HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

HELMHOLTZ ROADMAP RESEARCH INFRASTRUCTURES 2021

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LIST OF PLANNED NEW RESEARCH PROJECTS 2021

CONTENTS

FOREWORD

In the face of increasingly complex global and societal challenges, addressing challenging scientific questions often requires the use of large and comprehensive research infrastructures. Whether it be an accelerator facility, detector-based telescope, satellite, research vessel or supercomputer – it is often only with the help of state-of-the-art large-scale research facilities that the frontiers of knowledge can be pushed and scientific progress achieved. Not only does this bring deeper insights into the secrets and mysteries of nature, but also, in concrete terms, the development of technical innovations, from new materials and key technologies to medical applications in the field of diagnostic and therapeutic procedures.

The design, construction and operation of large-scale research infrastructures form an important element of the Helmholtz Association – Germany‘s largest scientific organization. Cooperation with strong partners from the national and international environment plays a decisive role. The user operation of large-scale research facilities is a prime example of the division of tasks in the German science system and the cooperation of German and foreign partners with the Helmholtz Association. Research groups from universities and non-university scientific institutions in Germany and abroad form focal points for large-scale international cooperation and networks. These contribute significantly to Germany‘s attractiveness as a location for research and technology development. This benefits not least the next generation of scientists, who receive the best research opportunities and chances for comprehensive and optimal training at these facilities. Research infrastructures also generate considerable added value in an economic sense. Suppliers and companies from industry and commerce collaborate with the Helmholtz Association to ensure that the high demands placed on research facilities can be met. In this way, the research centers of the Helmholtz Association increase innovation competence regionally, nationally and internationally. The combination of outstanding scientific personnel, critical mass, interdisciplinary expertise, high system competence and excellent research infrastructures creates ideal conditions for successful cutting-edge research.

The year 2021 marks the 200th anniversary of the birth of the Helmholtz Association‘s namesake: Helmholtz has left a lasting mark on the worldwide science community like few other research personalities of his time. To mark this anniversary, the Helmholtz Association is presenting the updated plan of its roadmap for major research infrastructures in its Research Fields. This planning was preceded by an extensive portfolio and “foresight” process of the Research Fields, which reflects and incorporates the further development of the scientific Programs for the next decade following international peer review. This process is in a state of flux: the Helmholtz Association aims to cooperate closely with its partners from basic research, systems analysis and technology transfer, to application-oriented areas of technology and society. Scientific excellence in research, strategic relevance and visible contributions to the international scientific community are the criteria by which the Helmholtz Association‘s research infrastructures must be measured. In dialog with scientific partners and users, the Helmholtz roadmap for new research infrastructures will therefore be subjected to a critical review in the course of 2021 in order to highlight thematic priorities, the chronological order of the planned projects, and possible gaps, and will thus incorporate the user needs and perspectives of strategic and scientific partners in the best possible way. Ultimately, this should also help the funding body to make balanced research policy decisions and set the course for which of the proposed research infrastructures should be pursued in the coming years.

Otmar D. Wiestler
President of the Helmholtz Association

ROADMAP PROCESS OF THE HELMHOLTZ ASSOCIATION

Design, construction and operation of large-scale facilities and complex, scientific infrastructures are core elements of the Helmholtz Association‘s mission. They enable the Association to pursue the long-term research goals for Germany in order to meet societal needs, and to preserve and improve the foundations of life. The Helmholtz Association makes its large-scale research facilities available to national and international partners for joint research. The list of planned, new research infrastructures compiled as part of the Helmholtz Roadmap identifies the projects that are important in the coming years for the strategic implementation of Helmholtz Association‘s scientific portfolio from the perspective of the Association‘s research centers, both for their own research and for providing exceptional infrastructures for an external user community.

The list of projects is the starting point for decisions on strategic expansion investments within the Helmholtz Association (Category A) as well as contributions to the National Roadmap (Category B) and European or international strategies (Category C). This list includes projects for which, as a rule, no funding decision has yet been made, but funding concepts for construction and operation are available.

The list of research infrastructures serves as a basis for:

- Discussions about strategic planning with the funding agencies, in particular for the preparation of the National Roadmap,
- The financial planning for the construction and operation of the research infrastructures,
- Concrete arrangements regarding coordination with the user communities.

This list is incorporated within the process for the Helmholtz Roadmap and comprises two phases:

PHASE I. Listing of planned, new research infrastructures.

Helmholtz scientists submit proposals, which are intensively discussed in the centers and Research Fields. The focus is on the question of which research infrastructures are needed in order to meet user requirements in the international environment and to be of significant scientific influence. This discussion is closely linked to the strategic planning of the research portfolio in the context of program-oriented funding, and takes into account the projects and schemes that exist or are being implemented. In this context, the time scales are by their nature different: a new synchrotron requires a longer planning and construction period than a research platform for Earth system research. In principle, the planning period covers the next ten years. National and international considerations play an important role in all proposals. With the proposals prioritized in this way, the Association has drawn up a roadmap that is intended to enable long-term planning of projects within the research centers, the Research Fields, and the community, which can be regularly adjusted with regard to current developments. The list is intended to serve as a basis, as realistic as possible, for the subsequent discussions with research partners and funding agencies on the possible implementation of the individual projects.

PHASE II. Inclusion of projects on the Helmholtz roadmap

For the projects on the list, applications or design reports are prepared then reviewed and prioritized in the Helmholtz Association’s process. The evaluation follows a transparent metric that includes the scientific potential of the proposed project, the strategic importance for the Helmholtz Association, for Germany as a science location, as well as the technical feasibility, the financial framework conditions for construction and operation, and a “lifecycle” analysis. Large projects with an investment volume of > € 50 million initially go through this phase with preliminary applications, which, in the case of a positive evaluation, are introduced into either the national roadmap, or European or multinational processes.

In order to evaluate the different proposals in an open and scientific manner, the Association has assembled a dedicated commission (FIS = Forschungsinfrastruktur-Kommission, Expert Commission for the Evaluation of Research Infrastructures of the Helmholtz Association). The commission is comprised of both internal and external members and organizes the evaluation of the proposals, then submits concrete recommendations for the individual proposals and their prioritization to the decision-making bodies, i.e. the General Assembly and the Senate. With this extensive process, the Association ensures that proposals are of a quality and maturity commensurate with the advised size and importance of the projects.

The Helmholtz Association has presented similar roadmap plans twice in the past. The lists presented in 2011 and 2015 included projects that could be introduced into the competitive processes within the Association as well as at national and European level in the following years, many of which are now being implemented. In the evaluations for the fourth program period, high-ranking international groups of experts also subjected the infrastructure planning to a critical review. This is a good time to bring together the plans and discuss them with scientific partners from universities and other research organizations at a one-day symposium. As a result of these discussions, the new 2021 list is now available.

HELMHOLTZ ROADMAP 2015 – A REVIEW

Sophisticated, highly complex large-scale research facilities, as well as interconnected infrastructures distributed across different sites are a hallmark of the Helmholtz Association. For example, the Association operates nearly two dozen research infrastructures as user facilities which are used by thousands of external researchers for their research. These user facilities are regularly maintained, modernized and, in some cases, successively expanded through investments in replacements, extensions and upgrades in order to meet the constantly growing requirements of the scientific community.

The Helmholtz Association also operates these and other research infrastructures for its own research. In addition, there are major international projects that are being built or already being operated with the participation — or under the leadership of – research centers of the Helmholtz Association, such as the European XFEL, which has been successfully operational since 2017, or the Facility for Antiproton and Ion Research (FAIR), which is under construction.

In the roadmap presented in 2015 the Helmholtz Association put forward numerous new plans that either continued existing projects or related to completely new projects. Of the latter group, here is a summary of the projects that have actually been realized or are in the process of realization since the publication of the 2015 roadmap:

- In the Research Field Energy, the Living Lab Energy Campus **(LLEC)** is being implemented in Jülich. Furthermore, the research and technology platform for the decommissioning of nuclear facilities and for the management of radioactive waste **(HOVER)** is under construction in Karlsruhe, Jülich and Dresden-Rossendorf. Following the presentation of the roadmap in 2015, the Helmholtz Energy Materials Foundry **(HEMF)** was also realized at various locations.

- In the Research Field Earth and Environment, the Modular Observation Solutions for Earth Systems **(MOSES)** is nearing completion. In addition, as a follow-up to the 2015 roadmap, work on the High Performance Computing System for Climate and Earth System Modeling in cooperation with the German Climate Computing Center **(DKRZ)** has been successfully started together with the Research Field Information.

- The Research Field Health is currently pursuing a number of projects that are under construction or close to completion: The Radiopharmaceutical Research and Development Center **(FER)** in Heidelberg, the Centre for Individualized Infection Medicine **(CIIM)** in Hannover, and the Optical Imaging Center **(OIC)** in Berlin. The Helmholtz Pioneer Campus **(HPC)** and the Enabling Technologies Center **(ETC)** are also under construction at the Munich site.

- The Research Field Aeronautics, Space and Transport has been able to implement three projects at DLR sites since the 2015 roadmap: The research platform Inflight Systems & Technology Airborne Research **(iSTAR)**, the project on the Research Vehicle Next Generation Car **(NGC)** and finally the establishment of the Concurrent Certification Centre **(C-Cube)**.

- In the Research Field Information, numerous projects have been realized: The Jülich Short-pulsed Particle and Radiation Centre **(JuSPARC)** has been implemented, as has the Helmholtz Association‘s project share in the establishment of the European Facilities in Electron Microscopy **(ER-C)** in Jülich. The Helmholtz Data Federation **(HDF)** is also close to completion. The Karlsruhe Center for Optics & Photonics **(KCOP)** is under construction. In recent years, the computing projects Infrastructure for the Helmholtz Earth System Science **(Tier-0/1)** and the Helmholtz Quantum Center **(HQC)** have been added, both also at the Jülich site.

- In the Research Field Matter, the modifications of the detectors at the Large Hadron Collider (LHC) at CERN **(LHC Detector Upgrades)** have been implemented as part of an international collaboration. The Variable Pulse Length Storage Ring **(BESSY-VSR)** in Berlin is in the demonstration phase. Finally, the Accelerator Technology HElmholtz iNfrAstructure **(ATHENA)** was brought to fruition. The construction of the Helmholtz International Beamline for Extreme Fields at the European XFEL **(HIBEF)**, an international project at the “free-electron laser” facility, was also completed, although the withdrawal of the Chinese cooperation partner requires replacement investment, which is why the project appears again on the current roadmap.

The list of strategic expansion projects that have been completed or are being implemented since 2015 impressively demonstrates the diversity and dynamism associated with the planning and implementation of research infrastructures.

