set-up, therefore delays or even failure in any of the modalities is highly unlikely to impact implementation of the RI. Constant re-evaluation of modalities based on pilot use feedback is embedded in the project.

The evaluation from industry about the potential for technology transfer and impact fostered by the proposed RI is critical. At a minimum, the anticipated collaborations can improve the mutual understanding and information exchange and help the RI to develop approaches with even greater impact. However, some similar initiatives failed because of lack of alignment between industrial and basic science partners. Specific use estimates from industrial partners backed by financial commitments might help the alignment process.

The participating institutions have a strong interest and commitment in the endeavour, and considerable experience in managing similar projects as well as providing access to institutional facilities. A hub and nodes structure permitting close collaboration of the distributed RI is well-thought out and very suitable. The RI will take advantage of the established infrastructure of its nodes to ensure a proper operation of the RI. The institutional requirements related to embedding of the RI in the strategy of all 18 involved institutions, as well as suitability and adequacy of the project management in all phases of operation are clearly shown in the project. There is a clear governance plan in place, which is solid, feasible and adequate for a decentralised RI.

The GerBI-RI personnel concept for the development, implementation and operation is adequate. The participating institutions have highly qualified staff, both from the life sciences and the engineering/informatics fields for implementation. In addition, new positions are planned in each of the individual nodes. The participating institutions are experienced with management and administration issues relevant to RI development, access and training. The plans on career development for the staff of the nodes including science-supporting staff are well developed and could serve as an example for other areas.

GerBI-RI builds on years of experience from the participating institutes, as well as highly relevant experience from GEBI and Euro-BioImaging, where participants are key stakeholders, and embarks on existing core facilities in bioimaging as entry points for the nodes. All five nodes agreed on how to distribute and assign the technologies they are offering, on a joint strategy to develop new algorithms and software tools for image processing, as well as on a joint financing concept, which involves facilities of responsible institutions and their clusters.

III.2.d Relevance to Germany as a location of science and research

Description

Biophotonics is seen as a promising, future-oriented area of research and a driving force of health technologies. This research area is key for maintaining the innovation potential of the world-class German optics industry. Therefore, gaining and keeping a leading role in biophotonics is seen as a crucial factor for Germany's economic success. GerBI-RI wants to act as an incubator and strong promoter of new ideas in biological imaging and can thus further strengthen Germany's research focus on biophotonics.

GerBI-RI wants to close an important gap in Europe's national imaging infrastructures. According to the proposal, its implementation is a prerequisite for Germany's participation in the ESFRI Project EuBI, which is seen as key to implementation and long-term success of the European RI.

GerBI-RI is supposed to attract international, especially European, scientists. Young academics will be offered extensive facilities enabling them to carry out independent projects and try out new ideas with the help of experts.

The Konstanz hub will regard the transfer of research findings to industry and business, to politics and society as one of its central missions. By establishing the TTC, the GerBI-RI hub will enable close collaborations between developing manufacturers and application-oriented scientists in which users are involved early on in development processes. Transfer to the public is pushed by regional events, press releases and cooperations with schools.

Assessment

The biological imaging community is struggling world-wide with the gap between developers of technology and biological oriented users, thus the RI will be followed with high anticipation. Germany has a long tradition and a strong place as an academic and industrial stake-holder in the fields of optics and advanced microscopy. The collaborations, the RI enables will produce highly relevant scientific results published in high impact journals and thus will significantly strengthen Germany's visibility and competitiveness in this field. It will also permit participation in the relevant initiatives at the European level, where German-based institutions now have a leading role. The planned inclusion of commercial prototypes into the instrumentation pool, offers German manufactures an international platform to highlight their expertise and products.

Access to novel imaging methodologies is essential for successful biological research projects and is likely to attract especially young principal investigators. The proposed RI would be a bonus when considering a scientific career in Germany. The GerBI-RI will be an attractive internationally recognised infrastructure in the medium and long-term perspective.

German industry has a leading role in the field of optics and bio-imaging (both large and small companies). Fast commercialisation of new technologies is a central aim of the RI. A dedicated TTC will be established in the hub at Konstanz, where companies will have the possibility to show-case their prototypes and receive feedback from the scientific community. GerBI-RI is expected to boost biomedical research and facilitate industrial developments in the bioimaging field, and is therefore expected to have both societal and economic impact.

III.2.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
Existing research infrastructures			
AIC – Advanced Imaging Center (complementary)	AIC aims at making imaging technologies developed at Janelia widely accessible, and at no cost, to scientists before the instruments are commercially available. Operating strategically at the interface of engineering and biological applications, the AIC is positioned to reduce the time between instrument development and widespread use in the increasingly technology-intensive field of biology. https://www.janelia.org/, last accessed 29 July 2016	2006	Ashburn; US
GBI – Global BioImaging Project (complementary)	GBI is built on three existing collaboration agreements for successful operation of imaging infrastructures, which EuBI has signed with the Australian Microscopy and Microanalysis Research Facility (AMMRF), the National Imaging Facility (Australia) and India-BioImaging already during Preparatory Phase I. The Global BioImaging Project enables Euro-BioImaging, the research infrastructure for access to biological and medical imaging technologies on the ESFRI roadmap, to work together with its international counterparts, enabling EuBI and its international partners to work on concrete services, such as setting-up a virtual platform for training in imaging technologies and a repository for image data tools, to be used by researchers around the	2015–2018	AU, AR, ZA, IN, JP, US

	world. Imaging facility staff is invited to participate to the facility exchange programme, to visit facilities at partner institutes for exchange of experience and best practice on all topics related to imaging infrastructure operation. Through its activities, GBI aims at sustainably providing services in imaging technologies to the international scientific community. http://www.eurobioimaging.eu, last accessed 29 July 2016		
BioMedBridges (complementary)	BioMedBridges aims at forming a cluster of the emerging biomedical sciences research infrastructures (BMS RIs) and construct the data and service bridges needed to connect them. The BMS RIs are on the ESFRI roadmap. Their missions stretch from structural biology of specific biomolecules to clinical trials involving thousands of human patients. Most serve a specific part of the vast biological and medical research community, estimated to be at least two million scientists in Europe across more than 1,000 institutions from more than 36 ESFRI Member States and Associated Countries. BioMedBridges builds a shared data culture in the life sciences by linking up 12 of Europe's new biological, biomedical and environmental research infrastructure. Integrating the vast data resources in the life sciences, including data from genomics, biological and medical imaging, structural biology, mouse disease models, clinical trials, highly contagious agents and chemical biology, shall enable new ways of analysing them to answer new, more complex scientific questions. http://www.biomedbridges.eua, last accessed 29 July 2016 http://www.biomedbridges.eu/, last accessed 25 August 2016	2012	AT, BE, BG, CZ, DE, ES, FN, FR, HU, IL, IT, NL, NO, PL, PT, SL, UK
NBIPI – Irish National Biophotonics Imaging Platform	NBIPI consists of a consortium of imaging and biophotonics laboratories from across the Universities and Institutes of Technology in Ireland, three EU partners and one associated international partner. It aims at providing a structured research and training framework for Ireland's investment in advanced imaging applied to the Life Sciences, at catalysing and support internationally competitive research grant applications, at developing and supporting Post-graduate Training Programmes underpinned by biophotonics and imaging and at bridging the Physical and Life Sciences interface. Furthermore it aims at providing a National Access for Core Facilities in Molecular, Cellular, Small Animal and Human Research Imaging and at providing the administrative and scientific infrastructure for Ireland's participation in large-scale international research programmes. http://www.nbipireland.ie, last accessed 26 August 2016	2007	IE, CNRS Montpellier; FR, CNR Institute of Biostructure and Bioimaging; IT, Nordic Imaging Network.

Planned research infrastructures/under construction			
EuBI – Euro-BioImaging (complementary)	EuBI aims at providing open physical user access to a broad range of technologies in biological and biomedical imaging for life scientists. In addition, EuBI plans to offer image data support and training for infrastructure users and providers. EuBI currently counts 28 EuBI Node Candidates offering open access to 36 imaging technologies for biological and biomedical imaging. EuBI has been listed on the ESFRI Roadmap since 2008. http://www.eurobioimaging.eu, last accessed 1 September 2016 www.eurobioimaging-interim.eu, last accessed 29 September 2016	Start of interim operation in 2016. Official launch foreseen to take place in 2017	AT, BE, BG, CH, CZ, DE, DK, ES, FI, FR, GR, HR, IE, IT, IL, LU, NL, NO, PL, SK, UK
EU-OPENSCREEN – The European Infrastructure of Open Screening Platforms for Chemical Biology (complementary)	EU-OPENSCREEN aims at building a sustainable European infrastructure for Chemical Biology, supporting life science research and its translation to medicine, agriculture, bioindustries and society. It is a distributed research infrastructure which builds on national networks in 16 European countries. It aims at embracing local research groups and facilitates transnational open access to the most advanced technologies, chemical and biological resources, knowledge and expertise throughout Europe. EU-OPENSCREEN is likely to be established as a European Research Infrastructure Consortium (ERIC). It will comprise high-throughput screening (HTS) centres at different sites in Europe with their special HTS and bio-assay expertise, chemical resources for optimisation of first hit compounds, bio- and chem-informatics capacities, and a publicly-accessible database (the ECBD) combining screening results, assay protocols, and chemical information. A large collection of diverse compounds, representing the chemical knowledge in Europe, will be made available from a central storage facility. http://eu-openscreen.eu, last accessed 17 October 2016	Start of preparatory phase in 2010. Expected start of operation in 2018	AT, BE, CZ, DK, FI, FR, DE, GR, HU, IT, NL, NO, PL, RO, ES, SE
LPI – Leibniz Center for Photonics in Infection Research (complementary)	For detailed information please see the concept proposal of LPI.	Utilisation phase: 2024–2033	Jena, DE

III.3.a Scientific potential

Description

According to the proposal photonic technologies have demonstrated their potential in providing sustainable solutions to pressing problems in the field of infectious disease diagnostics in recent years.

LPI plans to establish a globally unique spectroscopic imaging technology platform of high spatial and temporal resolutions, novel multimodal imaging technologies in the spectral range from the XUV to the far infrared (FIR) and photonic molecular biological point-of-care technologies that will allow the diagnosis, and treatment of difficult-to-treat infections and infections associated with immunosuppression and defined comorbidities.

As a user-oriented technology platform, LPI will offer a full range of photonic technologies for the diagnosis, monitoring, and experimental treatment of infections. The user should be accompanied in the development of new diagnostics and new therapeutic and monitoring solutions for infectious diseases along the entire path from the initial scientific/medical question to the technological solution to the implementation of a product or experimental treatment together with industrial partners. LPI aims to support users by setting up the following three research platforms:

_ An LPI-specific spectroscopic and imaging platform from the XUV to the far infrared FIR spectral range with high spatial and temporal resolution for basic infectiology research for new diagnostic and therapeutic approaches.

_ A diagnostic services pipeline supports users in the implementation and validation of novel spectral-optical and chip-based diagnostic and monitoring procedures. Through clearly-defined points of transfer between technological development and validation, as well as during the implementation of peripheral studies, the timeframe of development and content of the medical project can be optimised.

_ A therapeutic services pipeline that addresses the implementation and validation of therapeutic solutions and experimental treatment. Based on the medical needs of the patient, a therapeutic approach (e. g. with anti-infectives or immunotherapeutics) and accompanying diagnostics (companion diagnostics) will be compiled with the involvement of clinicians.

At LPI biophotonic and infection biology research groups will gain access to infectiological animal and cell models, appropriate verification and validation options in form of real and comprehensive clinical patient samples in a suitable safety lab environment, and support and guidance in research projects to activate and control application orientation in a sustainable network in a targeted manner.

As the authors of the proposal have pointed out, LPI is unique in its combination of infection research and photonic technologies and complements existing facilities. Research infrastructures in this area usually focus on either the technological or on the medical aspect. One example of an infrastructure with a technological focus is "Euro-BioImaging", as a distributed research infrastructure. The research infrastructure "BioMed-Bridges" links biomedical infrastructures. Moreover there are research infrastructures that – due to their translational orientation – are of a more competitive nature including BIOMEDREG |[122] and Infectious Disease Models and Innovative Therapies (IDMIT). Furthermore the Leibniz Institute for Molecular Pharmacology (FMP) is also home to light microscopic imaging techniques. Collaboration between LPI and the planned German BioImaging Research Infrastructure (GerBI-RI) is being considered, in particular, for, when LPI is at full capacity. Training resources for complex imaging methods are available for joint use at both institutes. According to the proposal, the basic difference between LPI and existing research infrastructures is that LPI will be a centre for the application of photonic technologies in diagnosis, monitoring, and therapy in the highly regulated clinical environment. This approach is described as unique in infection research and complements the existing facilities.