LIST OF PLANNED NEW RESEARCH INFRASTRUCTURES 2021

	Project	Acronym	Helmholtz Center Coord. & Participation		Cate-gory	Implemen-tation	Total invest-ment in € MM (= million Euro)	German Share in € MM	Helmholtz Share in € MM
Energy	Geothermal Laboratory in the Crystalline Basement	GeoLaB	KIT	GFZ, UFZ	A	2023 - 2029	49.8	49.8	35
	Bridging the innovation gap in catalyst research for electro-, photo- and thermocatalysis	4D-CAT	HZB	FZJ, KIT	A	2024 -2027	25.8	25.8	25.8
	High Power Grid Lab	HPGL	KIT		A	2025 - 2030	20	20	20
	Center for Resource Process Intensifi-cation and Interface Studies	CeRI^2	HZDR		A	2026 - 2029	16	16	16
	Center for Radioecology and Radiation Research	ZRS	HZDR		A	2027 - 2031 et seq.	28	28	28
	Flexible Processing Plant Demonstrator Platform	FlexiPlant	HZDR		B	2024 - 2030	66.7	66.7	
	International Fusion Materials Irradiation Facility - Demo Oriented Neutron Source	IFMIF-DONES	KIT		C	2023 - 2031	551	79.5	
	Research Vessel for Maritime Energy Systems	FSE	DLR		A	2021 et seq.	36	36	
Earth and Environment	Marine Environmental Robotics and Sensors	MUSE	AWI	GEOMAR, Hereon	A	2023 - 2029	46.8	29.7	29.7
	Observation Platforms for Real-Time Data Acquisition in the Terrestrial System	Terra-Lab	FZJ	AWI, DLR, GFZ, Hereon, KIT, UFZ	A	2024 - 2028	30	30	30
	SMART Cables And Fibre-optic Sensing Amphibious Demonstrator	SAFAtor	GFZ	GEOMAR, Hereon	A	2025 - 2029	300	30	30
	Sensing the Atmosphere	ATMOSense	KIT	AWI, DLR, FZJ, GEOMAR, GFZ, Hereon	A	2026 - 2030	35	35	35
	Urban Environmental Observatories	UrbENO	KIT	FZJ, GFZ, Hereon, UFZ	A	2027 - 2031 et seq.	30	30	30
	Atmospheric and Climate Satellite	AtmoSat	FZJ, KIT	AWI, GEOMAR, GFZ	B	2023 - 2028	165.5	152.5	
	From sensing to sustainable land use and management	TerraNet	FZJ	AWI, DLR, GFZ, Hereon, KIT, UFZ	B	2024 - 2028	100	54	
	Gravity Recovery and Climate Experiment (with ICARUS payload)	GRACE-I	GFZ	DLR	C	2022 - 2032 et seq.	510.9	211.5	
Health	Clinical Research Network for Neurode-generative Diseases	KFNE	DZNE		A	2023 - 2028	30.6	30.6	30.6
	3R Preclinical Cancer Trial Center	3R PCTC	DKFZ		A	2024 - 2030	35	35	35
	Berlin Cell Hospital	BCH	MDC		A	2025 - 2031 et seq.	48	48	48
	Comprehensive Environmental Health Exposure Center	CEC	HMGU		A	2026 - 2031 et seq.	35	35	35
	Next Generation Proton Therapy: Online Adaptive	PT2030	HZDR		A	2027 - 2031 et seq.	35	35	35
	National Alliance for Pandemic Thera-peutics	NA-PATH	HZI		B	2021 et seq.	105	105	

	Project	Acronym	Helmholtz Center Coord. & Participation		Category	Implementation	Total investment in € MM	German Share in € MM	Helmholtz Share in € MM
Information	The Jülich User Infrastructure for Quantum Computing	JUNIQ	FZJ		A	2023 - 2025	25	25	25
	In-situ Innovation Platform for Multifunctional Material Systems	InnoMatSy	Hereon	DESY, FZJ, HZB, HZDR, KIT	A	2024 - 2028	27	27	27
	The Karlsruhe Nuclear Magnetic Resonance facility	KNMR	KIT		B	2024 - 2029	93	93	
	Exascale Supercomputer	ESC	FZJ		C	2022 - 2023	277	277	
Aeronautics, Space and Transport	Satellite Mission for Monitoring Dynamic Processes on the Earth's Surface	Tandem-L	DLR	AWI, FZJ, GFZ, UFZ	B	2022- 2030	771	771	
	Research Platform for Atmospheric Research	ASTAR	DLR		B	2024-2029	76	76	
	Campus for Medicine and Informatics in Aerospace	CMI	DLR		A	2023-2028	43	43	43
Matter	Distributed Detector Laboratory	DDL	DESY	GSI (HI Jena), HZB, KIT	A	2023 - 2027	31.6	31.6	31.6
	Upgrade of the Grid Computing Centres for the HL-LHC	TIER-Upgrade	KIT	DESY, GSI	A	2025 - 2028	33	33	33
	Upgrade of the Synchtrotron Radiation Source PETRA III	PETRA IV	DESY	Hereon	B	2023 - 2028	670.8	670.8	
	Dresden Advanced Light Infrastructure	DALI	HZDR		B	2023 - 2029	200	200	
	Berlin Electron Storage Ring for Synchrotron Radiation III	BESSY III	HZB		B	2026 - 2031	550	550	
	ACcelerator-Driven multipurpose ion beam Complex	ACDC	HZDR	GSI	B	2024 - 2028	94	94	
	IceCube-Generation 2	IceCube-Gen2	DESY	KIT	C	2024 - 2031	285	40	
	Dark Matter WIMP Search with Liquid Xenon	DARWIN	KIT		C	2025 - 2030	175	44	
	Einstein Telescope, a 3rd Generation Gravitational Wave Detector	ET	DESY	HZDR, KIT	C	2026 - 2031 et seq.	1736	n/a	
	Global Cosmic Ray Observatory (GCOS)	GCOS	KIT		C	2028 - 2031 et seq.	390	40	
	Helmholtz International Beamline for Extreme Fields 2.0	HIBEF 2.0	HZDR	GSI	A*	2023 - 2025	28	28	28

Category A	Helmholtz projects financed through the Helmholtz Association's competitive procedure for strategic expansion investments (€15 to €50 million).
Category B	Large national projects of the Helmholtz Association that are included on the national roadmap and funded with additional project funding (> €50 million).
Category C	Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.
A*	The construction of HIBEF 1.0 at the European XFEL is almost complete, but the withdrawal of the Chinese cooperation partner means a replacement investment is necessary.

RESEARCH FIELD ENERGY

Profile

A climate-neutral energy supply that is economically and socially sustainable is the focus of the scientists within the Research Field Energy. The scientists are working to shape the energy transition in Germany and driving the sustainable transformation of the energy supply worldwide: To this end, they are researching and working out innovative conversion, distribution and storage technologies, and are developing solutions for a cross-sector energy system. The Research Field is developing holistic concepts that systemically incorporate all relevant energy conversion chains and comprise future-proof technological options.

Challenges

In order to counteract human-made global warming, decarbonization and the transformation of the energy system towards renewable sources are required. This demand for change results in priority challenges of the Research Field Energy:

- A sustainable energy system will be more decentralized, will have more flexibility, and the electricity, heat, transport, and resource sectors will be coupled. This requires novel systemic research approaches that combine technological with societal and economic aspects, enable the development of a new generation of digital concepts (Energy 4.0), and also include European and global perspectives.

- New technologies are needed along the entire value chain – from the development of feedstocks and suitable materials to the conversion, storage, distribution and utilization of energy. Energy efficiency must be significantly increased along the entire chain, and at the same time, energy use must be made more flexible in all sectors.

- The global nature of climate and energy issues requires pursuing long-term alternative solutions for safe and climate-neutral energy production, such as fusion, in order to generate technological options for the future.

- In the area of nuclear waste management and safety, significant challenges exist in the interim and final storage of radioactive waste, and in the dismantling of nuclear facilities. As many countries worldwide continue to rely on nuclear energy, the safety of nuclear reactors is yet another challenge.

Strategy

The Research Field Energy meets the above challenges by placing highly relevant scientific focuses in four programs: The Energy System Design (ESD) program takes a holistic approach. It combines systems analysis, social science, and economic competences into the design of the energy systems of the future. In addition to the analysis of energy systems, the focus is also on their digitalization and the development of system technologies. The Materials and Technologies for the Energy Transition (MTET) program uses an interdisciplinary approach to research into materials and technologies for energy generation, conversion, and storage, as well as energy and resource efficiency. It develops technological options for the energy transition from scientific foundations through to application.

The Fusion (FUSION) program investigates and develops the physical and technical principles for the design and construction of a fusion power plant. It is part of the European coordinated and funded fusion research. The Nuclear Waste Management, Safety, and Radiation Research (NUSAFE) program conducts essential research on interim and final storage, decommissioning of nuclear facilities, safety of nuclear reactors, and radiation research.

The development, construction and operation of research infrastructures are essential prerequisites for the activities of the Research Field Energy. They also make it a sought-after partner for research institutions from all over the world, for regional, national and international universities, and for companies and start-ups.

Infrastructure Planning

Infrastructure planning is aligned along the major lines of the Research Field's strategy.

To this end, systemic research in the ESD program requires: The planned High Power Grid Lab **(HPGL)**, which will enable the development of a holistic Power Hardware-in-the-Loop (PHiL) test environment and, in conjunction with the existing Energy Lab 2.0, testing in smart interconnected power systems. The Research Vessel for Maritime Energy Systems **(FSE)** will be used to demonstrate and test new energy systems for maritime applications.