Assessment

Infectious diseases are one of the main challenges in the clinic, mostly because precise diagnosis comes too late for targeted therapy. The biophotonic core of this proposal represents the most appropriate approach to diagnose infectious diseases and to monitor therapy response at an early state. The approach is strategically important and relevant to the current situation. The applicants of the LPI proposal have a very strong technological background in vibrational spectroscopy as well as in the field of infectious diseases. The merging of both fields in this proposal is outstanding. The proposal addresses current needs in the diagnosis and treatment of infectious diseases with an excellent research plan. The LPI concept is able to revolutionise pathogen diagnostics worldwide. The key questions are inventive. The emphasis to tackle the problem by focusing on optical techniques is unique and has not occurred so far in an orchestrated fashion in a clinical environment. The potential for novel technology, novel sensing and novel lead compounds is enormous. The researchers and institutions involved are experienced in protecting the novelties to be created. LPI provides an innovative strategy with many advantages for research in in-

| [122] Biomedicine for Regional Development and Human Resources.

fectious diseases. It proposes an entirely new concept using optical methods, with emphasis on vibrational spectroscopy for ultra-rapid detection and identification of pathogens from body fluids, followed by direct antibiotic susceptibility testing. This is scientifically solid and presents exciting prospects.

The photonic platforms within the LPI can be applied flexibly to different research and diagnostic projects involving different pathogens. The technology can also be applied in the future to cancer, veterinary medicine and food safety aspects. Technology scouts will identify technical innovations from the beginning on. The LPI will be able to quickly adjust its research focus to the needs of scientific projects.

There seems to be no competitor that focuses on biophotonics to target infectious diseases. The applicants have an excellent network with other existing research infrastructures. They will exploit photonics systematically for purposes of the LPI concept.

III.3.b Utilisation

Description

The expected user groups at LPI will primarily comprise scientists from the fields of infectiology, photonics, medicine, biology and chemistry. In addition, LPI will attract users from the academic sector and the industry working in the technological research and development in the area of diagnostics/ monitoring. Research groups either approach LPI on their own ("technology push") or are identified by LPI's technology scouts and motivated to carry out their research activities at LPI ("technology pull").

The LPI infrastructure is available for cross-disciplinary and international research. Individual services can be accessed by both academic and industrial users. The assessment of user requests is carried out by a peer review committee appointed by the science advisory board.

The aim of LPI's data management concept is to eliminate access barriers to data that is often filed in different places and in different formats, wherever possible and to optimise open access to data to improve scientific use. Therefore, LPI will be equipped with data infrastructure in the form of a database and materials registry. Initially data centres will be established at the participating institutions that already successfully produce larger data sets in LPI's research area. In the long run a data service centre will be developed to register and map all research data with relevance for the field of infectiology. An internet-based access portal, an LPI open data HUB, documents the rules of access and use of LPI data/material available under the responsibility of LPI. LPI's data management concept is designed such that data sharing is combined with user and methodology training.

Access to the technological and scientific resources of LPI's infrastructure will primarily be provided based on the scientific quality of the submitted projects and evaluated by a peer review committee.

Together with LPI's management, a board of scientific users (LPI user assembly) will be set up to ensure the continual maintenance and development of LPI's excellent research infrastructure. An LPI-specific Code of Conduct will be further developed and continuously revised over the course of the establishment of projects based on the specific data implications. In particular, ethical issues on data utilisation in the area of health technology will be fundamentally discussed by LPI with specialised partners.

Assessment

The expected user groups come from national and international academia and industry. There are many potential users, because infectiology is an interdisciplinary task in many aspects of clinical medicine. Furthermore, users can be expected from institutes with diagnostic expertise in microbiology, virology, parasitology, mycology, and hygiene. The LPI has already established public private partnerships which are interested in pursuing diagnostic applications as well as developing interesting drug candidates from preclinical research into the therapeutics pipeline.

Access to LPI's resources is granted based on scientific excellence of the proposed projects by a peer review committee appointed by the supervisory board. The evaluation is based on defined key criteria ranging from scientific and technological quality of proposed implementation to impact. A clear application horizon will be crucial for selection. Thereby, the best cross-disciplinary projects will be selected to obtain access to the LPI platform and programmes.

The applicants defined a unique strategy of push and pull. The push refers to pushing the existing initiatives and new approach outwards. The pull refers to outwards looking by technology scouts to extend the network to all possible groups and studies relevant to the main theme. A user's assembly and regular events of evaluation should help to permanently develop and improve LPI's services and to guarantee best possible research conditions.

The data management concept of the LPI aims to create a user-friendly and research-optimised environment without unnecessary barriers. Furthermore, the aim is to eliminate access barriers wherever possible and to optimise an open data access for the benefit of improved scientific use.

LPI put in place various measures of solid quality management to protect the integrity of data. The applicants have developed a first concept of data utilisation and data management in the planning and design of the research project as well as in the data collection, analysis, backup, archiving, and yearly evaluation. In this way, the data and the resulting knowledge models will be functionally linked. The diversity of aspects related to data handling is well addressed.

Relating to the adherence to ethical standards and good scientific practice they clearly pay attention to the ethical standards. The criteria for the project selection will include the observation of ethical rules among others.

III.3.c Feasibility

Description

According to the proposal, the risk of implementation of LPI is considered to be low, because of the long-standing positive development of all partners and their continuous cooperation, which provide as a solid basis for the development of LPI and its three platforms. Existing photonic and clinical expertise as well as expertise in infection biology, makes it possible for solutions to achieve a higher degree of technological maturity and to provide a unique LPI-specific spectroscopic/imaging platform from XUV to FIR for infection research. For the implementation of the LPI structure and its projects, the applicants revert to a viable organisational and management structure, as well as on the process and communication skills.

LPI will be implemented by *LPI Aufbau GmbH* and *LPI Betriebs GmbH*. The purpose of *LPI Aufbau GmbH* is the construction of a scientific building and the establishment of the research infrastructure during the development and utilisation phase. The purpose of *LPI Betriebs GmbH* is to organise and conduct research projects and services as well as a range of educational programmes, in the area of photonics and infectious diseases.

Both the leading institutes and cooperating partners have technical expertise and a wide range of the latest biophotonic technologies, as well as diagnostic and treatment methods in infectiology at their fingertips. The key skills for the planning, implementation, and continuous operation of LPI's elements are largely in place at LPI's leading responsible institutions and the other central institutions. In the area of technical competence, the existing expertise will be complemented by close cooperation with device manufacturers and external consulting for infrastructure planning and procurement during the development phase. In the individual areas of expertise, intensive education and training of LPI personnel, as well as the interface staff of LPI's project partners, is planned.

Assessment

The LPI aims to implement a thoughtful planning of internal and external governance. The sections for scientific coordination and administrative coordination are well interrelated.

The breakdown of the proposed plan for implementation into different phases (3 years preliminary phase, 5 years development phase by *LPI Aufbau GmbH*, and utilisation phase by *LPI Betriebs GmbH*) is explained in great detail and is very reasonable and comprehensible. Thus, the Technology Readiness Level (TRL) is high (6–7).

The applicants have established fruitful scientific collaborations in Jena with scientists and clinicians at the clinics, the Hans Knöll Institute (HKI) and Jena University. The excellent collaboration of the participating institutions thus far and the existence of a broad base of experts help to reduce the risk of implementation. Adequate measures for risk reduction are already planned. They can be taken if required and will reduce the total implementation risk. The risk assessment for the different modules to be implemented in LPI is convincing.

The contributions of existing personnel are considered as very important for the proposal. All participating parties will have substantial input of resources into LPI. The mixture of positions for established and young researchers is acknowledged. The personnel development concept involves technology programmes, medical programmes, network programmes, scientific programmes and graduate programmes, which will be particularly valuable for young academics to bridge the gap between photonics and life sciences.

III.3.d Relevance to Germany as a location of science and research

Description

LPI unites scientific expertise in infection research and combines it with technological know-how in the field of optical technologies. It is assumed that LPI will have an impact on the research area of health technologies in general due to its existing links to external networks.

LPI aims to unite application-oriented basic research in photonics and infection biology with the clinical requirements in the field of infectious diseases. LPI brings requirement fields into focus as stipulated in the High Tech Strategy 2020, by the Federal Government of Germany |[123], and develops new photonic solutions at the intersections between different technology fields.

According to the proposal, LPI opens the structures that have grown in Jena for users from all over Germany and Europe. An instrument for this includes the technology scouts who are supposed to identify research groups all across Germany and beyond whose work can be purposefully integrated into LPI in

|[123] http://www.hightech-strategie.de/de/The-new-High-Tech-Strategy-390.php, last accessed on 09/02/2017.

the form of a "technology pull". With the help of this scouting process, LPI is supposed to be able to attain high national and international visibility. An important objective of LPI is the cross-disciplinary promotion of young researchers. In this context, a master's programme on medical photonics will be offered at University of Jena. "Optics and photonics" is like infection biology one of the priorities of the University of Jena, JUH and non-university research institutions. Therefore, there is a great demand for appropriately trained employees.

The leading responsible institutions perform active and diverse public relations. This topic will also have high priority at the LPI office. On the one hand, this is necessary in order to network at the national and European level with topically relevant organisations and regulatory agencies, as well as professional associations and industrial, consumer and patient organisations. On the other hand, position papers and statements on current or critical issues of medical technology will help to inform and advise politicians and decision makers in health care.

LPI builds on the structures of knowledge and technology transfer, as well as on the extensive scientific portfolio of University of Jena, JUH and LPI's partners. One key element of the transfer strategy is an innovation analysis, which includes a review and conceptual processing of exploitation possibilities.

Assessment

Via the photonic approach, the LPI proposal offers also a breakthrough and improved method for high-throughput screening of new antibiotic drugs. The connection of these already internationally visible institutions in one joint research centre will additionally increase the local, national and international visibility of photonic and infectious research significantly.

LPI will transfer the new developed methods and technologies into clinical practice. The concept of LPI, if successful, can be transferred to other fields of medical illnesses as a best practice model. LPI addressed issues (e. g. drug-resistant pathogens) will have an enormous societal impact. The economic impact may be similarly impressive, because the photonics technology holds the promise, in the optimal scenario, to replace most of the other techniques of pathogen identification and susceptibility testing. The impact could be a worldwide improvement of diagnostics as well as the prospect of a new anti-infective pipeline, both of which are urgently needed with the rise in multidrug-resistant bacteria. LPI builds on the structure of knowledge and technology transfer, as well as on the extensive scientific portfolio of the university/medical center in Jena, and of the LPI's partners.

LPI will be very attractive to young and established scientists, but clinicians as well. The master's programme medical photonics in 2016/2017 as well as the

MD/PhD [124] programmes will attract young students and scientists. Long term impact is secured by creating an attractive environment and education stream to young researchers. The approach is strategically important, relevant to the current situation and original in the key questions. The LPI will have the support of the relevant scientific communities and it will stimulate collaborations beyond the proposed subject.

III.3.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
Forerunners			
BIOMEDREG - Biomedicine for regional development and human resources (competing)	BIOMEDREG infrastructure was a joined workplace of the four institutions located in the eligible region of the Czech Republic (Olomouc), and within an easy reach of the major biomedical and chemical campuses in the country. Its goals were to study the mechanisms and treatment of cancer and infectious diseases, the establishment of a national platform for chemical biology and drug design as well as the identification of new targets, biomarkers and diagnostic approaches leading to individualized therapy. BIOMEDREG took advantage of the close links with the project partners: i) the major regional hospital – the University Hospital in Olomouc (UHO, thereby providing direct access to clinical material and potential clinical trials), and ii) the Czech chemistry and biochemistry centres: Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences (IOCB) and Institute of Chemical Technology Prague (ICT), which directly participated in the project and were highly complementary to the mission of the BIOMEDREG, providing unique compound libraries and know-how and the unifying focus on biological chemistry applied to pathogenetic pathways and drug discovery. http://bioorganickachemiesite.upol.cz/site_en/?page_id=128, last accessed 21 September 2016 https://www.imtm.cz/biomedreg, last accessed 17 August 2016 http://biomedreg.eu/en/about-project/biomedreg, last accessed 15 August 2016	2004–2014	Olomouc, CZ
Existing research infrastructures			
AIC – Advanced Imaging Center	AIC aims at making imaging technologies developed at Janelia widely accessible, and at no cost, to scientists before the instruments	2006	Ashburn, US

[124] Medical Doctor/Doctor of Philosophy

(complementary)	are commercially available. Operating strategically at the interface of engineering and biological applications, the AIC is positioned to reduce the time between instrument development and widespread use in the increasingly technology-intensive field of biology. https://www.janelia.org/, last accessed 29 July 2016		
BioMedBridges (complementary)	BioMedBridges aims at forming a cluster of the emerging biomedical sciences research infrastructures (BMS RIs) and construct the data and service bridges needed to connect them. The BMS RIs are on the ESFRI Roadmap. Their missions stretch from structural biology of specific biomolecules to clinical trials involving thousands of human patients. Most serve a specific part of the vast biological and medical research community, estimated to be at least two million scientists in Europe across more than 1,000 institutions from more than 36 ESFRI Member States and Associated Countries. BioMedBridges builds a shared data culture in the life sciences by linking up 12 of Europe's new biological, biomedical and environmental research infrastructure. Integrating the vast data resources in the life sciences, including data from genomics, biological and medical imaging, structural biology, mouse disease models, clinical trials, highly contagious agents and chemical biology, shall enable new ways of analysing them to answer new, more complex scientific questions. http://www.biomedbridges.eu, last accessed 29 July 2016 http://www.biomedbridges.eu, last accessed 25 August 2016	2012	AT, BE, BG, CZ, DE, ES, FN, FR, HU, IL, IT, NL, NO, PL, PT, SL, UK
BSRC – Biomedical Sciences Research Center Alexander Fleming (complementary)	BSRC is a non-profit organisation operating under the supervision of the General Secretariat for Research and Technology (GSRT) of the Hellenic Ministry of Education. It performs cutting-edge research aiming to understand molecular mechanisms of complex biological processes in health and disease. It further aims to contribute to innovation in medicine, by developing novel therapeutic and diagnostic methods, focusing on immunity and inflammation, cancer, and neurodegenerative diseases. BSRC currently hosts 14 research groups in four Institutes covering the areas of immunology, molecular biology and genetics, molecular oncology, cellular and developmental biology, supporting researchers by providing state-of-the science infrastructures. http://excellence.minedu.gov.gr/thales/en/institutions/biomedical-sciences-research-centre-alexander-fleming, last accessed 15 September 2016. http://www.fleming.gr, last accessed 29 July 2016	1998 –	Vari, Athens; GR

DZIF – German Centre for Infection Research	DZIF aims at bringing together universities, university medical centres, Leibniz and Max Planck institutes, Helmholtz centres and other government research establishments with strong profiles in the field of infectious diseases to tackle the most urgent infectiology challenges with an integrative approach. Established by the German Federal Ministry for Education and Research (BMBF) established, DZIF affiliates with 35 research institutes located at seven sites distributed throughout Germany, enabling DZIF-researchers direct access to the infrastructures that already exist at each of the research institutes. http://www.dzif.de, last accessed 18 August 2016	2011 –	Hamburg-Lübeck-Borstel, Hannover-Braunschweig, Bonn-Cologne, Gießen-Marburg-Lagen, Heidelberg, Tübingen, Munich, DE
EATRIS – European Advanced Translational Research Infrastructure in Medicine (complementary)	EATRIS aims at providing a highly productive research infrastructure to enable a faster and more efficient translation of basic biomedical research discoveries into new innovative medicinal products. To achieve this EATRIS engages leading translational research centres and hospitals to provide key preclinical and clinical facilities and translational expertise necessary to support the development of new preventive, diagnostic or therapeutic strategies. Unmet medical needs in the most important disease areas and fields of research as well as in rare diseases will drive EATRIS' development policy. EATRIS was initiated by the European Strategy Forum on Research Infrastructures (ESFRI) and is currently funded by the 7th Framework Programme (FP7) of the European Commission. EATRIS aims at improving performance and conditions for translational research by _ providing easier access to research & development facilities and translational know-how for all scientists and researchers in Europe; _ overcoming fragmentation along the translational research path; _ fostering knowledge exchange and standardisation; _ providing training programmes for the next generation of translational researchers; _ facilitating and encouraging cooperation between academia and industry. http://www.eatris.eu, last accessed 29 July 2016 https://www.helmholtz.de/forschung/helmholtz_international/europaeische_projekte/kapazitaeten/forschungsinfrastrukturen/eatris/, last accessed 9 September 2016 http://cordis.europa.eu/result/rcn/187987_en.html, last accessed 16 September 2016	Preparatory phase in 2008-2010, implementation phase in 2011-2015, operational from 2016	CZ, DK, EE, ES, FI, FR, IT, NL, SE
ECRIN – European Clinical Research Infrastructures	ECRIN is a not-for-profit intergovernmental organisation which aims to support the conduct of multinational clinical trials in Europe. Support is primarily provided during imple-	2004 –	CH, CZ, DE, ES, FR, HU, IT, NO, PT

Network (complementary)	mentation, but also for preparation and protocol evaluation. As of 2013, ECRIN has the legal status of a European Research Infrastructure Consortium (ERIC). Based in Paris, it works with European Correspondents across Europe, national networks of clinical trial units (CTUs), as well as numerous European and international stakeholders involved in clinical research. ECRIN provides its nine Member and Observer Countries with diverse trial support services and contributes to collaborative projects with additional European and international partners. http://www.ecrin.org, last accessed 29 July 2016		
FMP – Leibniz Institute for Molecular Pharmacology	FMP conducts basic research in Molecular Pharmacology with the aim to identify novel bioactive molecules and to characterize their interactions with their biological targets in cells or organisms. These compounds are useful tools in basic biomedical research and may be further developed for the treatment, prevention, or diagnosis of disease. To this aim FMP researchers study key biological processes and corresponding diseases, such as cancer, aging including osteoporosis, or neurodegeneration. They also develop and apply advanced technologies ranging from screening technologies over NMR based methods to proteomics and in vivo models. http://www.leibniz-fmp.de, last accessed 18 August 2016	1992 -	Leipzig, DE
GLBC – Gruss Lipper Biophotonics Center (complementary according to concept proposal, competing according to evaluation report)	GLBC of Albert Einstein College of Medicine of Yeshiva University is a research facility dedicated to advanced biomedical research. Its mandates are to _ study and develop novel microscopy techniques that answer fundamental biological questions leading to cures for biomedical problems; _ make advanced and novel microscopy technologies, methods and reagents available to the research community; _ support the education and training of postdoctoral fellows and graduate students in advanced biophotonics techniques. GLBC is comprised of three closely collaborating entities: individual research groups led by independent primary investigators, the Innovation Laboratory and the Analytical Imaging Facility. Projects led by investigators within the centre range from characterizing the dynamics of single molecules within living cells, to the development of new fluorescent proteins and biosensors, to the study of cancer progression within whole animals. https://www.einstein.yu.edu/centers/biophotonics/aboutus/, last accessed 29 July 2016	Not specified	New York, US
IDMIT – Infectious Disease Models and Innova-	IDMIT is a national Research and Technological infrastructure for biology and health dedicated to preclinical research on infectious	2012	Fontenay-aux-Roses, FR

tive Therapies (competing)	diseases. The major objective of IDMIT is to provide the national and international scientific community with a competitive infrastructure for preclinical research, facilitating the discovery of markers of safety and efficacy of new vaccines and treatments and accelerating the translation of innovations from the bench to clinical practice. It combines the expertise of international partners with core facilities implemented in IDMIT for monitoring diseases and treatments including advanced technologies for high dimensional cell phenotyping (CyTof) and in vivo imaging (Near Infra-Red fluorescence, two-photon microscope, confocal-endo microscopy, PET-CT). http://imeti.cea.fr/drf/imeti/english/Pages/SIV/IDMIT.aspx, last accessed 17 August 2016 http://www.idmitcenter.fr/, last accessed 17 August 2016		
moSAIC - Molecular Small Animal Imaging Centre (complementary)	moSAIC is a core facility of the University of Leuven (KU Leuven). It combines all major in vivo imaging modalities for pre-clinical research (Magnetic Resonance, Positron Emission Tomography, Ultrasound, optical imaging (bioluminescence, fluorescence, intravital microscopy, OCT) and computed tomography). Close links to the Department of Imaging and Pathology exist that allow rapid translation of pre-clinical findings. Research is performed in all fields of biomedical sciences (for example neurology, cardiology, oncology, infectious diseases, endocrinology etc.). moSAIC is also part of the Medical Imaging Research Center (MIRC) at KULeuven, which is a collaborative project of the faculties of Medicine and Engineering focussing on image processing. The molecular imaging program includes research on the development of novel tracers, contrast agents and imaging reporters. http://portal.meril.eu/converis-esf/publicweb/research_infrastructure/3452, last accessed 15 September 2016	2007 –	Leuven, BE
NCTCR – National Centre for Translational and Clinical Research (complementary)	NCTCR is a national research infrastructure formed by the University of Tartu, Estonian University of Life Sciences and Tartu University Hospital. The aim of the Centre is to improve the quality and innovation in the health research in Estonia. NCTCR brings together researchers working in different areas in health research, and combines competencies from diverse areas of medical research. NCTCR is partner for the state, businesses and society to provide expertise in the field of health research. The vision of the National Centre for Translational and Clinical Research is to implement Estonian research, development and innovation (R & D & I) strategy for health research. NCTCR is a national centre for medical innovation. http://www.ctm.ee, last accessed 15 September 2016	2014	Tartu, EE

	http://portal.meril.eu/converis-esf/publicweb/research_infrastructure/2977, last accessed 29 July 2016		
NBIP – National Biophotonics Imaging Platform (complementary)	NBIP Ireland is a platform consisting of a consortium of imaging and biophotonics laboratories from across the Universities and Institutes of Technology in Ireland and three EU partners; CNRS Montpellier (France), the CNR Institute of Biostructure and Bioimaging, Naples (Italy)and The Nordic Imaging Network. NBIP's mission is to _ provide a structured research and training framework for Ireland's investment in advanced imaging applied to the Life Sciences; _ catalyse and support internationally competitive research grant applications; _ develop and support Post-graduate Training Programmes underpinned by biophotonics and imaging; _ bridge the Physical and Life Sciences interface; _ provide a National Access for Core Facilities in Molecular, Cellular, Small Animal and Human Research Imaging; _ provide the administrative and scientific infrastructure for Ireland's participation in large-scale international research programmes. http://www.nbipireland.ie, last accessed 29 July 2016	2007	IE; Montpellier, FR; Naples, IT; Nordic Imaging Net, FI/SE
NIF – Australian National Imaging Facility (complementary)	NIF aims at providing state-of-the-art imaging capability of animals, plants, and materials for the Australian research community. NIF's grid of imaging facilities spreads across Australia, aiming to provide a range of leading-edge imaging instrumentation and expertise in the optimal use of imaging technology to the Australian research community. NIF aims at providing: _ access to molecular imaging instrumentation, including a range of MRI and PET scanners; _ access to other live animal imaging equipment including bioluminescence, microCT, ultrasound and intravital microscopy; _ development and validation of novel biomarkers/radioligands for in-vivo imaging using PET and MRI; _ development and application of stable isotope-labelled analogues to new radioligands; _ magnetic resonance spectroscopy, coil design and pulse sequence development; _ application of these new technologies in large-scale trials in animal models of disease; _ bio-mathematical modelling of tracer kinetic data and integration of the high-dimensional data in a dedicated neuroinformatics system; _ the creation of databases of normative data, and a common platform of base data;	2007	AU (distributed RI)

	_ links to existing national infrastructure for ultra-structural imaging and measurement technologies through the Australian Microscopy and Microanalysis Research Facility. http://anif.org.au, last accessed 29 July 2016		
THD – Translating Health Discovery (complementary)	TIA aims at supporting Australian researchers in taking promising medical research from the laboratory bench and translating it into clinical application. TIA achieves this through a national network of 45 sites located at universities, medical research organisations, hospitals and clinical networks that enable development of small molecules, biopharmaceuticals, cell therapies and biomarkers. TIA forms a central partnering function between researchers, capability managers and experts in product development from academic and industry sectors. In 2013–14, TIA supported 67 proof of concept products and 80 clinical trials. http://www.therapeuticinnovation.com.au/, last accessed 19 August 2016	2011	AU
Planned research infrastructures/under construction			
CIIM – Centre for Individualized Infection Medicine	CIIM is a joint venture of the Helmholtz Centre for Infection Research (HZI) and the Hannover Medical School (MHH) which aims at individualising therapies for infectious diseases. Researchers of the centre will identify individual parameters that influence the progress of infection and will translate these findings into optimized and individualised care of patients with infectious diseases. The research at the CIIM aims at consequently promoting personalisation of health care in infection medicine. Being initially a virtual centre, the CIIM aims at utilising infrastructures of the parental institutions to align, co-ordinate and further expand research activities in the field of personalised medicine. https://www.helmholtz-hzi.de/en/organisation/locations/centre_for_individualised_infection_medicine, last accessed 19 August 2016 http://www.fz-juelich.de/SharedDocs/Downloads/JCNS/EN/HBS/Road%20Map.pdf?__blob=publicationFile, last accessed 19 August 2016	Founded in 2015, construction in 2018–2022, operation at least 35 years	Hannover, DE
ERINHA – European Research Infrastructure on Highly Pathogenic Agents (complementary)	ERINHA aims at reinforcing the European capacities for the study of Risk Group 4 pathogens and enhance the coordination of Biosafety Level 4 (BSL-4) and supporting infrastructures. It seeks to give access to BSL-4 facilities to all interested European scientists with a relevant research project by establishing a pan-European distributed Research Infrastructure and supporting cutting-edge research into the pathogenesis of human diseases caused by the most dangerous microorganisms as well as applied research to develop new therapeutic techniques, diagnostic tools and prophylactics.	Preparatory phase 1: 2010–2016, preparatory phase 2: 2016–2017, operation phase from 2018	AT, BE, FR, GR, HU, IT, PT, RO, SE, UK

	http://www.erinha.eu, last accessed 28 August 2016		
EuBI – Euro-BioImaging (complementary)	EuBI aims at providing open physical user access to a broad range of technologies in biological and biomedical imaging for life scientists. In addition, EuBI plans to offer image data support and training for infrastructure users and providers. EuBI currently counts 28 EuBI Node Candidates offering open access to 36 imaging technologies for biological and biomedical imaging. EuBI has been listed on the ESFRI Roadmap since 2008. http://www.eurobioimaging.eu, last accessed 1 September 2016 www.eurobioimaging-interim.eu, last accessed 29 September 2016	Start of interim operation in 2016. Official launch foreseen to take place in 2017	AT, BE, BG, CH, CZ, DE, DK, ES, FI, FR, GR, HR, IE, IT, IL, LU, NL, NO, PL, SK, UK
EU-OPENSCREEN – The European Infrastructure of Open Screening Platforms for Chemical Biology (complementary)	EU-OPENSCREEN aims at building a sustainable European infrastructure for Chemical Biology, supporting life science research and its translation to medicine, agriculture, bioindustries and society. It is a distributed research infrastructure which builds on national networks in 16 European countries. It aims at embracing local research groups and facilitates transnational open access to the most advanced technologies, chemical and biological resources, knowledge and expertise throughout Europe. EU-OPENSCREEN is likely to be established as a European Research Infrastructure Consortium (ERIC). It will comprise high-throughput screening (HTS) centres at different sites in Europe with their special HTS and bio-assay expertise, chemical resources for optimisation of first hit compounds, bio- and chem-informatics capacities, and a publicly-accessible database (the ECBD) combining screening results, assay protocols, and chemical information. A large collection of diverse compounds, representing the chemical knowledge in Europe, will be made available from a central storage facility. http://eu-openscreen.eu, last accessed 17 October 2016	Start of preparatory phase in 2010. Expected start of operation in 2018	AT, BE, CZ, DK, FI, FR, DE, GR, HU, IT, NL, NO, PL, RO, ES, SE

III.4 National Biomedical Imaging Facility (NIF)

III.4.a Scientific potential

Description

According to the proposal, there is broad consensus on the demand for high-level biomedical imaging to help answer diverse scientific questions; this consensus has been reached following community questionnaires (Euro-BioImaging) and focused workshops Therefore, NIF pursues a broad range of scientific objectives. NIF will develop, optimise, and apply biomedical imaging to improve the understanding of disease pathogenesis at a molecular and functional level by facilitating comprehensive translation into the clinic. NIF will focus on methodological advancements in hybrid MR-PET and their application to the study of the human brain and tumour diseases as well as on extremely high-field (EHF) |[125] human MRI.