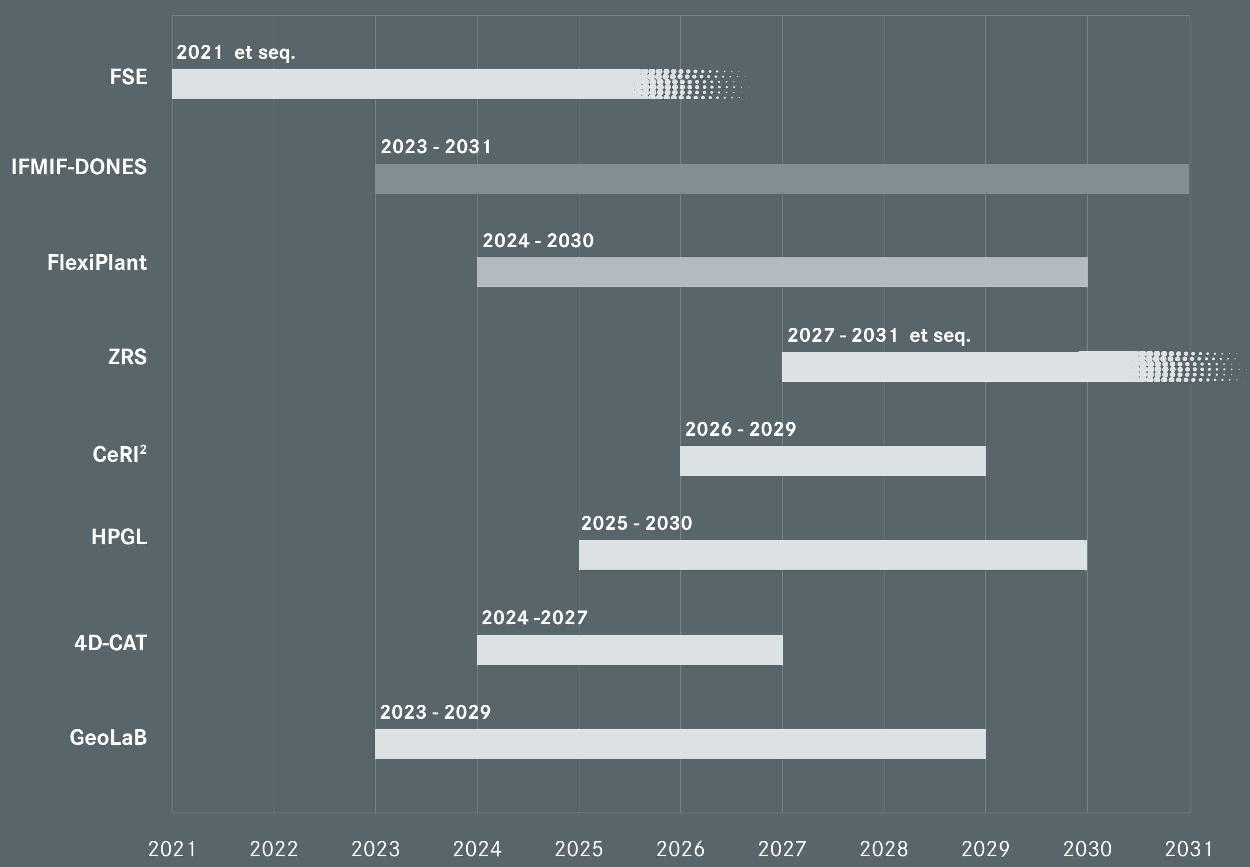
In the MTET program, several new research infrastructures are required along the entire innovation chain for technology development towards the energy transition: The generic underground laboratory Geothermal Laboratory in the Crystalline Basement **(GeoLaB)** is designed as the first reservoir simulator for applications with high flow rates, and thus offers a unique selling point worldwide. **4D-CAT** provides the infrastructure to develop electro-, photo- and thermo-catalytic functional materials in hydrogen-based CO_2-neutral process chains for the production of chemical intermediates and energy carriers. The Center for Resource Process Intensification and Interface Studies **(CeRI²)** will significantly advance the development of energy- and resource-efficient technologies for recovering valuable materials.

The Flexible Processing Plant Demonstrator **(FlexiPlant)** will uniquely advance the development and combination of adaptive and flexible resource technologies, as well as enable their transfer to industry.

The Center for Radioecology and Radiation Research (ZRS) supports radiation research in the NUSAFE program and across Research Fields.

The Fusion program is significantly advanced by participation in the International Fusion Materials Irradiation Facility - Demo Oriented NEutron Source **(IFMIF-DONES)**. For the first time, IFMIF-DONES will provide structural material data for a fusion demonstration reactor under near-application conditions, and is thus an indispensable prerequisite for its realization.

Planned Implementation



Legend:

- **A** – Helmholtz projects financed through the Helmholtz Association's competitive procedure for strategic expansion investments (€15 to €50 million).
- **B** – Large national projects of the Helmholtz Association that are included on the national roadmap and funded with additional project funding (> €50 million).
- **C** – Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.

GEOLAB – GEOTHERMAL LABORATORY IN THE CRYSTALLINE BASEMENT

Summary

The generic geothermal underground laboratory, GeoLaB, is designed as the first reservoir simulator for high flow rate applications and thus offers a unique selling point worldwide. Full-scale experiments address the development of reservoir technologies specifically for geothermal energy on the one hand, and well safety in crystalline rock near geothermal hotspots on the other. This rock has the greatest geothermal potential in the world. GeoLaB includes an approximately 1-2 km long access tunnel to individual caverns near fault zones. Controlled high-flow experiments will be conducted in these caverns at depths of around 400 m. The experiments will be continuously monitored by measurements in fan-shaped boreholes. This will create a unique 4D benchmark dataset worldwide, covering thermal, hydraulic, mechanical and chemical (THMC) parameters. A virtual twin will support planning and communication processes and allow further investigations.

Scientific Importance

With the planned experiments, experimental determination and 3D verification of hydrodynamics (e.g. Navier-Stokes laws) and hydromechanics (e.g. triggering and propagation of microseismicity) in fractured crystalline basement on a 10-100 m scale will be possible at high flow rates for the first time. Also for the first time, dynamic and coupled processes such as stress field variability in space and time, and THMC processes can be experimentally recorded. The use and development of state-of-the-art observation and evaluation methods lead to insights that are of great importance for a safe and ecologically sustainable use of geothermal energy and the entire underground space.

Strategic Relevance

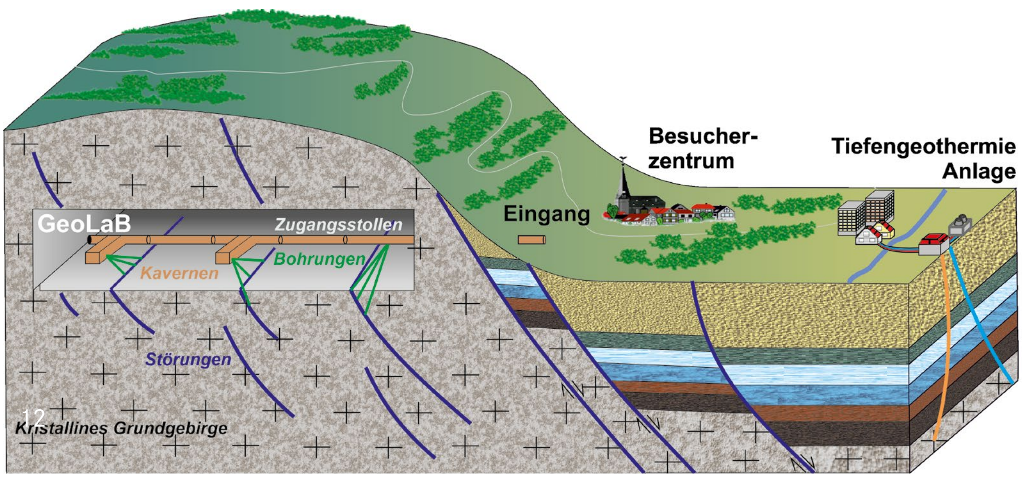
Cutting-edge research for the energy transition:

- Efficient and safe management of fractured reservoirs through controlled high-flow experiments to develop and calibrate smart stimulation technologies to mitigate induced seismicity.
- Multidisciplinary THMC+ cutting-edge research and visualization concepts through systematic experiments to characterize large-scale processes. This includes Big Data management, benchmarking, calibration, and advances in numerical simulation and reservoir visualization.
- Development of environmentally friendly strategies for geothermal installations using tests of well installation safety measures under reservoir conditions with innovative monitoring methods, and developments of new technologies to avoid emissions or radioactive deposits.
- Transparent interaction with the public through participation concepts such as Citizen Science.

Dates and numbers

Acronym:	**GeoLaB**
Category:	A
Period of realization:	2023 - 2029
Estimated investment* in € MM:	49.8 (35)
Estimated operating costs per year in € MM:	1.3
Lead Helmholtz Center:	KIT
Other Helmholtz Centers involved:	GFZ, UFZ

*) Helmholtz Association share in parentheses.



4D-CAT - BRIDGING THE INNOVATION GAP IN CATALYST RESEARCH FOR ELECTRO-, PHOTO- AND THERMOCATALYSIS

Summary

Central to a climate-neutral energy system are novel process technologies that ensure the efficient and sustainable use of available raw material resources and enable the cross-sector application of green hydrogen technologies. For these innovative leaps, the development of active, selective and durable catalysts is a central task of research and development worldwide. 4D-CAT addresses this via an integrated approach by linking the following dimensions: (1) design from nano to makro, (2) operando, (3) theory, and (4) lab to fab. The key added value is the acceleration of innovation cycles from material design to industrial application. This is achieved by the direct feedback of the determined functional properties into the catalyst design process, while simultaneously linking lab and pilot scales.

Scientific Importance

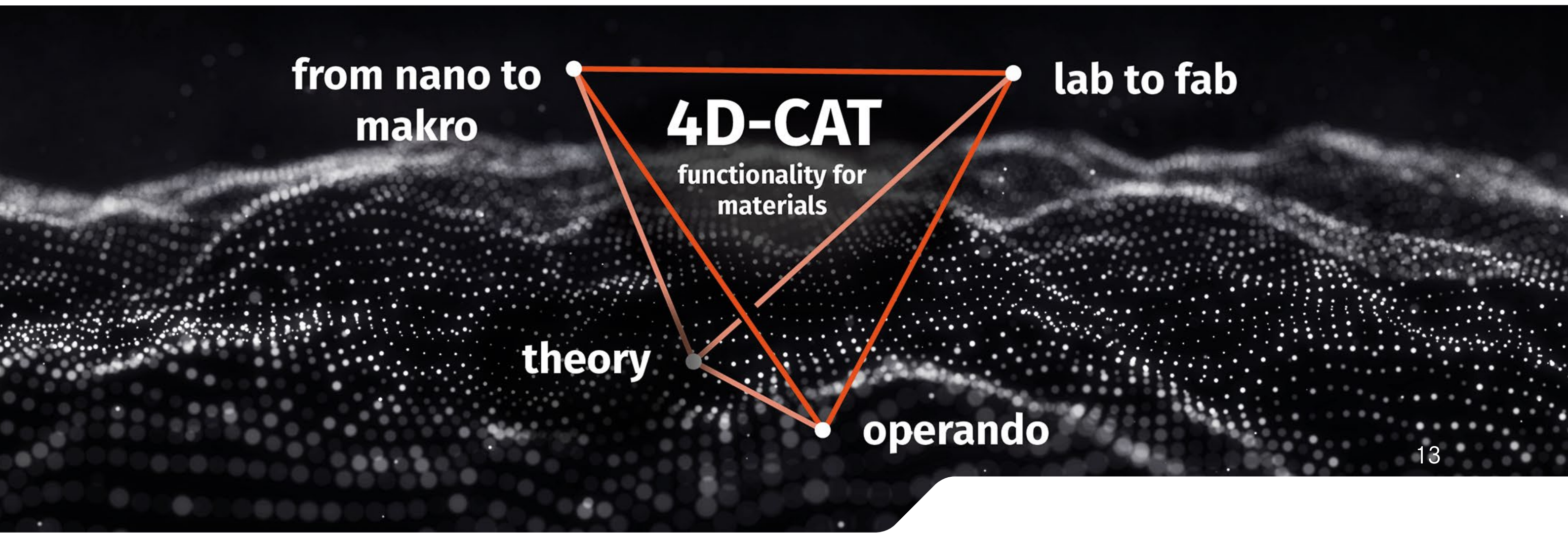
4D-CAT provides the infrastructure for the development of electro-, photo- and thermo-catalytically active functional materials in mainly hydrogen-based, CO_2-neutral process chains. This enables the production of chemical intermediates and energy carriers in a sustainable energy system. The scaling from microscopic functionality in catalysts to industrial process along the TRL scale is transdimensionally linked by:
(i) synthesis process automation and agile scale-up for accelerated development towards industrial applications, (ii) operando methods to understand and control processes at all relevant length and time scales, (iii) high-throughput experimentation, and (iv) digital catalysis. 4D-CAT integrates state-of-the-art synthesis and processing technologies with world-leading developments in characterization, exploiting the potential of computer-aided methods. Such an integrated infrastructure does not exist in Germany and is also unique internationally.