In the proposal, the multimodal approach of NIF, comprising simultaneous acquisition of MR-PET-EEG data as well as MEG data, is emphasised. The instrumentation of NIF will enable scientists for the first time to acquire a unique dataset constituting the human structural-functional-metabolic (SFM) connectome. The multimodal imaging methods of the NIF infrastructure will enable a new, deeper understanding of how the brain works by the simultaneous observation of physiological and biochemical processes with the concomitant temporal dimension. It is pointed out in the proposal that ultra high-field (UHF) - MRI |[126] and multimodal imaging also have a high impact on cancer diagnostics. A highly-resolved, multi-dimensional, multi-modal depiction is the key in understanding diverse disease processes and it is claimed that this will increase individual prognosis and optimise personal therapy especially in cancer.

Moreover, in EHF-MRI, NIF aims to establish the world's first human 14 T scanner. The complete non-invasiveness of MRI makes 14 T MRI a convenient tool for cancer and longitudinal studies in neuroscience. It will be possible to detect early anatomic, vascular, and metabolic changes at 14 T, making it a novel tool for studying inflammatory response in immune disease or for monitoring the tumour microenvironment under various oncological therapy regimens including novel immune therapies.

Furthermore, NIF plans to house state-of-the-art MEG and to advance the field by implementing helium-free MEG as well as real-time MEG. For the users, access to a professionally operated MEG facility including data-processing in real time will thus be provided.

NIF is expected to focus on unravelling the SFM connectome of the human brain and its lifespan changes. The "entry-level" metabolic connectome can and will be acquired at 9.4 T and the advanced one later at 14 T. According to the proposal, the full SFM connectome will constitute an internationally unique dataset complementing the human connectome dataset being acquired in the U.S. The SFM connectome will open up new avenues of investigation for the scientific community as well as industry looking to establish early bi-

|[125] Extremely high field refers to field strengths above 14 T.

|[126] Ultra high field refers to field strengths in between 7 and 14 T.

omarkers of neuropsychiatric diseases. It is anticipated that the SFM connectome will bring about a paradigm shift in understanding the brain by including the metabolic and temporal dimensions.

Nine research infrastructures for biomedical imaging exist and four are currently under construction. The highest magnetic field for human use currently in operation is a 10.5 T whole-body system at the University of Minnesota. In small-animal imaging, there are a number of EHF magnets in operation, e. g. NeuroSpin, France (17 T), University of Minnesota (16 T), Vanderbilt University (15 T), and Vienna Biocenter (15 T). An 11.7 T whole-body system is scheduled to be installed at the NeuroSpin research facility in Paris as well as a head-only system in the Neuroscience Research Institute, Korea. According to the proposal, none of these infrastructures directly competes with NIF because of its focus on simultaneous, hybrid imaging and EHF human MRI.

Assessment

This proposal aims at developing multimodal imaging technologies based on MRI, PET and MEG/EEG, for identifying pathologies related to neurological diseases and cancer, and providing powerful tools for fundamental neuroscience. One of the central aims is to develop the SFM connectome, which offers fascinating prospects. The proposed project is of highest scientific importance and highly relevant for many research disciplines. No other research units worldwide will have the equipment and capabilities for studying the proposed research questions. These advances are expected to lead to a paradigm shift in brain imaging as well as in the investigations of disease pathogenesis and ageing. If successful, the proposed RI would be a major and prominent contribution to the field of biomedical imaging research in general and to efforts focused on understanding human brain function, connectivity and metabolism in particular The two areas, neuroscience, centred at FZJ and cancer, centred at DKFZ will provide the motivation and focus for developing imaging technology, which can then be applied to a broader range of biomedical applications.

Beyond the contributions to basic and clinical science, the proposal includes several technical levels of equipment, with different time horizons for user availability. Some of the instruments will be immediately available once installed. These include the four 7 T MRI systems which are approved for patient care. The next set of instruments is research oriented. This includes a 7 T MR-PET-EEG system. A 14 T small animal MR-PET will be acquired. Furthermore, another 7 T system will also be installed for high resolution connectivity mapping of the human brain. An MEG system will be installed with its high temporal resolution to complement the high spatial resolution of MRI. This is a revolutionary design. This will allow the detectors to be placed closer to the patient. In addition, a 21 T animal system will be acquired. This is right at the cutting edge of what is possible. All of these are state-of-the-art systems for research, and are particularly well suited for answering basic questions in neuroscience, and in cancer. The final instrument, and the central focus of the proposal, is a whole body 14 T system. This is the next step from current generation systems at 7 T to 10.4 T, leading to a 20 T system in the next decade. Development of the 14 T MRI system will be a tremendous scientific and engineering achievement. The impact for brain studies and cancer diagnosis will be tremendous. There are many significant challenges, from the magnet construction, the gradient design, and particularly the Radiofrequency (RF) systems. Many technical breakthroughs will be required. However, the group of investigators are among the best in the world in solving these problems, as they have demonstrated with the development of 7 T MRI. This provides great confidence that these challenges will be met, and the system will be successful. It will keep German academics and their industrial partners at the forefront of this important area of science and technology.

Furthermore, the proposal addresses the needs of a broad user base that extends from basic neuroscience to clinical medicine. There is wide support for the RI within the German Ultra High Field MR community. Major players from numerous different institutions are actively participating in research projects included as work packages, and/or are providing letters expressing their support. The technological innovations are tackle major technical and engineering challenges; if successful they would bring major new gains in biomedical studies of human biology.

The proposal has a broad spectrum of instrumentation that ranges from the 7 T MRI systems that will have an immediate scientific and clinical impact, to the 14 T human MRI that will take several years to develop. This guarantees that the project will have a continuing and sustained scientific productivity.

The proposal is divided into an acquisition phase and an operation phase, over a ten year period. Some of the instruments will be available early in the project, while others, such as the 14 T human MRI, will be available only in the last half. It is expected that the addition of the new instrumentation would be relatively seamless.

A major distinguishing feature of this proposal compared to other institutions, is the vision of connecting many different imaging modalities together. The combination of instruments is more important than any particular machine. This will uniquely position investigators in Germany to be able to ask and answer fundamental research questions. Existing RIs do not have the comprehensive suite of equipment and capabilities that the applicants of this proposal will create. Should the applicants be successful, the result will be a unique research resource in the world.

Description

NIF will offer a user facility for the needs of biomedical researchers. As a fully open imaging platform, it wants to attract methodologists, neuroscientists, physiologists, experts on health effects of static magnetic fields, contrast agent developers, molecular biologists, and medical researchers from within Germany and presumably beyond. In addition to internal users from the FZJ and the DKFZ, researchers from universities and university hospitals are expected. Demands are also expected from the pharmaceutical industry and non-university research institutions. NIF will provide access based on the policies and recommendations developed by German Ultrahigh Field Imaging (GUFI). These policies are largely based on those developed by Euro-BioImaging, adapted for German users. NIF will not charge fees for measurement time; access will be based solely on scientific merit as determined through a rigorous review process.

At NIF, different types of data will be produced, such as raw image data from the devices including reconstructed raw data. Because of their characteristics, the NIF data require appropriate handling, processing, and management. The data management concept provides processes and will set up an e-infrastructure for all phases of the data life cycle (acquisition, processing, storage, analysis, distribution). The NIF infrastructure pursues an open data strategy: after completion of the primary phase of a project, all acquired data will become available and can be used by other working groups upon request.

A quality assurance programme will be designated within NIF with the goal to develop and establish approaches for capturing and characterising system performance and to define standardised quality assurance procedures for all systems. These procedures will provide a high detection rate of artefacts and system deficiencies, enabling early detection of slowly emerging failures. With regard to scientific ethics, NIF is committed to upholding the standards for Safeguarding Good Scientific Practice outlined by the German Research Foundation. Studies with animals and human subjects will conform to international standards including the Declaration of Helsinki. Studies employing ionising radiation will require the approval of the Federal Radiation Protection Board.

Assessment

The research initiative will attract many researchers. The applicants explicitly designed an open user concept. The RI will be associated with all UHF centres in Germany. As outlined in the application many other user groups will be attracted by this project (e. g. MR methodologists, physiologists, experts on health effects of static magnetic fields, contrast agent developers, molecular biologists and medical researchers). Thus a broad group of researchers from many disciplines will be interested in this research endeavour. Combining technology development and applications by the more biologically and medically oriented user community is a major challenge. Instruments that are technologically in an unstable "developmental" state can produce unique results but are not necessarily easily accessible to a wide biologically oriented user group. Meeting this challenge will enable access to this unique technology by the neuroscience and cancer biology communities, which otherwise would not take advantage of this sophisticated instrumentation.

NIF follows a very liberal access policy, the uniqueness of the resources, and the large potential user base will produce a substantial demand for scan time on these systems. Once in the operational phase of the proposal, access management and service will be provided by the hosting institutions, free of cost to the users. This is a very remarkable feature of this proposal. Most important will be having dedicated experts on the technology that can interface with the potential biomedical users. Virtually none of the instruments are easy to use systems and need real expertise to exploit their potential. There are many positions requested in the RI to provide this expertise. The applicants mention that they will choose the researchers purely by scientific merit. They should guarantee scientific and geographic diversity in the advisory board and in the user group.

NIF will have a management board to interact with the responsible institutions. The written proposal describes a management and governance plan that appears adequate for this task; ultimately the successful implementation of the plan will be critical.

Data will be retained in a data base, and made accessible via a web interface. The proposed open data access is consistent with current trends. This is a critical issue and in this respect, the RI proposes to achieve this. In addition to saving data in data bases mentioned above, all of the processing pipelines will be documented, and preserved with version control, so any particular research result can be recreated retrospectively, or the data reprocessed if new techniques have been developed. The data strategy of NIF as well as the use of discipline specific standards and the data management plans are state-of-the-art. FZJ has an established supercomputing centre that is active in the human brain project in the context of data stewardship, which provides a feasible background for the data sharing concept.

The process integrity appears fully adequate and state-of-the-art. The key issue for process integrity for the NIF is assuring that the instrumentation is functioning properly at all times. This will be assured by a systematic regime of Quality Assessment (QA) studies that are performed periodically to detect any degradation in performance. This methodology is already successfully used with other systems, and is well understood.

Description

The realisation risk of much of the planned NIF infrastructure can be categorised as low, since the requisite technologies have been demonstrated and can be purchased commercially to a large extent. A notable exception is the ambitious plan to establish a whole-body MR imager with a magnetic field of 14 T, since this field strength goes beyond what has thus far been attempted for human imaging. Design studies have been generated and the technological know-how is available at the FZJ and the DKFZ. Furthermore, all UHF sites within Germany have expressed their willingness to contribute to the 14 T system.

NIF is organised as a virtual institute through the partner institutions FZJ and DKFZ. For supervising the technical and scientific tasks of NIF and for the strategic advancement of the institution, committees and boards such as the Board of Trustees or the Science and Technology Board will be established. Particular attention will be paid to the appropriate integration of other partners and users. The cooperation and use of the planned infrastructure by the FZJ and the DKFZ will be controlled by a collaboration/cooperation agreement. At the same time, the addition of future partners is possible.

It is pointed out in the proposal that NIF fits into the strategy of both research institutions. The imaging infrastructure of NIF will be complemented by the existing expertise at the FZJ in neuroscience and at the DKFZ in cancer research. The FZJ has a number of unique or rare instruments that will be committed to NIF. These include a 9.4 T human MR-PET scanner and a 9.4 T animal MRI scanner based on clinical hardware and software. A 7 T human scanner is already available at the DKFZ; the FZJ is currently in the final stages of a consultation process to purchase a new generation 7 T scanner that will be CE-certified and therefore ready to use in normal patient scanning. The FZJ and DKFZ will also contribute extensive research facilities including animal labs, cyclotron, radio-pharmacy, and other imaging equipment. All other systems needed to realise NIF will be purchased during the implementation phase.

Assessment

The single biomedical imaging techniques proposed to combine are well manageable so far. The new aspect is in combining them. It seems possible that this RI can manage that very well since they have lots of experiences in managing technical advancements. One potential risk is the 14 T instrument. There are several components.

Probably the most major risk is the safety and tolerability of 14 T magnetic field by humans. This is an unknown. It should not be assumed that the record with instruments operating up to 9.4 T, demonstrating safety and tolerability, could be extended to 14 T. Animal experiments testing cognitive, physiological, and biological effects, briefly discussed in the proposal, would be a critical component of this aspect of the proposal and should receive timely and intense attention.

Another risk concerns the RF transmit system. At 14 T the wavelength of RF in tissue is on the order of 6 cm. Wave propagation effects will be a major concern. It will require major technical advances to be able to control the RF transmit field, and ensure that local RF hot spots do no exceed safety limits. The investigators are well aware of these issues. Several of the work packages are devoted to studying and solving these issues. Given their previous success at developing 7 T MRI, it is likely they will be successful.

Furthermore another risk is simply producing the magnet. This requires the use of new magnet fabrication techniques, and will be the first of its kind. The project investigators are well aware of the risks, and have set up specific work packages and have a management plan in place for contingencies.

The FZJ and the DKFZ are well-known research centres for such kind of imaging facilities. So the proposed project perfectly fits into the research policy of these centres. The both institutions each have a long history of managing similar instruments and programmes.

The proposed participation of many other groups in Germany for this RI will be critical to the success of the project. Realising this participation and managing it towards achieving integration and coordination, through association of all German UHF centers, is an important and convincing step.

The ability to attract the best and brightest investigators will be critical to the success of this proposal. Free access to the most advanced instrumentation will be a strong attractor for new talent. One issue to consider is the career trajectory for these new investigators. The established graduate schools and the participating universities in Heidelberg, Aachen and Cologne are expected to offer an adequate career pathway. There are a substantial number of positions that will be funded under the development phase of the project. A large amount of new personnel will be required and is requested in the proposal. The core personnel of the RI will engage in the development required to establish the platform and will also assist external users in carrying out their experiments. Given the unique nature of the planned platform, it would be unrealistic to expect external researchers to be able to operate the equipment; the RI will provide the expertise for outside researchers to access the instruments and facilitate the research projects.

Without any doubt the RI is “mature” and perfectly suited for this project. The FZJ and the DKFZ are already well established institutions with a broad array of state-of-the-art instrumentation. This is an excellent environment for the development, management and utilisation of the new imaging instruments described in this proposal. Challenges exist in bringing together leaders from so many different institutions to work in a coordinated way. The institutions where the infrastructure investments will be made, FZJ and DKFZ, will develop new instrumentation capabilities that will be the envy of the world in this field of research. Bringing together all the parts from the different institutions throughout Germany for integrating the technologies needed for the proposed goals will be critical.

III.4.d Relevance to Germany as a location of science and research

Description

According to the proposal, imaging technologies offer a high potential to develop new approaches in medicine and life sciences. In addition to addressing scientific questions, new aspects will also emerge for clinical diagnostics. Metabolic imaging with unprecedented spatial and temporal resolution is supposed to drive the goal of acquiring the structural-functional-metabolic connectome of the human brain, studying changes thereof over a lifespan, and also provide an unrivalled tool for examining the pathogenesis of various diseases including cancer, diabetes, dementia, heart disease, arthritis, psychiatric disorders, ageing, and obesity. The 14 T human MRI proposed as part of NIF would be an important step toward realising this potential, and NIF intends to examine the feasibility of proceeding to 20 T at a later stage.

The facilities of NIF, including imaging devices and supercomputing resources as well as expertise, will provide a platform to develop new approaches for neuroimaging and biomedical imaging and drive the visibility of German research in Europe and on a wider international level. Furthermore, the infrastructure of NIF will foster partnerships with industry to promote the transfer of innovative research results into commercial developments.

The infrastructure will not only be attractive to device manufacturers but also in particular to the pharmaceutical industry to accelerate drug development and testing. The NIF-operated Translational Centres in Aachen, Cologne, and Heidelberg, the National Center for Tumor Diseases (NCT) in Heidelberg and Dresden and nine further university hospitals through the German Consortium for Translational Cancer Research will also profit from the basic and clinical research possibilities provided by the infrastructure. Because of the partnerships between both the FZJ and DKFZ and various university hospitals, new imaging techniques with great clinical potential can be applied directly in clinical trials in larger populations. This has already been implemented successfully in the past, and imaging methods developed in the FZJ and DKFZ are now being used in a number of countries. It is pointed out in the proposal that NIF will ensure that German academia and industry retain their pre-eminence in UHF-MRI and MR-PET research and commercial application.

Assessment

This RI, if successfully implemented and realised would make Germany a world leader and one of the most attractive places to work in in the area of biomedical imaging. This project will stimulate high visibility in Europe since a centre like this one will be unique. The RI will promote research visibility by creating a worldwide unique infrastructure comprising cutting-edge multimodal imaging hardware enabling simultaneous acquisition of MR-PET/EEG data as well as MEG data and, over time, an invaluable e-infrastructure, namely the human structural-functional-metabolic connectome. Moreover, the 14 T human MRI scanner will be one of a kind and will attract researchers from all over Europe and internationally thereby enhancing visibility.

Researchers from around the world will be able to exploit access to this unique infrastructure and e-infrastructure. The RI will strengthen and optimise the existing networks between the neuroscience and imaging communities, between brain imaging and neuro-oncology as well as bring together the MRI and PET communities.

NIF would provide a unique resource that will attract investigators from all over the world. The free, merit based, access will be particularly attractive, as will be the wide range of instrumentation that will be available.

This centre will have enormous impact in Germany simply because of its uniqueness and attractiveness. This project would extend this leadership in both science and academics, as well as for the industrial partners who will ultimately design and fabricate these systems. By focusing many different imaging resources at a few sites, investigators will be able to explore a much larger parameter space of biomedical data. This should provide German investigators with unique advantages over other countries where the resources are more distributed.

The RI will be a "hotbed" for the training of the next generation of young researchers whose projects – selected based on scientific merit – will be funded by the RI. This will very directly ensure dissemination of knowledge and technology. In particular, in keeping with the policies of the Helmholtz Association, the RI will promote and encourage young researchers who form the backbone of the future research community. This knowledge transfer will surely be documented through joint publications as they have done in recent years. A major strength of this proposal is the potential for translation both to clinical medicine, and also to industry.

The technologies developed on one system can be translated either towards clinical application, or towards the very high field animal systems. Developments on one system should be beneficial to others. In particular, the clinical 7 T systems should benefit directly from problems solved for the much more demanding 14 T systems.

The work packages are another major strength of the proposal. Many of these are major research projects that, if successful, would dramatically alter the way MRI systems are designed and used. These will have major commercial impact in the development of future UHF MRI systems, and will help Siemens maintain its leadership in this field.

Additionally, the annual international conference on hybrid MR-PET imaging jointly hosted by the FZJ, the PSMR |[127], will be utilised for dissemination of research.

The societal impact of early disease detection is expected to be enormous. Metabolic signatures of the brain (a core aspect of the project application), for example, will be mapped together with structural and functional information leading to a unique e-infrastructure, the human structural-functional-metabolic connectome. This will expedite the discovery of early biomarkers for a range of diseases, in particular those affecting the ageing brain such as Alzheimer's disease. In other body organs, the RI will provide outstanding tools for examining the emergence and progression of various diseases including cancer, diabetes, heart disease, arthritis, and obesity.

The RI plans to tightly integrate industry into the formation of the platform. The core staff of the RI will lead technological developments together with a number of companies including imaging equipment manufacturers and the pharmaceutical industry. The improved capability to examine metabolic mechanisms and detect early therapy response will provide a platform to accelerate development of new pharmaceuticals and reduce costs. The results arising from research and technology development in the RI will be transferred into medical application.

III.4.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
Existing research infrastructures			
AIC – Advanced Imaging Center (complementary)	AIC aims at making imaging technologies developed at Janelia widely accessible, and at no cost, to scientists before the instruments are commercially available. Operating strategically at the interface of engineering and bio-	2006	Ashburn, US

| [127] Conference on PET-MR and SPECT-MR.

	logical applications, the AIC is positioned to reduce the time between instrument development and widespread use in the increasingly technology-intensive field of biology. https://www.janelia.org/, last accessed 29 July 2016		
BioMedBridges (complementary)	BioMedBridges aims at forming a cluster of the emerging biomedical sciences research infrastructures (BMS RIs) and construct the data and service bridges needed to connect them. The BMS RIs are on the ESFRI Roadmap. Their missions stretch from structural biology of specific biomolecules to clinical trials involving thousands of human patients. Most serve a specific part of the vast biological and medical research community, estimated to be at least two million scientists in Europe across more than 1,000 institutions from more than 36 ESFRI Member States and Associated Countries. BioMedBridges builds a shared data culture in the life sciences by linking up 12 of Europe's new biological, biomedical and environmental research infrastructure. Integrating the vast data resources in the life sciences, including data from genomics, biological and medical imaging, structural biology, mouse disease models, clinical trials, highly contagious agents and chemical biology, shall enable new ways of analysing them to answer new, more complex scientific questions. http://www.biomedbridges.eu last accessed 29 July 2016 http://www.biomedbridges.eu/, last accessed 25 August 2016	2012	AT, BE, BG, CZ, DE, ES, FN, FR, HU, IL, IT, NL, NO, PL, PT, SL, UK
CNIR – Center for Neuroscience Imaging Research (competing)	Small-animal imaging: 15 Tesla http://cnir.ibs.re.kr/html/cnir_en/, last accessed 25 August 2016	Not specified	Sungkyunkwan University, KR
EPFL – École polytechnique fédérale de Lausanne (competing)	Small-animal imaging: 14 Tesla www.cibm.ch/14-Tesla, last accessed 25 August 2016	Not specified	Lausanne, CH
Max Planck Institute for Biological Cybernetics (competing)	Small-animal imaging: 14 Tesla (16 Tesla before magnet repair) www.kyb.tuebingen.mpg.de/de/forschung/abt/ks.html, last accessed 25 August 2016	Since 2007	Tübingen, DE
National High Magnetic Field Laboratory (competing)	Small-animal imaging: 21 Tesla Designed for Fourier Transform Ion Cyclotron Resonance (FT-ICR) mass spectroscopy; not used routinely for small-animal imaging www.nationalmaglab.org/user-facilities/icr, last accessed 25 August 2016	Not specified	Florida, US
NeuroSpin (competing)	Small-animal imaging: 17 Tesla www.meteoreservice.com/neurospin, last accessed 25 August 2016	Not specified	Paris, FR
NIF – Australian National Imaging Facility	NIF aims at providing state-of-the-art imaging capability of animals, plants, and materials for the Australian research community. NIF's grid of imaging facilities spreads across Australia, aiming to provide a range of leading-	Since 2007	AU (distributed RI)

	edge imaging instrumentation and expertise in the optimal use of imaging technology to the Australian research community. NIF aims at providing: _ access to molecular imaging instrumentation, including a range of MRI and PET scanners; _ access to other live animal imaging equipment including bioluminescence, microCT, ultrasound and intravital microscopy; _ development and validation of novel biomarkers/radioligands for in-vivo imaging using PET and MRI; _ development and application of stable isotope-labelled analogues to new radioligands; _ magnetic resonance spectroscopy, coil design and pulse sequence development; _ application of these new technologies in large-scale trials in animal models of disease; _ bio-mathematical modelling of tracer kinetic data and integration of the high-dimensional data in a dedicated neuroinformatics system; _ the creation of databases of normative data, and a common platform of base data; _ links to existing national infrastructure for ultra-structural imaging and measurement technologies through the Australian Microscopy and Microanalysis Research Facility. http://anif.org.au, last accessed 29 July 2016.		
University of Minnesota (competing)	Human imaging: 10.5 Tesla whole-body system www.cmrr.umn.edu/magnets/105t88.shtml, last accessed 25 August 2016 Small-animal imaging: 16 Tesla www.cmrr.umn.edu/magnets/164t26.shtml, last accessed 25 August 2016	Since 2013	Minnesota, US
VUIIS – Vanderbilt University Institute of Imaging Science (competing)	Small-animal imaging: 15 Tesla https://www.vuiis.vanderbilt.edu/index, last accessed 25 August 2016	Not specified	Nashville, US
VBCF – Vienna BioCenter Core Facilities (competing)	Small-animal imaging: 15 Tesla www.csf.ac.at/home/, last accessed 25 August 2016	Not specified	Vienna, AT
Planned research infrastructures/under construction			
EuBI – Euro-BioImaging (complementary)	EuBI aims at providing open physical user access to a broad range of technologies in biological and biomedical imaging for life scientists. In addition, EuBI plans to offer image data support and training for infrastructure users and providers. EuBI currently counts 28 EuBI Node Candidates offering open access to 36 imaging technologies for biological and biomedical imaging. EuBI has been listed on the ESFRI Roadmap since 2008.	Start of interim operation in 2016. Official launch foreseen to take place in 2017	AT, BE, BG, CH, CZ, DE, DK, ES, FI, FR, GR, HR, IE, IT, IL, LU, NL, NO, PL, SK, UK