Strategic Relevance

A project like 4D-CAT can only be implemented and operated by a leading research organization with a strong infrastructure focus like the Helmholtz Association and its partners. 4D-CAT has the potential to play a key long term role in the development of production technologies for catalytically active functional materials. 4D-CAT connects extraordinary synergies with new or planned activities of the participating research centers, such as the CatLab project with a new building at HZB, the new building of the Institute of Catalysis Research and Technology at KIT, the Helmholtz Institute Erlangen-Nürnberg, as well as the JoLIE Joint Lab at FZJ. The resulting scientific and technological expertise will open up and strengthen application-oriented research collaborations with industry and provide a research and development environment for partners. This aligns with the overarching goal of significantly advancing the major transformation towards sustainable chemical processes.

Dates and numbers

Acronym:	**4D-CAT**
Category:	A
Period of realization:	2024 - 2027
Estimated investment in € MM:	25.8
Estimated operating costs per year in € MM:	3
Lead Helmholtz Center:	HZB
Other Helmholtz centers involved:	FZJ, KIT



ENERGY

HPGL – HIGH POWER GRID LAB

Summary

In the medium and long term, electrical grids at all voltage levels will develop into meshed grids dominated by power electronics and characterized by decentralized generation and storage of energy with bidirectional power flow. The High Power Grid Lab (HPGL) provides a research and test infrastructure in the multi-MW range that is unique in Europe for investigating the system behavior of the electrical equipment required for this purpose, and its effect on the electrical grids. By combining real-time simulation and control of the grid with the investigation of grid resources in real operation, the HPGL enables the establishment of a holistic Power Hardware-in-the-Loop (PHiL) test environment. In conjunction with the Energy Lab 2.0, it enables the testing of technologies for the energy transition.

Scientific Importance

The aim of the HPGL is to research the system behavior of new types of grid operating equipment (e.g. power converters for DC grids) in their most realistic grid environment possible. This is simulated in combination with the real-time simulation in the Energy Lab 2.0. In contrast to the already existing or planned systems of this kind, the effect of the equipment on the grid can be precisely observed. Only then can the required stability and resilience of the overall system be guaranteed. HPGL thus enables a holistic view of the operating equipment – from its modeling and dimensioning, to the testing of the hardware in realistic scenarios.

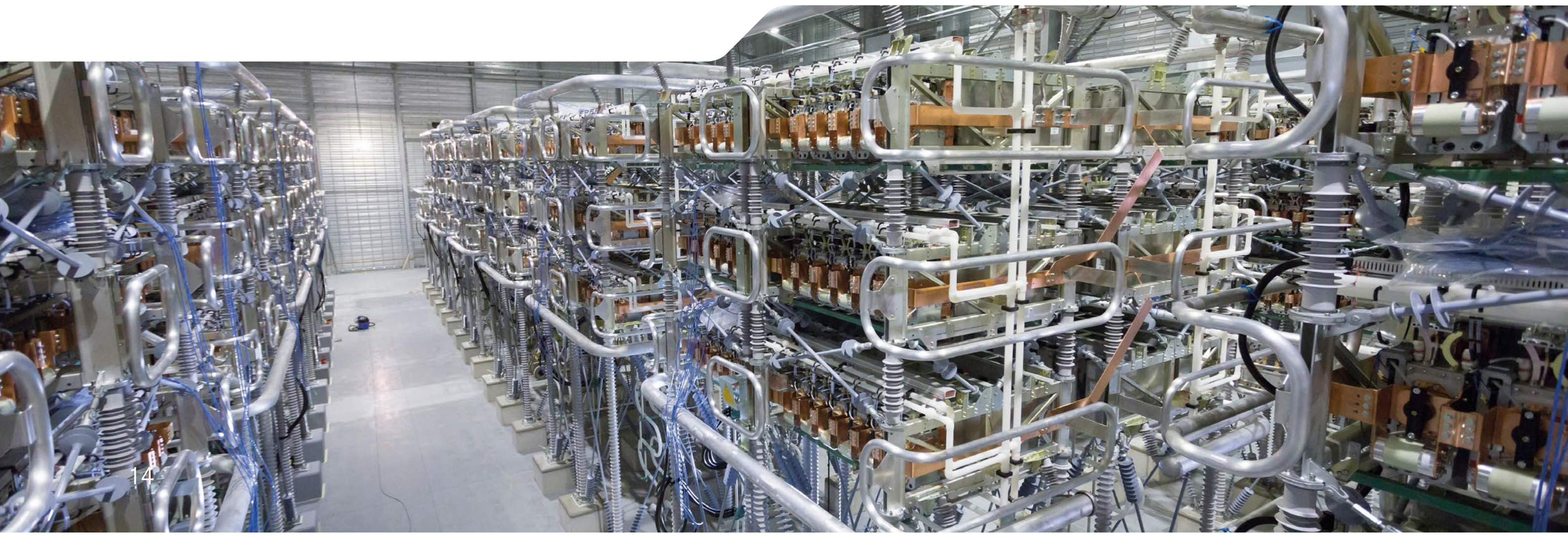
Strategic Relevance

With the HPGL, the Helmholtz Association can put itself at the forefront of such test infrastructures in Europe. This will sustainably strengthen the Helmholtz Association's visibility in the field of technologies necessary for a successful energy transition.

The scientific objectives and equipment of the HPGL are planned by KIT and its partners on the basis of the findings in the Energy System Design (ESD) program. They will enable the investigation of novel grid equipment in the environment of future grid structures and usage scenarios. In addition to research institutions, potential users of the HPGL are primarily grid operators and manufacturers of grid equipment.

Dates and numbers

Acronym:	**HPGL**
Category:	A
Period of realization:	2025 - 2030
Estimated investment in € MM:	20
Estimated operating costs per year in € MM:	1.5
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	None



CERI^2 – CENTER FOR RESOURCE PROCESS INTENSIFICATION AND INTERFACE STUDIES

Summary

A resource-efficient circular economy plays a prominent role in the German government‘s high-tech strategy as well as in the EU's raw materials initiative. Energy-efficient resource technologies will play a key role, however, their further development faces major challenges. In many cases, turbulent multiphase flows are used for resource recovery, which are optically opaque due to their high solids and gas content and thus not measurable using conventional techniques. Central processes in such multiphase flows, such as the attachment of valuable material particles to bubbles, are therefore still largely misunderstood. CeRI^2 addresses both of these problems. It investigates the micro- and mesoscopic length scales of multiphase flows relevant for valuable material extraction. It develops measurement techniques for these flows and tools for process intensification. For process optimization, strong emphasis is placed on the incorporation of artificial intelligence methods.

Scientific Importance

The goal is to develop energy and resource efficient technologies for resource recovery. Resource technologies are based on an enormous range of complex physical-chemical phenomena. The processes relevant to resource recovery span a length scale hierarchy of ten decades: from the nanometer-scale particle surface, to the micrometer scale of characteristic vortices, and the meter scale of industrial plants. While the FlexiPlant infrastructure at the Helmholtz Institute Freiberg for Resource Technology (HIF) focuses on integral resource recovery, CeRI^2 investigates key processes of resource recovery in turbulent multiphase flows on micro- and mesoscopic length scales. In close collaboration with HIF, this will create a world-leading R&D facility at HZDR with many industry collaborations.

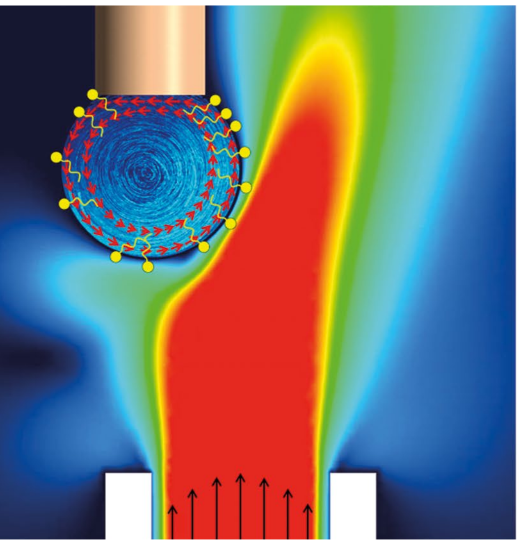
Strategic Relevance

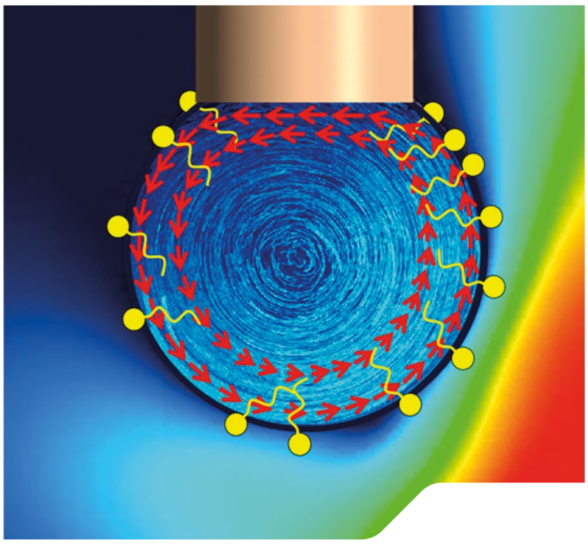
With the unique combination of high-end measurement technology for processes on all length scales enabled by CeRI^2, applied to flexible, modular reactors up to the implementation in the pilot plants of HIF, HZDR assumes a strategically prominent role in Europe and is able to compete with large Australian initiatives. Saxony‘s position as a raw material region with strong partners in Poland will be significantly strengthened, and industrial collaborations will be sustainably expanded and extended. The EU project “FineFuture” on breakthrough concepts in fine particle flotation, coordinated by HZDR since 2019, provides a strong basis for this claim with eight scientific and eight industrial partners. CeRI^2 combines basic research with applied research and industrial collaboration on a pilot plant scale, thus sustainably strengthening the transfer to industry.