	http://www.eurobioimaging.eu, last accessed 1 September 2016 www.eurobioimaging-interim.eu, last accessed 29 September 2016		
EU-OPENSCREEN – The European Infrastructure of Open Screening Platforms for Chemical Biology (complementary)	EU-OPENSCREEN aims at building a sustainable European infrastructure for Chemical Biology, supporting life science research and its translation to medicine, agriculture, bioindustries and society. It is a distributed research infrastructure which builds on national networks in 16 European countries. It aims at embracing local research groups and facilitates transnational open access to the most advanced technologies, chemical and biological resources, knowledge and expertise throughout Europe. EU-OPENSCREEN is likely to be established as a European Research Infrastructure Consortium (ERIC). It will comprise high-throughput screening (HTS) centres at different sites in Europe with their special HTS and bio-assay expertise, chemical resources for optimisation of first hit compounds, bio- and chem-informatics capacities, and a publicly-accessible database (the ECBD) combining screening results, assay protocols, and chemical information. A large collection of diverse compounds, representing the chemical knowledge in Europe, will be made available from a central storage facility. http://eu-openscreen.eu, last accessed 17 October 2016.	Start of preparatory phase in 2010. Expected start of operation in 2018	AT, BE, CZ, DK, FI, FR, DE, GR, HU, IT, NL, NO, PL, RO, ES, SE
Neuroscience Research Institute, Gachon Medical School (competing)	11.7 Tesla human system http://nri.gachon.ac.kr/d_02_e.html, last accessed 29 September 2016	Call for bids	Incheaon, KR
NeuroSpin (competing)	11.7 Tesla whole-body system www.cea.fr/english-portal/fundamental-research/inauguration-of-neurospin-a-major-neuroimaging-4342, last accessed 29 September 2016	Installation: 2016	Paris, FR
NIH - National Institute of Mental Health (competing)	11.7 Tesla head-only system scheduled for re-installation after magnet repair Small-animal imaging: 18 Tesla https://amri.ninds.nih.gov, last accessed 29 September 2016 www.nimh.nih.gov/labs-at-nimh/research-areas/clinics-and-labs/mib/smrs/index.shtml, last accessed 29 September 2016	11.7 T: Start: near future 18 T: Start: 2016	Bethesda, US

III.5.a Scientific potential

Description

The recent wide acceptance of imaging science and the successful integration of imaging applications in basic and clinical biomedical research has been strongly triggered by the availability of integrative multi-modal imaging. This is prominent in classical areas such as oncology, neurology and cardiology, and is currently gaining traction in the areas of immunology, infectious diseases and regenerative medicine. The approach yields multi-parametric data which can, for example, simultaneously quantify anatomical structures, morphology, function, receptor status, and metabolism. However, integrative multi-modal imaging is currently mainly based on macroscopic imaging modalities, realised by the hardware fusion of PET with computed tomography (PET-CT) and magnetic resonance imaging (PET-MRI), or the combination of independent imaging information of different modalities.

According to the proposal, the following integrations into imaging sciences have yet to be realised:

_ Combination of complementary multiparametric and multiscalar technologies, like microscopic and macroscopic imaging;

_ The spatial, temporal and parametricly-quantitative connection of in vivo imaging data with ex vivo data (e. g. omics, pathology);

_ The tight interdisciplinary integration of tracer development, in vivo and ex vivo preclinical validation, clinical translation and data processing;

_ The establishment of standardised workflows and standard operating procedures (SOPs) for research, development, preclinical validation and clinical translation in consideration of the multiparametric scientific approach;

_ The integration of interdisciplinary scientific sectors and experts, as well as pharmaceutical and technological industry partners.

According to the proposal, it is essential to have a scientific institute under one roof where experts from diverse fields can interact on a daily basis to discuss their latest results in a formal and informal setting. Such a physical agglomeration of interdisciplinary scientists is supposed to catalyse innovations in the field of imaging sciences. Such an integrated concept, which utilises predominantly non-invasive imaging technologies for basic research, allows to massively reduce the number of laboratory animals required and the experimental burden in imaging studies compared to most conventional procedures. Moreover, imaging allows longitudinal studies on the same animal, which enables monitoring of disease development or therapy response. In turn, this can reduce animal numbers and yield more reliable data with less statistical variance.

NISC aims to provide the foundation for an easily accessible platform to perform complex and scientifically innovative research studies, ensuring a swift and robust translation from basic science, probe development and preclinical testing to clinical phase studies. NISC will commit to ensure reproducible data with a high level of scientific integrity. It's IT infrastructure group is supposed to develop data analysis and visualisation tools as well as web based access tools for registration, information, education and data exchange for the service centre and core labs. According to the proposal, the university campuses at Tübingen and Stuttgart, in combination with the Max Planck Institutes in Tübingen, have achieved the critical mass necessary to become a prominent imaging centre with the aim of performing world-class research and provide the best service for external and internal users. However, all these institutes, laboratories and infrastructure set-ups are distributed over the diverse campuses and are currently only unified as a virtual structure, reducing the potential for interdisciplinary, translational, comprehensive and collaborative high-end studies.

NISC will be used in the field of preclinical (e. g. rodents, pigs) and clinical imaging research studies. According to the proposal, a major strength and novelty of the NISC concept is that biomedical research from all disciplines (oncology, neurology, cardiovascular diseases, immunology, infectiology, microbiology, regenerative medicine) will be performed. NISC will also be open to other life science areas (e. g. plant imaging).

NISC is supposed to operate at limited resources as a virtual structure during the implementation phase, until the building is erected. At this time the virtual structure will be used to develop standardised protocols, multi-modal imaging workflows, SOPs, internet based tools for information, registration, and data storage to combine the complementary disciplines working together at NISC.

According to the proposal, NISC will be a unique structure in Europe, globally there are no comparable physical RIs. Cells in Motion for a Multiscale Imaging Centre (MIC) in Münster is predominantly focused on microscopic imaging and image analysis. The NISC proposers see a great synergy between the two concepts and plan to work together. The University of Aachen has built up the Aachen Center for Biomedical Image Analysis, Visualisation and Exploration (ACTIVE) within their biomedical engineering RI, but with a focus on engineering in general. NISC will be complementary to Euro-BioImaging and both RIs offer broad options for collaborations. In the US, the Institute for Imaging Science at Vanderbilt University has implemented a physical structure, assembling imaging experts and infrastructures at a large scale under one roof. The Moffitt Cancer Center in Florida operates a large imaging centre for cancer research, which includes omics approaches and bioinformatics. However, compared to these centres, NISC is supposed to have a much broader range of expertise as it includes areas of sequencing/omics, bioinformatics, systems biology, and pharmacology (compared to Vanderbilt) and does not only focus on one disease area (compared to Moffitt).

Assessment

The scientific potential of the planned RI is high. The overarching goal is the integration of microscopic technologies with macroscopic imaging modalities. This integration has the potential to provide deeper insights into biological and medical questions, and help validate in vivo imaging methods. The proposal is consistent with the recent growth of imaging technology and its impact and importance in modern biomedical research. Although access to imaging for research purposes is already widely available in other major European centres, there are not many places that can offer the range of imaging techniques planned here, nor the resources for new radiotracer development. The ability to study animals with a comprehensive array of tools for preclinical studies is already present at the existing institutes in Tübingen. Furthermore, there exists a very strong programme in the development of novel molecular probes. A particularly novel aspect and strength of this proposal is the core vision of integrating information from different types of images (micro- and macroscopic imaging) with information from other measurement techniques (such as proteomics) and the use of advanced computing algorithms to analyse and interpret the imaging data. Primary innovation in terms of scientific insights that have potential for broader impact will come from this cross-technology data linking and functional integration. However, there is a lack of detail on how microscopic and macroscopic imaging will be combined. Several examples were given of how this might be achieved, but it was unclear as to the generalisability of these approaches to a broader range of biological systems. Although the integration of imaging with omics and other data is worthy, it is unlikely that NISC can maintain international leadership in these other areas. An alternative model would be to collaborate with centres or departments that will ensure these complementary technologies are maintained at state-of-the-art. Therefore, cooperation with the Multiscale Imaging Centre of the University Münster (MIC) and the Central Institute for Translational Cancer Research (TranslaTUM) is seen as very important. Overall the proposal combines some outstanding features (such as the molecular probe development) with other aspects that are important incremental advances but not necessarily groundbreaking.

These resources are planned to be hosted under the same roof, offering the potential to achieve synergies and efficiencies. The proposal stresses that establishing a single facility is the only way to achieve international prominence. While the argument in favour of having a coherent single entity in a single building is compelling, the proposal does not fully explore alternative strategies. Worldwide there exist many different biomedical imaging centres of excellence that are developing advanced imaging technologies for biological and medical applications. However, they generally specialise on a limited number of technologies and rarely aim at the level of multimodal integration proposed by the establishment of NISC. The RI will be unique in Europe and more comprehensive in its ambitions than centres elsewhere.

To successfully implement and establish NISC, it is important to clearly define what constitutes biomedical imaging science. Otherwise the integration of omics, bioinformatics, probe development, machine learning, and systems biology can lead to a dissipation of resources due to a lack of focus.

Trying to apply multiple imaging modalities to a wide range of disciplines (oncology, neurology, cardiovascular diseases, immunology, infectious diseases and microbiology) could reduce the ability to communicate well and find synergies. The formulation of a joint core objective is needed. NISC will house accomplished and productive scientists with strong backgrounds in technological innovation but details of what specific directions will be emphasised are not well described in the proposal.

NISC will take some years to materialise and during that time there are likely to be developments in some of the core technologies relevant to its mission. Consequently, there needs to be provisions for flexible diversion of resources into new directions. For example, in neuroscience new microscopy and optogenetic methods are rapidly developing, which may make current modalities obsolete in a few years. Although NISC has designated a fund for integrating some additional instrumentation, it was not clear what mechanisms would be put in place to select them.

NISC enjoys strong support from several participating groups with diverse types of expertise. The level of support and degree of engagement with clinical studies appears less well developed.

III.5.b Utilisation

Description

User groups will comprise internal and external users from academia as well as industries. In the second full operational year of NISC, 100 preclinical imaging users are expected of which 85 will be academic (~40 % national, 40 % European, 20 % international) and 15 will be from industry. Furthermore, NISC expects 220 clinical imaging and in vitro diagnostic users (~70 % national, 20 % European, 10 % international users) performing scientific clinical and translational studies. As backup (e. g. conflict of measuring slots, service times of imaging equipment, very sick in house study patients who cannot be transported to NISC) the users will have access to existing clinical scanners at the Department of Radiology.

Projects will be selected based on their innovation and scientific merit. All user requests will go through the study peer review panel consisting of interdisciplinary experts approved by the advisory board. Industry will be charged a 70 % overhead, of which 25 % will be used to provide new investments into scientific devices and infrastructure. A further 25 % will be used to support innovative academic projects with insufficient funding. NISC will provide peer support for study planning, regulation, experiment execution, data analysis, and data interpretation.

According to the proposal, it is a mandatory part of an imaging centre to manage, mine, explore and visualise data obtained and derive information to support insight and understanding. This requires significant (bio-)informatics expertise in different areas of computer science, data mining and visualisation. The Universities of Tübingen and Stuttgart want to team up to establish a joint Computing and Visualisation Center within NISC to advance the fundamental research in computer science and to provide and support the computational infrastructure. A central computer centre will be established to store, manage, and process all anticipated data. According to the proposal, one of NISC's goals is to make as many anonymised imaging data sets available to the public as possible. Unlimited access (free of charge to collaborating academic institutions) to a large set of data can have an enormous potential to positively impact imaging science, bioinformatics and computer engineering.

To maintain scientific integrity at NISC, all users must sign a declaration to work according the DFG rules "Safeguarding Good Scientific Practice". Twice a year there will be offered a compulsory class on good scientific practices. SOPs will be reviewed annually and amended where necessary.

Assessment

The number of investigators potentially able to make use of the resources is high. The expected user groups include basic and clinical scientists from biomedical disciplines and industries, dealing with e. g. cancer, neurological diseases, metabolic disorders and cardiovascular diseases. These groups are likely to perform MRI studies of the brain, molecular imaging studies of animal tumor models, and structural and functional studies of genetically modified mice. Estimates on user groups seem reasonable based on current experience of the preclinical and clinical departments at the university. The current use and the expected growth rate are encouraging and impressive.

NISC will be available on an open access basis. There are appropriate policies defined for access management and service. A peer review panel will review proposed studies, which will help to ensure merit-based approval. An additional screening of proposals for feasibility, carried out by an internal panel should be included. A process for selecting the review panel and scoring proposals is clearly described.

Overall, the plans for managing and access are appropriate. But more careful thought will need to be given to the formal mechanisms by which collaborations are formed, how routine service use becomes elevated to a collaboration, and how upfront costs and commitments are established. For example, the development of new methods, protocols and compounds may entail very diverse levels of expense and use of resources so they cannot all be open ended commitments from the centre. Different levels of access and ownership and support for the data need to be provided to different users.

Furthermore, the proposal does not provide much detail on how training and user support services will be provided. Also missing is a plan concerning user participation in subsequent development of the RI.

Overall, the plans for data management and archiving are well designed. However, data stewardship was considered the weakest part of the proposal. There will be an enormous amount of data produced. Therefore, an accompanying budget for data management and long-term storage (at least 10 years) should be included. It is realistic to budget between 5 and 10 % of total investment costs but this is not mentioned in the proposal. How NISC interacts and integrates many of the existing data infrastructures such BBMRI |[128], EATRIS |[129], ELIXIR |[130], is insufficiently addressed within the proposal. None of the modern linked data and cloud approaches that are crucial for a centre like this are discussed in any detail. The correct statements about the need to integrate data from many other fields (omics and beyond) is not backed by any execution vision, which could prevent the RI to reach its full potential. NISC will also undertake to make anonymised data sets available to other researchers (metadata, open access and data sharing). This approach has been very positively used elsewhere. For example, the ADNI (Alzheimer's disease Neuroimaging Initiative) data base and connectome data within the USA have attracted many outside users to test hypotheses. These efforts will require long term continuing support and considerable management of data and resources by dedicated staff separate from scientific personnel.

The overall plans for quality assurance and adherence to ethical standards are adequate. However, it appears that these plans have not specifically been tailored to imaging data, and instead are simply based on very general criteria.

| 128 Biobanking and Biomolecular Resources Research Infrastructure.

| 129 European Advanced Translational Research Infrastructure in Medicine.

| 130 ELIXIR - A distributed infrastructure for life-science information.

Adherence to the DFG guidelines is mandatory but SOPs should specify how reproducibility and image quality will be tested for each imaging protocol. In addition, careful power analyses need to be performed for many studies that will require explicitly knowledge of sources of variance and their magnitudes. Given that the clinical studies will be spread over different instruments and sites, careful thought needs be given to ensure comparability and standardisation of results. The recruitment of a qualified biostatistician with expertise in preclinical-study and clinical-trial design is essential.

III.5.c Feasibility

Description

NISC proposers state that all relevant technological developments to realise the concept already exist. While technological advances will be pursued during the entire set-up and lifespan of NISC, the basic realisation and operation is supposed to not depend on these technological or methodological advances. According to the proposal, there are no major risks that could jeopardise the overall realisation.

NISC will be a legal entity of the University of Tübingen that acts as Corporation under Public Law. To maintain the scientific quality of NISC, two external advisory boards (one with eight international peers and an industry board) will be installed.

Since the University of Tübingen already operates an imaging centre based on a virtual structure, all of the required peer experts for imaging science, bioinformatics and omics are on site. NISC will provide a structure to recruit further experts for innovative areas, in trainee, satellite, or directorial levels. For the implementation phase, the University of Tübingen will provide dedicated personnel to support the planning and realisation phase of the NISC building. There are state-of-the art labs for pre-clinical imaging, clinical imaging, systems biology, pharmacy, radiochemistry, bioinformatics, IT/QBiC |[131] and sequencing/omics existing at the University of Tübingen. The departments, junior groups and satellite groups will ultimately move into the NISC building as soon as it is finished.

Assessment

The goal is to expand and integrate existing programmes and achieve synergy by bringing them together into a single administrative and physical structure. This is a phased plan that is supported by existing commitments and policies of

|[131] Web portal that provides software tools to analyse and store data. QBiC: Quantitative Biology Center.

the main institutions involved. Still a residual risk exists, as the successful integration of macro- and microscopic data to understand biological processes and disease, which is introduced as a novel capacity of NISC, is not a foregone conclusion. Another risk is that the selection of modalities to be embraced could in principle prove to be of much less scientific value or even obsolete over the extended time frame envisaged. For example, major expense items include 7 T MRI and Hyperpolarised MRI systems both of which have been around for several years, have great potential, but which have thus far had little practical clinical impact. In addition, it is possible that the time lag between discovery and the ability to undertake meaningful research in new areas will be too long in some cases. On the other hand, the firm commitments from the major partners involved in the project increase the chances the project goals will be achieved.

There is strong institutional support from the Universities of Tübingen and Stuttgart. The plans for project management and governance at all stages are well developed and suitable. There is a strong basis for how NISC would be embedded within the universities and align with their strategic priorities. The governance concept includes two external boards, which should provide strong oversight. The current situation provides a solid basis for establishing and expanding NISC. There are existing facilities, programmes, cooperations and a virtual presence of nearly all aspects of NISC such that it would quickly be able to mature into the facility envisioned. The financial structure and underpinnings, as well as the operational support provided by the institutions appear solid. The estimates of usage and throughput of the various facilities appear realistic.

The proposal states all the required peer experts are already present. This may well be true with the current envisioned focus, but could potentially limit the perspective and outlook to include other promising technologies in the future. In fact, the best scientists should be recruited. It will be important to develop a sounder strategy for establishing leadership of the sub-programmes and to recruit new personnel. This also includes a clearer plan for career development. The academic tracks have clear criteria but the other members of the centre need a similar set of growth points.

III.5.d Relevance to Germany as a location of science and research

Description

According to the proposal, NISC will be the first physical integrated imaging RI in Europe to provide high-level research and access for national and international researchers, without large administrative and organisational obstacles. NISC can help maintaining Germany's strength in research and continuing its long history in imaging technology development.

Two annually workshops in Tübingen, one small animal imaging and multi-modal clinical-translational imaging (PET-MR, PET-CT), are currently established. For at least six junior group leaders NISC will provide the environment to develop their independent academic careers. NISC researchers will regularly attend scientific meetings and organise workshops as well as international scientific conferences. NISC will acquire, secure and transfer intellectual property.

Assessment

Germany is already highly regarded and active in imaging science but lacks a single leading centre that is comprehensive in its scope. Therefore, NISC is likely to contribute strongly and positively to the international visibility of German research. However, given the strength in Germany in some microscopy modalities that are not mentioned in the proposal (nanoSIMS [132], SHG/THG [133], super-resolution, and light sheet imaging) it may not be fully exploiting those possibilities.

There are strong programmes in relevant areas but NISC would outrank any current efforts and be a strong signal to others that Germany intends to continue to play an even bigger role in this important area of biomedicine. It certainly should be a major resource for leading German pharmaceutical companies and a place to attract international and national collaborators. This is especially true for the programme in radiochemistry, which is very strong and a rare resource within Europe.

NISC positions itself at the very attractive junction of basic and applied interdisciplinary biomedical research. This area is sure to grow in the future. Core facilities tend to act as magnets for investigators who need them but whose expertise lies in other areas. Thus the creation of NISC should enable the research careers of various user groups in Biological and Medical Sciences. NISC will support five well established senior groups, six new junior group leaders, and many international students and postdocs. These are mostly derived from collaborating laboratories and institutions that will not move in their entirety to the new building. It will attract trainees in imaging science and different areas of application.

NISC as proposed has relatively weak links to existing national and international infrastructures on bioimaging, biomarker development, biobanking, bioinformatics and data analysis. The embedding in the broader landscape should have been more emphasized within the proposal. Setting up such a large re-

| 132 *Nano Sekundärionen-Massenspektrometer.*

| 133 Second Harmonic Generation/Third Harmonic Generation.

search infrastructure introduces a risk of underutilisation and could lead to a relatively low visibility. Furthermore, the aspect of data integration with other disciplines and the (semantic) linking of annotation, etc. is a weaker part of the proposal, which could negatively impact the attraction beyond NISC`s own walls.

The new centre will undoubtedly be a catalyst for increased collaborations between academic and industrial users. The plans for transfer and impact rely too much on traditional modes of dissemination and there could be much greater efforts to disseminate technological advances. For example, imaging agents, software and technical innovations should be actively advertised and made available through websites. Examples of such dissemination already exist within the imaging field and NISC should make specific efforts to export its products. There is infrastructure in place for the creation and prosecution of intellectual property and it would be useful to develop specific goals in terms of the return on such inventions.

Members of NISC are actively involved in organising conferences and publishing in highly visible journals. The research area of preclinical and clinical diagnosis and treatment is expected to have important societal impact.

III.5.e Complementary and competing research infrastructures

Research infrastructure landscape			
Name	Brief description and internet link	Time frame	Location/ participants
	Existing research infrastructures		
AIC – Advanced Imaging Center (complementary)	AIC aims at making imaging technologies developed at Janelia widely accessible, and at no cost, to scientists before the instruments are commercially available. Operating strategically at the interface of engineering and biological applications, the AIC is positioned to reduce the time between instrument development and widespread use in the increasingly technology-intensive field of biology. https://www.janelia.org/, last accessed 29 July 2016	2006	Ashburn, US
BioMedBridges (complementary)	BioMedBridges aims at forming a cluster of the emerging biomedical sciences research infrastructures (BMS RIs) and construct the data and service bridges needed to connect them. The BMS RIs are on the ESFRI Roadmap. Their missions stretch from structural biology of specific biomolecules to clinical trials involving thousands of human patients. Most serve a specific part of the vast biological and medical research community, estimated to be at least two million scientists in Europe across more than 1,000 institutions from more than 36 ESFRI Member States and Associated Countries. BioMedBridges builds	2012	AT, BE, BG, CZ, DE, ES, FN, FR, HU, IL, IT, NL, NO, PL, PT, SL, UK

	a shared data culture in the life sciences by linking up 12 of Europe's new biological, biomedical and environmental research infrastructure. Integrating the vast data resources in the life sciences, including data from genomics, biological and medical imaging, structural biology, mouse disease models, clinical trials, highly contagious agents and chemical biology, shall enable new ways of analysing them to answer new, more complex scientific questions. http://www.biomedbridges.eu, last accessed 29 July 2016 http://www.biomedbridges.eu/, last accessed 25 August 2016		
CAI – Centre for Advanced Imaging	CAI is a strategic initiative of The University of Queensland, reflecting the growth in biotechnology and biomedical research requiring spectroscopic and imaging research capabilities. Its researchers work on innovations in spectroscopic and imaging technology, imaging biomarker development and in biomedical research disciplines, frequently in collaboration with clinical research sites and other local, national, and international research institutes in a range of programmes. https://cai.centre.uq.edu.au/, last accessed 25 August 2016 https://cai.centre.uq.edu.au/files/1162/2015_CAI_Ann_Rep.pdf, last accessed 25 August 2016	Since 2014	Brisbane, AU
CMINT – Memorial Sloan Kettering's Center for Molecular Imaging and Nanotechnology	CMINT is a broad-scope, multidisciplinary translational research programme that unites two rapidly evolving fields — molecular imaging and nanotechnology — by creating expert teams of researchers working in diverse areas such as cancer biology, medicine, chemistry, developmental biology, physics, radiochemistry, immunology, genomics, pharmacology, and engineering. https://www.mskcc.org/research-areas/programs-centers/molecular-imaging-nanotechnology, last accessed 6 September 2016	Launched in 2014	New York, US
CRUK & EPSRC Cancer Imaging Centre – Cancer Research UK & Engineering and Physical Sciences Research Council Cancer Imaging Centre	The CRUK and EPSRC Cancer Imaging Centre brings together scientists and clinicians working on imaging technologies within the field of oncology. The partnership intends to drive forward the development of non-invasive imaging techniques that provide early disease detection, give prognostic information and can detect early treatment response in order to guide therapy in individual cancer patients. http://www.cam-man-cic.ac.uk/, last accessed 15 September 2016	Established in 2013	Manchester and Cambridge, UK
CSB – The MGH (Massachusetts General Hospital) Center for Systems Biology	The CSB was established as one of the five thematic interdisciplinary centres at MGH. It is home to over 200 researchers in 12 PI groups. The mission of the centre is to analyse at a systems level how biological molecules, proteins and cells interact in both healthy and	Established in 2007	Boston, US

	diseased states. https://csb.mgh.harvard.edu/, last accessed 25 August 2016		
EIMI – European Institute for Molecular Imaging (complementary)	EIMI is an established imaging infrastructure at the University of Münster. It was initiated and is primarily operated through the clinic of nuclear medicine. The RI focuses on cardiovascular disease, oncology, neurology and immunology. EIMI depends on radiotracer production from the clinic for nuclear medicine and has a number of locations distributed campus-wide (high field animal MR, PET/CT/Optical, and radiopharmacy). Currently, EIMI is a virtual infrastructure, as not all imaging-relevant infrastructures (radiochemistry, cyclotron, high-field MRI, microscopy, etc.) are under one roof and one leadership. This will change with the inauguration of MIC, where the EIMI concept will be integrated with molecular biology and microscopy. http://www.uni-muenster.de/EIMI/, last accessed 9 September 2016	Since 2007	Münster, DE
IBMI – The Institute of Biological and Medical Imaging of the Helmholtz-Zentrum München	The IBMI is an institute in the realm of optical imaging technology development and its translation into clinical application. The individual groups perform research at nearly all levels of macroscopic optical imaging, ranging from fluorescence and bioluminescence optical imaging, optoacoustic imaging and optical microscopy. Research groups at the centre also cover areas like molecular magnetic resonance imaging, inverse problems and computation, image and signal processing and cell engineering. https://www.helmholtz-muenchen.de/ibmi/, last accessed 9 September 2016	Not specified	Munich, DE
MD Anderson of the University of Texas	Research performed at the institution focuses on four key areas: basic science, translational research, clinical research, and prevention and personalized risk assessment. It hosts different Imaging core facilities being available to external users. https://www.mdanderson.org/research/departments-labs-institutes/programs-centers.html, last accessed 18 October 2016	Not specified	US
ICMIC - In-vivo Cellular and Molecular Imaging Center at Johns Hopkins University	The ICMIC conducts multidisciplinary research on cellular and molecular imaging related to cancer. It provides resources, such as consultation on biostatistics and bioinformatics and optical imaging and probe development, to understand and effectively treat cancer. Its molecular oncology experts consult on preclinical studies, use of human tissues, interpretation of data and molecular characterization of cells and tumour tissue. http://icmic.rad.jhmi.edu/, last accessed 9 September 2016 http://www.hopkinsmedicine.org/research/labs/in-vivo-cellular-and-molecular-imaging-center, last accessed 18 October 2016	Not specified	Baltimore, US
MGH/HST Athinoula A. Martinos	The Athinoula A. Martinos Center for Biomedical Imaging at MGH is devoted to the devel-	Launched in	Charlestown,