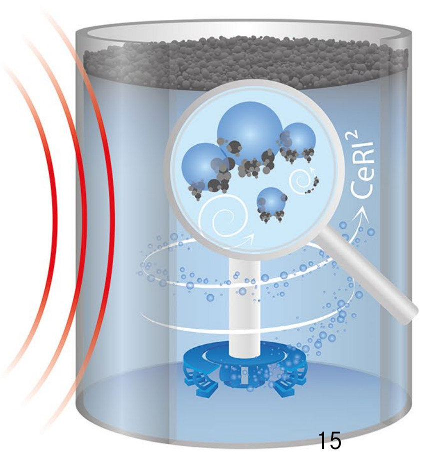
ENERGY

Dates and numbers

Acronym:	**CeRI^2**
Category:	A
Period of realization:	2026 - 2029
Estimated investment in € MM:	16
Estimated operating costs per year in € MM:	0.3
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	None







ENERGY

ZRS - CENTER FOR RADIOECOLOGY AND RADIATION RESEARCH

Summary

The core concerns of radioecology and radiation research are the detection, explanation, and health-relevant evaluation of the effects of radionuclides on biological process chains. Experimental data obtained on biomolecules are complemented by quantum theoretical analyses using molecular dynamics. For even more complex systems, such as living organisms and microbial communities, innovative coupling techniques are needed to quantify radionuclide effects on their metabolism. The immune system of plant cells will be used as a model system to understand the stress responses of cells to radionuclides (e.g. formation of metabolites) at the molecular and cellular levels.

Scientific Importance

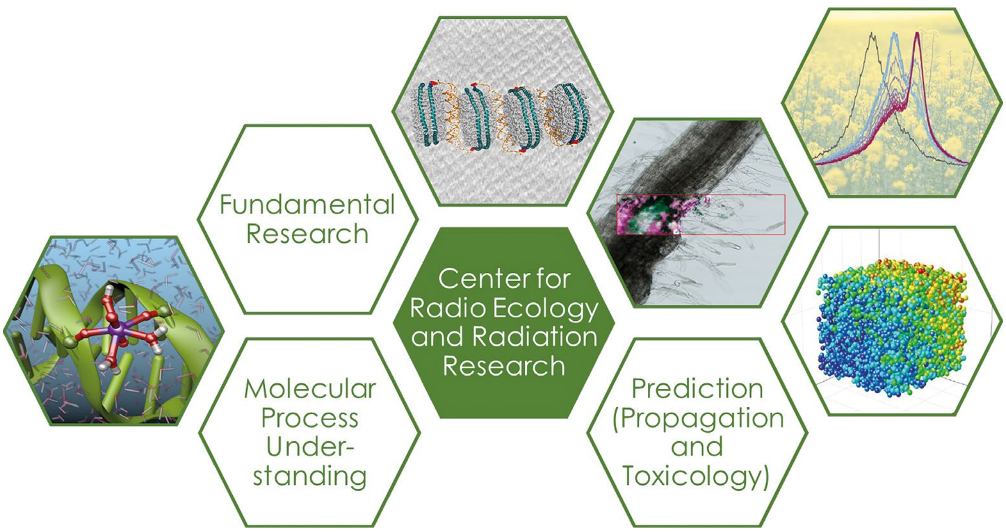
The effects of radionuclides (RNs) on the environment have been studied primarily using statistical methods. In contrast, the Center for Radioecology and Radiation Research (ZRS) aims to explore the topic using basic scientific research and clarify processes at the molecular and cellular level. The activities of the Research Fields Energy, Matter and Health at the HZDR will be combined, including all controlled areas for radioactive materials, BSL-1 laboratories and the Rossendorf Beamline at the ESRF. In addition, the planned, substantive collaboration with the UFZ will bring together cross-disciplinary scientific expertise from the Research Fields Earth and Environment, and Energy. This makes the enormous advantages of the interdisciplinarity of the center and the Helmholtz Association internationally visible.

Strategic Relevance

The ZRS opens up the possibility to occupy a scientific field of great societal relevance, which has not been represented in the Helmholtz Association so far. Internationally, competitiveness with the Belgian Nuclear Research Centre SCK·CEN and the French Institute for Radiological Protection and Nuclear Safety IRNS is achievable, making leadership positions in alliances such as the European Radioecology ALLIANCE possible. The future-oriented work of ZRS is independent of reactor safety or repository research and represents a further development of the Helmholtz program NUSAFE. Research on the impact of radiation on humans and of released radionuclides on the environment, through mining, geothermal energy, or accidents is absolutely necessary and fits perfectly with the mission of the Helmholtz Association.

Dates and numbers

Acronym:	**ZRS**
Category:	A
Period of realization:	2027 - 2031 et seq.
Estimated investment in € MM:	28
Estimated operating costs per year in € MM:	2
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	None



FLEXIPLANT - FLEXIBLE PROCESSING PLANT DEMONSTRATOR PLATFORM

Summary

Closing material cycles is one of the great societal challenges of our time and a decisive prerequisite for a sustainable Circular Economy (CE). This is the only way to avoid already foreseeable bottlenecks in the supply of raw materials and to drive technological change (e.g. electromobility, digital transformation). To this end, a new generation of adaptive, flexible and, above all, digitized reprocessing processes must be developed. This will enable the recovery of all the raw materials (including rare earths), even from complex systems, in an energy-efficient and function-preserving manner, which is to say, as far as possible without downcycling. The increasing complexity of globally generated material streams represents a fundamental challenge for resource technology developments. FlexiPlant is a globally unique research platform on a pilot scale (at the end of the expansion to TRL 6-9), with which scientific models, methods, and technologies can be developed and tested for any raw material stream.

Scientific Importance

Three fundamental goals define the scientific importance of FlexiPlant: a) Closing the material loops of complex raw materials, b) Maximizing energy and resource efficiency, c) Digitally transforming the raw materials industry and thereby dramatically reducing the current carbon footprint.

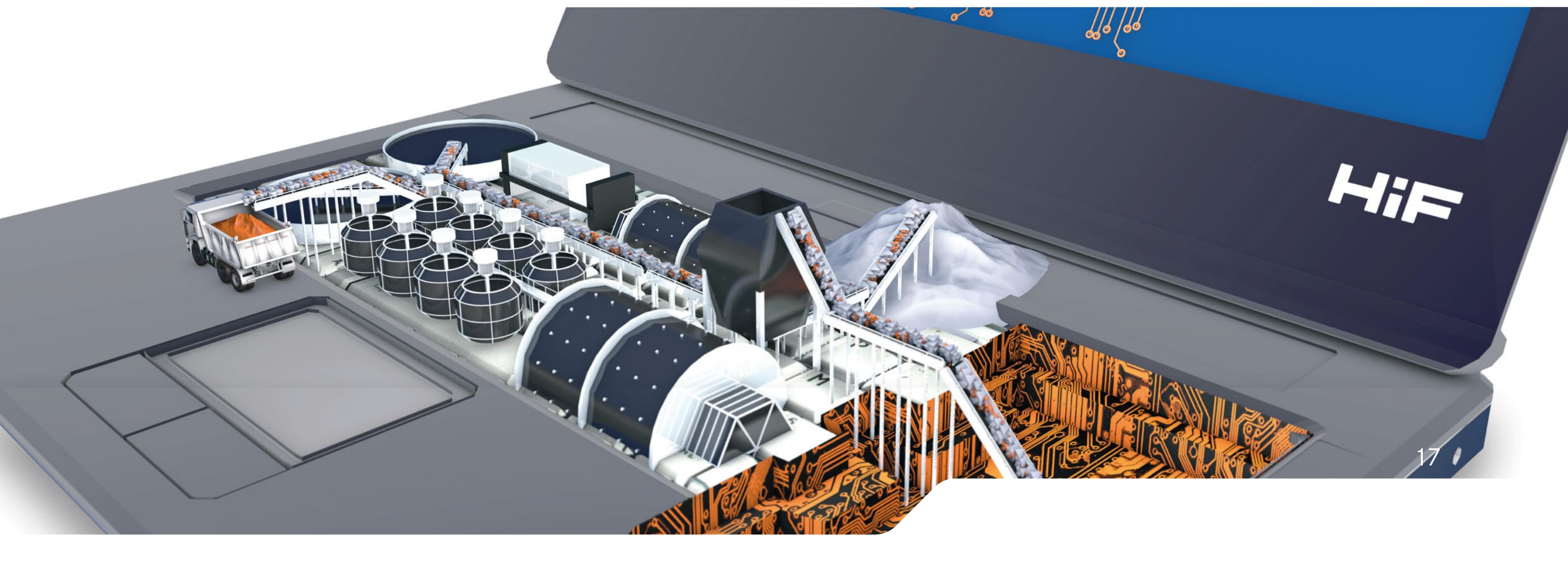
To achieve these goals, a paradigm shift in the raw materials processing industry is required. The path moves away from process chains that process variable feed materials in a single process optimum to flexible, automated and digitalized processing technologies that can be supplemented and interconnected with new technological developments at any time. The combination of precise raw material characterization (shape, color, physicochemical properties, etc.) with further processing ideally adapted to the specific material stream enables almost complete recovery of the valuable materials contained in the products at the end of their life, in particular the technology metals. The fully automated collection and (pre-)sorting of recyclable material streams in FlexiPlant prior to further processing, for example in the metallurgy pilot plant, is intended to prevent technologically induced losses as far as possible, and thus return up to 90 percent of the previously lost raw material back to the material cycle.

Strategic Relevance

As a unique digitized infrastructure on a pilot scale, FlexiPlant will be a global attraction for collaboration partners from science and industry. The research infrastructure thus directly pursues the socio-political requirements for climate change mitigation and the energy transition. Keywords here are the German federal government‘s energy research program and the EU‘s Green Deal, which aim to achieve an ecological transition towards climate neutrality.

Dates and numbers

Acronym:	**FlexiPlant**
Category:	B
Period of realization:	2024 - 2030
Estimated investment in € MM:	66.7
Estimated operating costs per year in € MM:	2.2
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	None



ENERGY

IFMIF-DONES – INTERNATIONAL FUSION MATERIALS IRRADIATION FACILITY - DEMO ORIENTED NEUTRON SOURCE

Summary

IFMIF-DONES is an accelerator-based neutron source with intensity maximum of 14.1 MeV, i.e. the energy of neutrons released during D-T fusion. It will serve to test, validate and qualify materials to be used in the neutron field of fusion reactors, from basic research and confirmation of simulation models to qualification of reactor materials for nuclear licensing. IFMIF-DONES has been included in the European ESFRI roadmap from 2018 and preliminary work with EU funding is already underway. Starting in 2022 the project will be implemented in Granada, Spain. It will provide structural material data under near-application conditions for a fusion demonstration reactor (DEMO) for the first time and is an indispensable prerequisite for its realization. A consortium, which will be the legal entity responsible for the on-site construction, was established on June 09, 2021.

Scientific Importance

The hard spectrum of D-T fusion neutrons (14.1 MeV compared to <2 MeV in fission reactors), exhibits nuclear reaction cross sections of action for nuclear reactions leading to transmutation and the formation of significant amounts of H and He in the material, and thus to currently undetermined degradation in service. To date, no experimental means exists to simultaneously study neutron damage together with transmutation in a relevant spectrum. IFMIF-DONES opens this possibility by means of a continuous deuteron accelerator (5 MW) impacting on a liquid Li target with a rectangular beam cross section and producing a neutron flux of 10^{18} m^{-2} s^{-1} at 14 MeV.

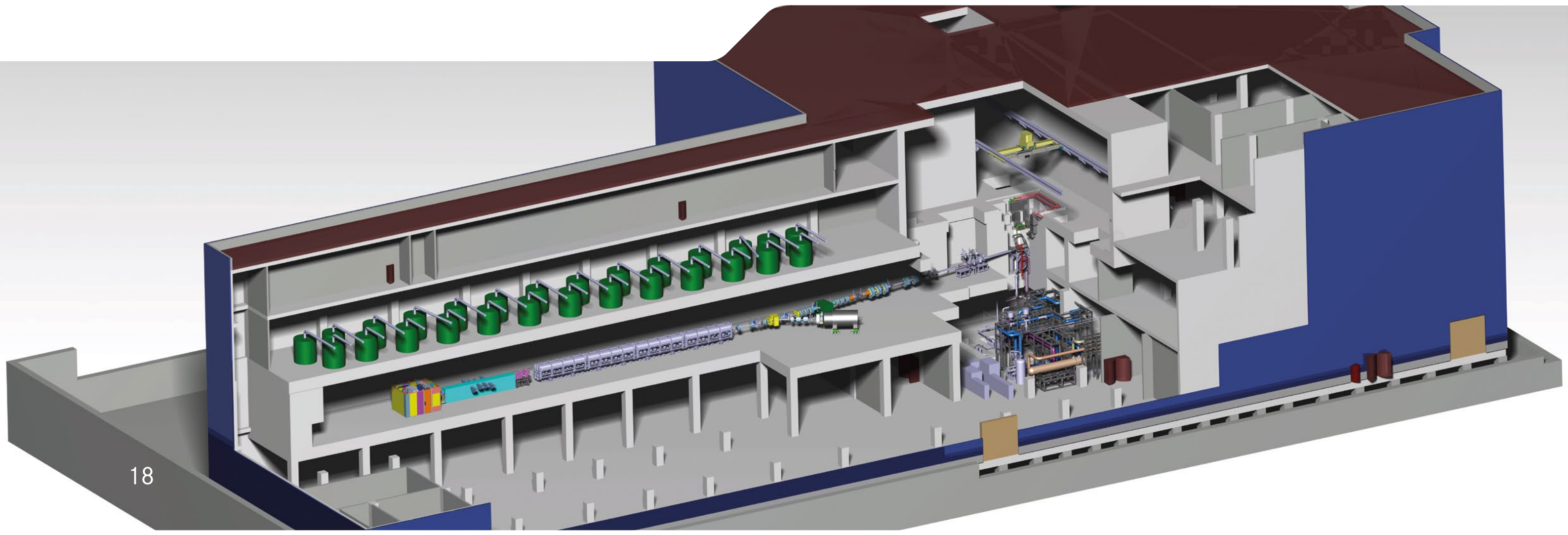
Strategic Relevance

Fusion as a global element of the energy transition is being advanced in international cooperation and pursued as a long-term option at Helmholtz. The EUROfusion roadmap envisages the commissioning of a DEMO power plant by 2050, with the qualification of different power plant materials at fusion-type conditions in IFMIF-DONES in the 2030s creating the basic prerequisite for a licensable power plant. KIT has made essential contributions of high international visibility to IFMIF-DONES in the development of key elements such as, among others, the test facilities, and has unique capabilities for testing and qualification of neutron-exposed samples. Participation in IFMIF-DONES is expected to ensure access to such samples and thus continued leadership in the qualification of neutron-resistant fusion materials.

Dates and numbers

Acronym:	**IFMIF-DONES**
Category:	C
Period of realization:	2022 - 2033 (2023 - 2031)
Estimated investment* in € MM:	551 (79.5)
Estimated operating costs* per year in € MM:	55 (n. a.)
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	None

*) German share in parentheses.



FSE - RESEARCH VESSEL FOR MARITIME ENERGY SYSTEMS

Summary

A globally unique research vessel for energy systems (FSE) will be built to demonstrate and test new energy systems for maritime applications, including their certification. In addition, sensors and actuators will be installed that can be used for the development of digital control and testing autonomous driving. The data generated will enable the digitization and visualization of the ship's operation. Abnormal conditions can thus be tested quickly, safely and cost-effectively.

The vessel will have maritime certification in the IMO registry. A diesel-electric propulsion system will ensure safe navigation at all times. The research vessel is able to carry several 20-foot containers which contain newly developed electrical systems that provide energy to replace the ship's standard power supply.

Scientific Importance

The development of alternative energy systems is needed to reduce CO_2 emissions from shipping by 2050 and make a significant contribution to meeting global climate goals. Internationally, there is not yet a research vessel on which different fuels and conversion systems for shipping can be tested. To achieve this, research and development is necessary in the areas of:

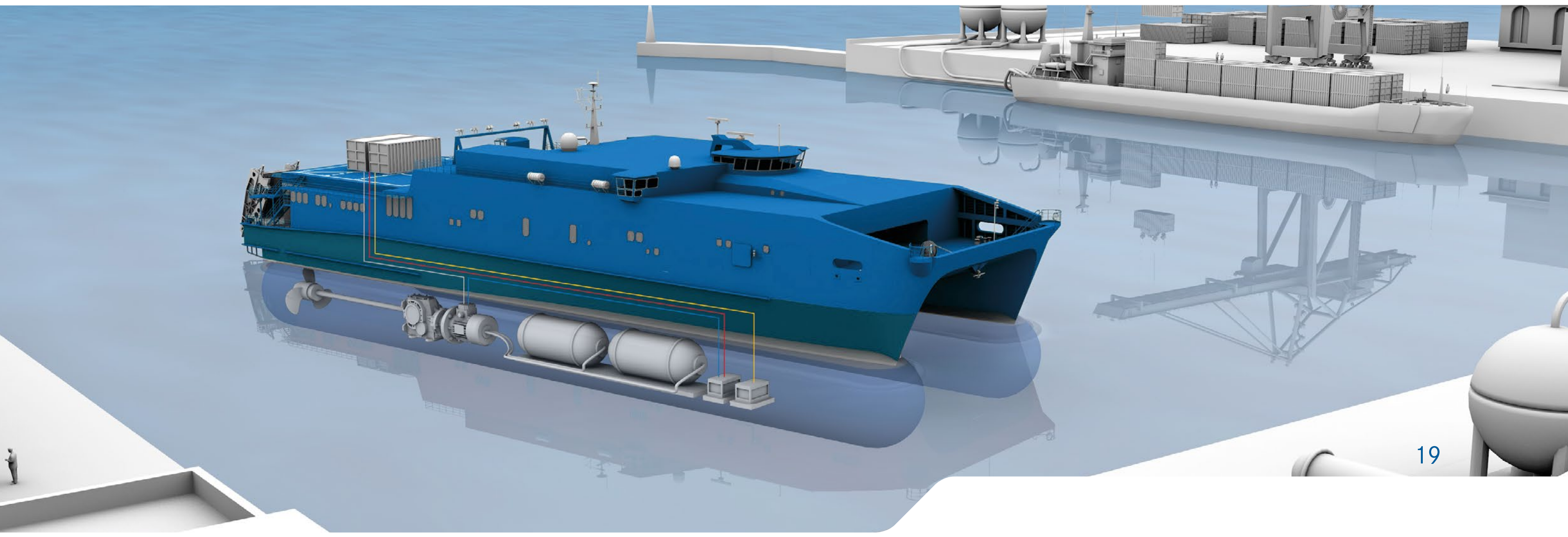
- Alternative fuels, as well as their handling, storage and use,
- Energy converters for power generation for electric propulsion,
- Further development of intermediate storage systems for optimized operation,
- Improved media supplies for heat, cold and electricity,
- Safety concepts for licensability.

Strategic Relevance

According to European guidelines, CO_2 emissions from shipping are to be reduced to half of today's levels by 2050. The research vessel gives DLR and external users the opportunity to test and verify their developed energy-efficient systems. This can support value creation among equipment suppliers and shipping companies in the German shipbuilding industry. The development of autonomous operation is intended to increase traffic safety on shipping routes. The ship also offers other Helmholtz centers the possibility of measuring technology for coastal and marine research.

Dates and numbers

Acronym:	**FSE**
Category:	A
Period of realization:	2021 et seq.
Estimated investment in € MM:	36
Estimated operating costs per year in € MM:	n. a.
Lead Helmholtz Center:	DLR
Other Helmholtz centers involved:	None



RESEARCH FIELD EARTH AND ENVIRONMENT

Profile

In the joint program Changing Earth - Sustaining Our Future, the seven Helmholtz centers of the Research Field Earth and Environment investigate the foundations of life on our planet across disciplines and with a systematic approach. The three sub-areas of the Earth system – the terrestrial, marine and atmospheric components – are inextricably related, therefore research in the joint program is organized across compartments.

The centers accomplish these tasks not only thanks to their excellent personnel, but also by means of their modern research infrastructures that enable long-term monitoring of the Earth system. This advances research on the sustainable use of global resources and their long-term protection, as well as the management of natural hazards.

Challenges

The Research Field Earth and Environment aims to develop a profound knowledge of the complex processes of the Earth system in the past, present and future. Understanding feedback and interlocking mechanisms as drivers of change is particularly challenging. These processes and potential hazards must be recorded with much higher temporal and spatial resolution than before. The processes and potential hazards should be analyzed together with drivers and their consequences, which should be documented in equal detail. Therefore, powerful real-time monitoring systems that enable automated workflows can be developed, e.g. in early warning systems. Given the significantly expanding technical capabilities in the field of Earth observation, one challenge is to digitally integrate the collected data to form a digital continuum in the future. In this process, AI-based analysis methodology increasingly complements the existing (physical) model systems.

Strategy

Key structural objectives of the Changing Earth - Sustaining Our Future program are to expand the relevance and utility of research infrastructures to both advance program research and provide platforms that attract outstanding national and international users. This includes the provision and analysis of Earth observation data. The existing and planned infrastructures for Earth system and climate research will make a crucial contribution to the high-resolution detection, prediction, and management of global climate and environmental changes. The transfer of knowledge to the economy, society and politics is to be increased.

The Research Field plans to expand the existing instrumental infrastructures with further strategically complementary sets of instruments. The three compartments will be integrated into the common data infrastructure through the complementary research infrastructures over the next few years in order to build a holistic integrative data infrastructure.

Infrastructure Planning

The Research Field is planning to initially implement the **MUSE** project. MUSE will provide new methods for continuous and interdisciplinary observation with robotic systems as well as urgently needed technology and infrastructure capacities with high transfer potential. Acting as an exemplary project, the marine system will be the first of the three compartments to be integrated into the cross-center data infrastructure.

The second planned project is **Terra-Lab**. This project consists of different observation platforms and enables spatially distributed real-time data acquisition of the terrestrial system. With Terra-Lab, the Helmholtz Association will take a pioneering role in the developing field of environmental forecasting and will also contribute to the creation of a bioeconomy and promote climate-smart urban, agricultural and forestry management systems.