Center for Biomedical Imaging	opment and application of advanced biomedical imaging technologies. Its mission is to advance imaging in healthcare through technology development, translational research and education. http://www.martinos.org/, last accessed 9 September 2016	2000	US
MIPS – Molecular Imaging Program at Stanford	The MIPS was established as an interdisciplinary programme to bring together scientists and physicians who share a common interest in developing and using state-of-the-art imaging technology and developing molecular imaging assays for studying intact biological systems. The goals of the programme are to fundamentally change how biological research is performed with cells in their intact environment in living subjects and to develop new ways to diagnose diseases and monitor therapies in patients. Areas of active investigation are cancer research, microbiology/immunology, developmental biology and pharmacology. http://med.stanford.edu/mips.html, last accessed 25 August 2016	Since 2003	Stanford, US
The Moffitt Cancer Center	Moffitt is the only NCI (National Cancer Institute)-designated Comprehensive Cancer Center based in Florida. Its impact on cancer research spans basic science, prevention and clinical research with a focus on translating discoveries into better care. It operates a large imaging centre for cancer research which also includes omics approaches and bioinformatics. https://moffitt.org/, last accessed 6 September 2016	Established in 1981, operation since 1986	Tampa, US
VUIIS – Vanderbilt University Institute of Imaging Science	The VUIIS supports advances in physics, engineering, computing, chemistry, and other basic sciences for the development and application of new and enhanced imaging techniques to address problems and stimulate new research directions in biology and medicine in health and disease. It has implemented a physical structure, assembling imaging experts and infrastructure at a large scale under one roof. https://www.vuiis.vanderbilt.edu/, last accessed 25 August 2016	Since 2002	Nashville, US
Planned research infrastructures/under construction			
EuBI – Euro-BioImaging (complementary)	EuBI aims at providing open physical user access to a broad range of technologies in biological and biomedical imaging for life scientists. In addition, EuBI plans to offer image data support and training for infrastructure users and providers. EuBI currently counts 28 EuBI Node Candidates offering open access to 36 imaging technologies for biological and biomedical imaging. EuBI has been listed on the ESFRI Roadmap since 2008. http://www.eurobioimaging.eu, last ac-	Start of interim operation in 2016. Official launch foreseen to take place in 2017	AT, BE, BG, CH, CZ, DE, DK, ES, FI, FR, GR, HR, IE, IT, IL, LU, NL, NO, PL, SK, UK

	cessed 1 September 2016 www.eurobioimaging-interim.eu, last accessed 29 September 2016		
EU-OPENSCREEN – The European Infrastructure of Open Screening Platforms for Chemical Biology (complementary)	EU-OPENSCREEN aims at building a sustainable European infrastructure for Chemical Biology, supporting life science research and its translation to medicine, agriculture, bioindustries and society. It is a distributed research infrastructure which builds on national networks in 16 European countries. It aims at embracing local research groups and facilitates transnational open access to the most advanced technologies, chemical and biological resources, knowledge and expertise throughout Europe. EU-OPENSCREEN is likely to be established as a European Research Infrastructure Consortium (ERIC). It will comprise high-throughput screening (HTS) centres at different sites in Europe with their special HTS and bio-assay expertise, chemical resources for optimisation of first hit compounds, bio- and chem-informatics capacities, and a publicly-accessible database (the ECBD) combining screening results, assay protocols, and chemical information. A large collection of diverse compounds, representing the chemical knowledge in Europe, will be made available from a central storage facility. http://eu-openscreen.eu, last accessed 17 October 2016.	Start of preparatory phase in 2010. Expected start of operation in 2018	AT, BE, CZ, DK, FI, FR, DE, GR, HU, IT, NL, NO, PL, RO, ES, SE
MIC – Multiscale Imaging Centre of the University Münster (complementary)	In the MIC, biomedical imaging and the respective technologies will be united under one roof. Imaging techniques ranging from high-resolution microscopy to whole body positron emission tomography (PET) are integral to the project. Cellular components of tissues and molecular processes at the scale of a millionth of a millimetre, as well as tissue and organ structure and function, will be visualised and thereby better understood. http://www.uni-muenster.de/Cells-in-Motion/research/multiscale-imaging-centre/index.html, last accessed 25 August 2016	Construction to be completed by 2019	Münster, DE
NIF - National Biomedical Imaging Facility	For detailed information please see the concept proposal of LPI.	Project start 2018	DE
TranslaTUM – Central Institute for Translational Cancer Research	The centre places medical doctors, biologists, engineers, physicists and chemists under one roof, closely working together to multi-disciplinary tackle cancer. It also includes core labs for small animal imaging (PET, SPECT, CT, MRI, and optical), bioinformatics and microscopy, a central sequencing unit and histology. http://www.tum.de/en/research/research centers/translatum/#c27695, last accessed 25 August 2016	Construction to be completed by the end of 2016	Munich, DE

ACTRIS	Aerosol, Clouds and Trace gases Research Infrastructure
ACTRIS-D	*Aerosole, Wolken und Spurengase Forschungsinfrastruktur – Deutscher Beitrag* / Aerosol, Clouds and Trace gases Research Infrastructure – German Contribution
AIC	Janelia Advanced Imaging Center
AIM Photonics	American Institute for Manufacturing Integrated Photonics
ALM	Advanced Light Microscopy
ALM-CFs	Advanced Light Microscopy – Core Facilities
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
BBMRI	Biobanking and Biomolecular Resources Research Infrastructure
BESSY FEL	The BESSY Soft X-ray Free Electron Laser
BGBM	Botanic Garden and Botanical Museum Berlin
BioM-D	*Deutsches Zentrum für Biodiversitätsmonitoring* / German Center for Biodiversity Monitoring
BMBF	*Bundesministerium für Bildung und Forschung*
CETAF	Consortium of European Taxonomic Facilities
CT	Computer Tomography
DCOLL	*Deutsche Naturwissenschaftliche Sammlungen als integrierte Forschungsinfrastruktur* / German Natural Science Collections Infrastructure
DESY	*Deutsches Elektronen-Synchrotron* / German Electron Synchrotron
DFG	*Deutsche Forschungsgemeinschaft* / German Reserch Council
DKFZ	*Deutsches Krebsforschungszentrum*
DKIST	Daniel K. Inoue Solar Telescope

DLR	*Deutsches Zentrum für Luft- und Raumfahrt* / German Aerospace Center
DOI	Digital Object Identifier
DSMZ	*Leibniz-Institut DSMZ – Deutsche Sammlung von Mikroorganismen und Zellkulturen* / Leibniz Institute – German Collections of Microorganisms and Cell Cultures
DWD	*Deutscher Wetterdienst* / German Meteorological Service
EAST	European Association for Solar Telescopes
EATRIS	European Advanced Translational Research Infrastructure in Medicine
ECSS	European Cooperation for Space Standardization
EEG	Electroencephalography
EHF	Extreme high-field
e-IRG	e-Infrastructure Reflection Group
ELIXIR	ELIXIR - A distributed infrastructure for life-science information
ERA	European Research Area
ER-C	*Ernst Ruska-Centrum für Mikroskopie und Spektroskopie mit Elektronen*
ER-C 2.0	*Ernst Ruska-Centrum 2.0: Die Nationale Forschungsinfrastruktur für höchstauflösende Elektronenmikroskopie* / Ernst Ruska-Centre 2.0: National Research Infrastructure for Ultra-High-Resolution Electron Microscopy
ERIC	European Research Infrastructure Consortium
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Southern Observatory
EST	European Solar Telescope
EU	European Union

EuBI	Euro-BioImaging – The European Research Infrastructure for Imaging Technologies in Biological and Medical Sciences
EUCOLL	European Science Collection Infrastructure
EU-OPENSCREEN	European Infrastructure of Open Screening Platforms for Chemical Biology
EUR	Euro
EUROCHAMP	Integration of European Simulation Chambers for Investigating Atmospheric Processes
FAIR (data principles)	Findable, Accessible, Interoperable, Reusable (data principles)
FEI	FEI Company, Inc.
FIR	Far Infrared
FZJ	*Forschungszentrum Jülich*
GBIF	Global Biodiversity Information Facility
GEBI	German Euro-BioImaging
GerBI-RI	German BioImaging Research Infrastructure
GFBio	German Federation for Biological Data
GFZ	*Deutsches GeoForschungsZentrum – Helmholtzzentrum Potsdam*
GHz	Gigahertz
GLORIA	Global limb Radiance Imager for the Atmosphere
GmbH	*Gesellschaft mit beschränkter Haftung*
GPS	Global Positioning System
GREST	Getting Ready for EST
GSI	*GSI Helmholtzzentrum für Schwerionenforschung GmbH*
GSRT	General Secretariat for Research and Technology
H2020	Horizon 2020 – The EU Framework Programme for Research and Innovation
HGF	*Helmholtz-Gemeinschaft Deutscher Forschungszentren*

HKI	*Hans-Knöll-Institut – Leibniz-Institut für Naturstoff-Forschung und Infektionsbiologie*
IAGOS	In-service Aircraft for a Global Observing System
ICOS	Integrated Carbon Observation System
iDigBio	Integrated Digitized Biocollections
IGBP	International Geosphere-Biosphere Programme
IOF	*Fraunhofer-Institut für Angewandte Optik und Feinmechanik*
IT	Information Technology
JUH	Jena University Hospital
KCS	Key Community Scientist
KIT	Karlsruhe Institute of Technology
LPI	*Leibniz-Zentrum für Photonik in der Infektionsforschung* / Leibniz Center for Photonics in Infection Research
LTER	Long Term Ecological Research
MCAO	Multi-Conjugate Adaptive Optics
MEG	Magnetoencephalography
MERIA	Multiple Eye for Remote Investigation of the Atmosphere
MfN	*Museum für Naturkunde* – Leibniz Institute for Evolution and Biodiversity Science
MIC	Multiscale Imaging Center
MPG	*Max-Planck-Gesellschaft* / Max Planck Society
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
NCB NATURALIS	*Nederlands Centrum voor Biodiversiteit Naturalis* / Naturalis Biodiversity Center /
NFDI	*Nationale Forschungsdateninfrastruktur* / National Research Data Infrastructure
NIF	*Nationale Biomedizinische Bildgebungseinrichtung* / National Biomedical Imaging Facility

NISC	National Imaging Science Center
NPL	National Photonics Labs
OECD	Organisation for Economic Co-operation and Development
PET	Positron Emission Tomography
PI	Principal Investigator
PTB	*Physikalisch-Technische Bundesanstalt*
QS mode	Queued-Service mode
R&D	Research and Development
RF	Radiofrequency
RfII	*Rat für Informationsinfrastrukturen*
RI	Research Infrastructure
SAR	Synthetic Aperture Radar
SDC	Science Data Centre
SFM	structural-functional-metabolic
SHS	Spatial Herodyne Spectrometer
SME	Small and medium-sized enterprises
SNSB	*Staatliche Naturwissenschaftliche Sammlungen Bayerns*
SOLARNET	High-Resolution Solar Physics Network
SOP	Standard Operation Procedure
SPM	Scanning Probe Microscopy
T	Tesla
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TB	Terabyte
TEM	Transmission Electron Microscope
TERENO	Terrestrial Environmental Observatories
TOSC	Telescope Operation and Science Centre
TriG	Triple GNSS = GPS/Glonass/Galileo
TRL	Technology Readiness Level

TTC	Training and Technology Center
UBA	*Umweltbundesamt* / (German) Federal Environment Agency
UHF	Ultra high-field
USA	United States of America
UV	ultraviolet
VTT	Vacuum Tower Telescope
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
XUV	Extreme ultraviolet
ZFMK	*Zoologisches Forschungsmuseum Alexander König – Leibniz-Institut für Biodiversität der Tiere* / Zoological Research Museum Alexander Koenig - Leibniz Institute for Animal Biodiversity

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