The next project in the Research Field's strategy proposes to establish the global monitoring and user center **SAFAtor**. This will use (submarine) telecommunications cables as sensors and carriers for earth and environmental processes. This research infrastructure is essential for the strategic development of the Research Field due to its special innovation potential and the opportunity to expand industrial cooperations in the process.

In order to obtain a complementary view of all components of the Earth system, the implementation of **ATMOSense** as a modular and mobile atmospheric observation facility is planned. The coherent, cross-center system will integrate existing atmospheric observation infrastructures and integrate them into the overarching data infrastructure concept.

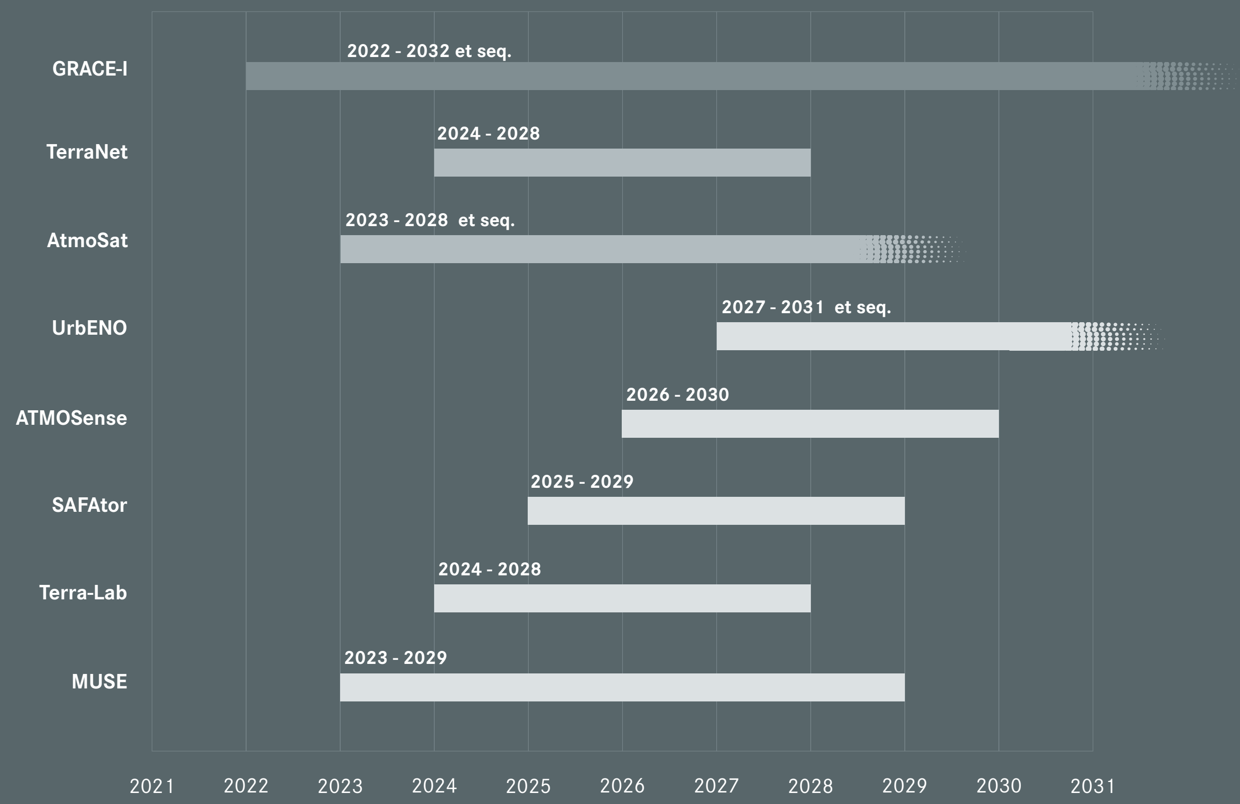
For the purpose of expanding Earth system research more specifically through the perspective of urban environmental observation, the **UrbENO** project is planned. The project's goal is to establish urban environmental observatories focusing on climate, water, biodiversity, seismic risk, air quality, and quality of life.

The proposed category B project called **AtmoSat** is essential for the strategic development of the Research Area as it will provide unique global data of the middle atmosphere (5 to 100 kilometers) in 3D. Through AtmoSat, the influence of the middle atmosphere on global as well as regional climate and weather can be studied in detail for the first time. **TerraNet** is another envisaged infrastructure that is spatially distributed and based on the digital twin concept. TerraNet will automatically collect and aggregate real-time data of the land surface. This will enable forecasts and long-term projections.

With the international project **GRACE-I**, the Helmholtz Association, together with NASA and the Max Planck Society, is planning a satellite mission to measure the Earth's gravitational field. GRACE-I is to succeed the very successful GRACE and GRACE-FO satellite missions on a significantly lower orbit. The Research Field Earth and Environment strongly supports the implementation of the mission, as it offers a unique technological and scientific opportunity for Germany.

In addition, the replacement of the research vessels Polarstern and Poseidon is planned for the further development of the German marine research fleet.

Planned Implementation



Legend:

A – Helmholtz projects financed through the Helmholtz Association's competitive procedure for strategic expansion investments (€15 to €50 million).

B – Large national projects of the Helmholtz Association that are included on the national roadmap and funded with additional project funding (> €50 million).

C – Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.

MUSE – MARINE ENVIRONMENTAL ROBOTICS AND SENSORS FOR SUSTAINABLE EXPLORATION AND MANAGEMENT OF COASTS/SEAS/POLAR REGIONS

Summary

MUSE is proposed as a strategic investment from the Hemholtz Association marine centers AWI (lead coordinator), GEOMAR and Hereon. MUSE is envisioned as a marine infrastructure of robotic platforms and next-generation sensors. With a cross-center approach it will explore the nearshore, marine, and polar regions of the Earth, reinforcing the synergistic approach in the fourth program period.

Scientific Importance

Increasing anthropogenic activities are threatening the marine environment on a global scale – from coastal waters to the deep sea, and from the tropics to the polar regions. The marine research of the Research Field Earth and Environment plans to use innovative technical solutions to enable process studies of the multiple environmental stressors in the ocean. This will include exploring their impact on life and the environment, and the dynamics of complex communities in the water column and seafloor. MUSE will: 1) Implement a strategically aligned, integrated ocean infrastructure of innovative robotic platforms and next-generation sensors; 2) Enable synchronous and standardized measurements in nearshore, marine, and polar regions of the Earth at a range of scales; and 3) Strengthen the synergistic approach to Earth system research in the program to provide essential information, particularly in the pressing issues of climate, marine environmental, and species conservation.

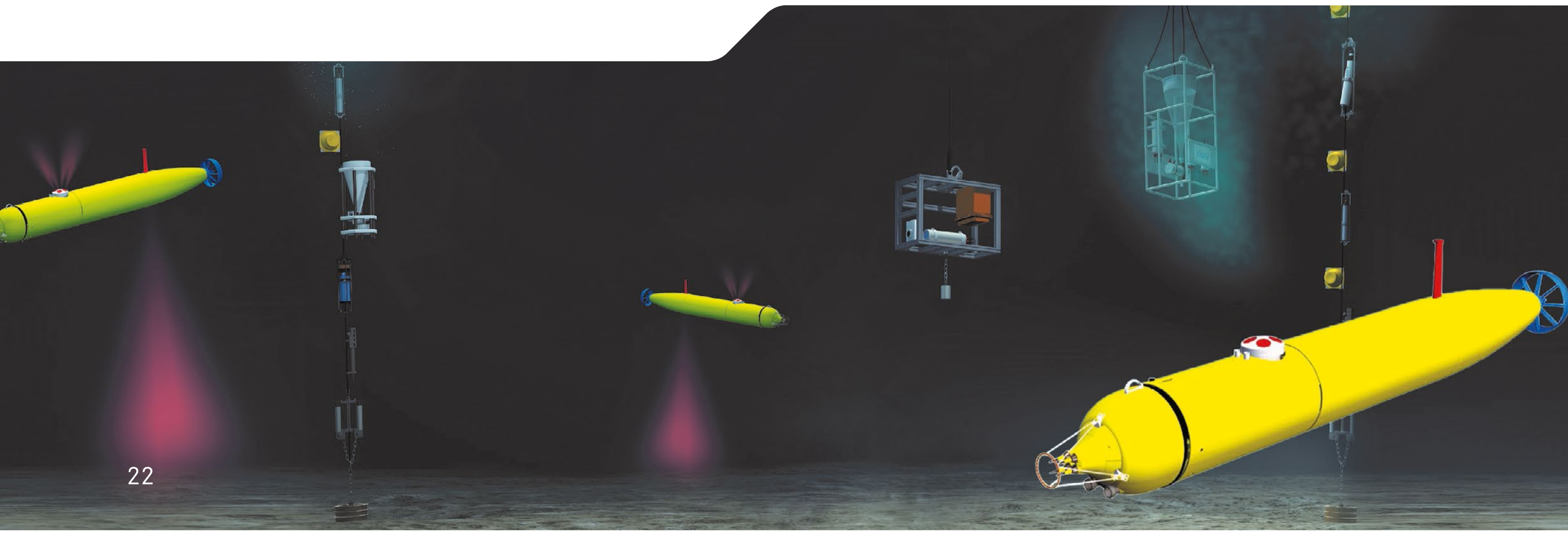
Strategic Relevance

The technological developments outlined in the Helmholtz Roadmap 2015-2020 will be further developed with MUSE and national capacity in marine robotics, sensor technology, and digital value chains (including in the Global Ocean Observation System) will be future-proofed. MUSE will combine the technological strengths of AWI, GEOMAR and Hereon, ensuring the best possible synergy between the centers. Other national and international user groups will also be supported by MUSE (marine research clusters of excellence, Max Planck and Fraunhofer institutes). Existing cooperations with other centers of the Helmholtz Association will be strengthened by the infrastructure. MUSE is a forward-looking building block in the implementation of the German MARE:N/FoNa strategy and is to be expanded into a national contribution in the UN Decade of the Oceans. Special innovation paths are laid out in the digital remote monitoring of environmental conditions, nature conservation and marine pollution as well as in the optimized functionality under extreme conditions in the sea.

Dates and numbers

Acronym:	**MUSE**
Category:	A
Period of realization:	2023 - 2029
Estimated investment* in € MM:	46.8 (29.7)
Estimated operating costs per year in € MM:	4
Lead Helmholtz Center:	AWI
Other Helmholtz centers involved:	GEOMAR, Hereon

*) Helmholtz Association share in parentheses.



TERRA-LAB - OBSERVATION PLATFORMS FOR REAL-TIME DATA ACQUISITION IN THE TERRESTRIAL SYSTEM

Summary
The goal of Terra-Lab is to manage agricultural, forestry and urban areas according to the climate. The basis for this is a system that collects data and allows predictions to be made in real time of the terrestrial system – from groundwater to the atmosphere.

Terra-Lab consists of various observation and modeling platforms that use computers to monitor the conditions and fluxes of the Earth system and make predictions. Based on the observations made, measures can be taken in response to the indicators that are provided. On the one hand, the indicators and subsequent measures are used to control and mitigate the effects of extreme events such as heavy rainfall. On the other hand, they can be used to design agricultural and forestry management practices and products in digital form. Terra-Lab also provides data products for urban applications such as urban planning, climate change adaptation, and health care.

Scientific Importance
Terra-Lab is the world‘s first attempt to combine two concepts of Earth observation: stationary, interconnected observatories (Project TERENO) will work together with highly flexible and mobile modules. These are specifically designed to study the interactions of short-term events and long-term trends in the Earth system (MOSES project). The link can be further developed into a fully automated and spatially distributed real-time observation and prediction system throughout Germany. The goal is to understand and predict the effects of climate extremes on the Earth System.

This integrated approach will make it possible for the first time to provide continuous impact assessments on the ecosystem, initially on a national scale and later on a European and global scale. The concept further develops powerful climate, impact and integrated terrestrial models. In combination with this, innovative products are offered in the agricultural, forestry and urban sectors.

Strategic Relevance
With Terra-Lab, the Helmholtz Association will be at the forefront of the evolving field of environmental forecasting and will be able to establish global standards. The novelty and strength of Terra-Lab is that it brings together key partners such as universities and research institutions, government agencies and stakeholders, and European research infrastructures. Terra-Lab is central to the program of the Research Field Earth and Environment and provides an essential platform for trans- and interdisciplinary collaboration.

Dates and numbers

Acronym:	**Terra-Lab**
Category:	A
Period of realization:	2024 - 2028
Estimated investment in € MM:	30
Estimated operating costs per year in € MM:	3
Lead Helmholtz Center:	FZJ
Other Helmholtz centers involved:	AWI, DLR, GFZ, Hereon, KIT, UFZ

SAFATOR – SMART CABLES AND FIBRE-OPTIC SENSING AMPHIBIOUS DEMONSTRATOR

Summary

It is proposed to establish the global monitoring and user center SMART Cables And Fibre-optic Sensing Amphibious Demonstrator (SAFAtor). The concept is based on the supplementary use of submarine telecommunication cables and transforms them into a global geomonitor through two complementary approaches:

(a) Equipping the repeaters with robust sensor technology, initially oceanographic sensors for continuous, real-time trans-oceanic measurements (monitor water body),

b) Using the optical fiber in the cable itself as a sensor by applying technologies of spatially Distributed Acoustic, Strain and Temperature Sensing (monitor subsurface).

This innovative combination is intended to connect areas that have been partially separated by measurement technology to date, as well as to close the large gaps in global models (geology, climate, oceanography) for the first time and with a minimized footprint.

Scientific Importance

SAFAtor will:

- Enable capability for permanent seismic monitoring of the oceans: complete seismic imaging, hazard assessment, and earthquake early warning.
- Increase reliability, integrity and coverage of seismological warning networks: increase warning times, improve forecasts and forecast quality.
- Provide geotechnical estimation of slope stability and motion: e.g. identify submarine landslides as potential tsunami sources.
- Optimize quantification of climate-relevant and fundamental oceanic quantities in the ocean and coastal regions: continuously monitor water mass redistribution, ocean heat content, etc.
- Provide high quality data for satellite-based ground truthing and model validation.

Strategic Relevance

SAFAtor will routinely monitor critical parameters of climatic and tectonic changes and help mitigate seismic and tsunami hazards. As a result, the system will save lives and reduce economic losses. The demonstrator will also provide valuable data from target regions such as the Mediterranean or Indonesia. This system is expected to be the blueprint for cabled systems and initiate an international effort for global instrumentation. SAFAtor will be implemented as a user facility with open data distribution (Findable/Accessible/Interoperable/Reusable, FAIR) and a user center.

Dates and numbers

Acronym:	**SAFAtor**
Category:	A
Period of realization:	2025 - 2029
Estimated investment* in € MM:	300 (30)
Estimated operating costs per year in € MM:	1.5
Lead Helmholtz Center:	GFZ
Other Helmholtz centers involved:	GEOMAR, Hereon

*) Helmholtz Association share in parentheses.

ATMOSENSE - SENSING THE ATMOSPHERE

Summary

ATMOSense is a modular and mobile infrastructure for atmospheric observation. It is characterized by an unprecedented spatial and temporal resolution, which enables the Whole Atmosphere approach in the Changing Earth - Sustaining our Future program. Within the participating centers, ATMOSense integrates and further develops the relevant infrastructures. The focus is on new, partially autonomous sensor systems and real-time integration of data streams. This coherent observational capacity will allow large national and international atmospheric research campaigns to be initiated and carried out. In addition, the ATMOSense data will contribute to the further development of the cross-scale numerical models available in the Research Field.

Scientific Importance

In order to develop highest resolution atmospheric models, a deeper understanding of previously unresolved dynamical, microphysical, and chemical processes is needed. These include turbulent solute transport and the highly nonlinear interactions of trace substances, aerosols, clouds, and radiation. Novel high-resolution and autonomously operating sensor systems enable unprecedented spatial and temporal resolution of the relevant processes and parameters. With model data fusion, ATMOSense will improve the predictive capability of atmospheric and climate models. In addition to in-situ instruments, remote sensing networks as well as mini-satellites and novel sensors on airborne platforms are being developed for this purpose.

Strategic Relevance

The current strategy of the Research Field Earth and Environment is focused on significantly improved climate, weather and air quality prediction. This progress is based on an improved model representation of the changing processes in the atmosphere and the adjacent compartments in the course of global change. ATMOSense will make decisive contributions in this respect as a central instrument in the Research Field, thus consolidating and further expanding the leading role of the Helmholtz Association's atmospheric research on an international level.

Dates and numbers

Acronym:	**ATMOSense**
Category:	A
Period of realization:	2026 - 2030
Estimated investment in € MM:	35
Estimated operating costs per year in € MM:	2
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	AWI, DLR, FZJ, GEOMAR, GFZ, Hereon

URBENO – URBAN ENVIRONMENTAL OBSERVATORIES

Summary

The plan is to establish urban environmental observatories that collect data focusing on air quality, climate, water, biodiversity and quality of life in the face of global change. The goal is to ensure the long term development of sustainable and resilient cities, including the relationship between urban rural environments. The data will be used to achieve an understanding of the processes and system interactions taking place with unprecedented resolution. This will provide recommendations for action based on simulations and urban climate modeling, touching on issues such as the mitigation of anthropogenic climate change and other stressors, ensuring air quality standards, and resilience to extreme climatic events. UrbENO is intended to provide a long-term research platform for international collaboration, which is essential for the operation of the research infrastructure.

Scientific Importance

Urban areas are significant drivers of global change while at the same time being particularly vulnerable to extreme events, natural hazards, disasters, and their subsequent impact on health and the environment. The overarching goal is to strengthen the resilience of populations and infrastructures to environmental risks and to make urban areas more environmentally sound and sustainable. Based on unique and completely novel environmental monitoring systems, UrbENO creates the data basis for deriving decision-making tools to (1) better manage environmental risks in urban areas, (2) protect the quality of life and health, and (3) develop novel solutions for securing urban ecosystem services and infrastructure management.

Strategic Relevance

A coordinated, long-term network of urban observatories of environmental change and natural hazards does not exist in Germany or internationally. UrbENO intends to break new scientific ground here, carrying out international pioneering work and consolidating the leading role of the Research Field Earth and Environment. The implementation of UrbENO will initiate and lead international urban research campaigns and experimental spaces in the future, as well as develop high-resolution models of urban environmental quality and climate. UrbENO as a research infrastructure is an essential basis for the planned cross-cutting activity Resilient Cities / Urban Spaces in the Changing Earth - Sustaining our Future program.

Dates and numbers

Acronym:	**UrbENO**
Category:	A
Period of realization:	2027 - 2031 et seq.
Estimated investment in € MM:	30
Estimated operating costs per year in € MM:	3.5
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	FZJ, GFZ, Hereon, UFZ

Bild: www.webbaviation.de

ATMOSAT - ATMOSPHERIC AND CLIMATE SATELLITE

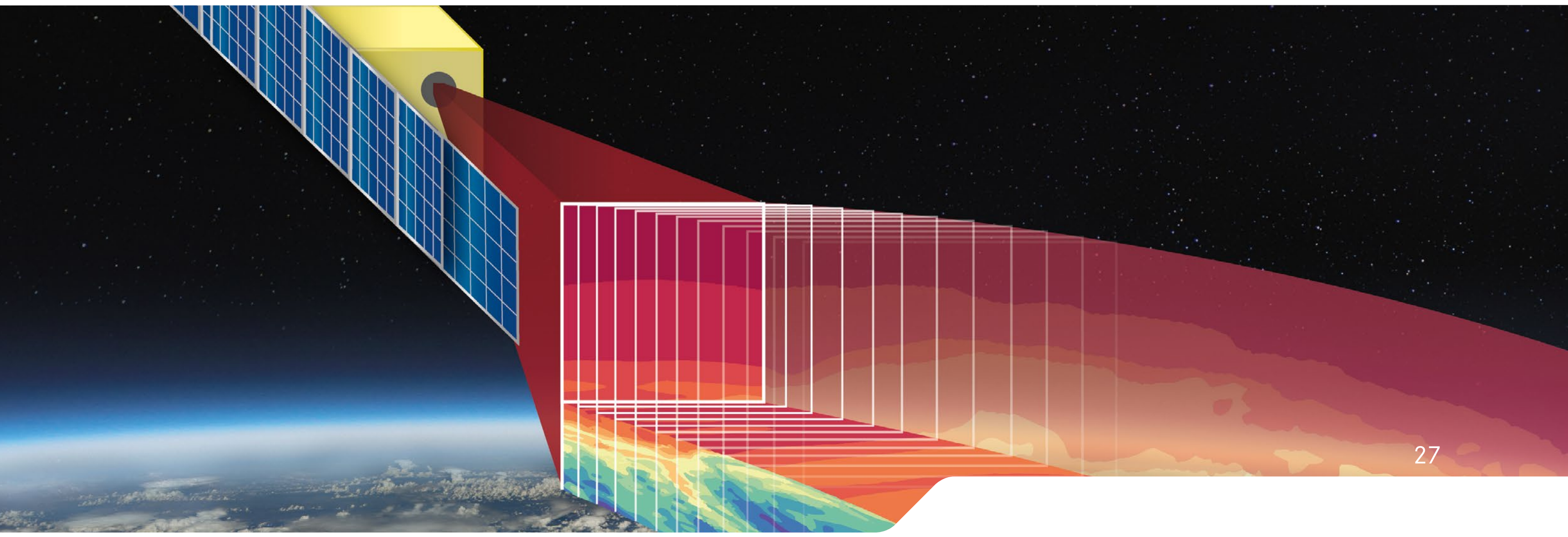
Summary
The AtmoSat satellite is the first to conduct detailed research into how the middle atmosphere between 5 and 100 kilometers above the earth's surface influences global and regional climate and weather. The most important instrument on board is the IR spectrometer GLORIA, which can be used to produce global 3D maps of the most important atmospheric trace gases, such as ozone, methane and water vapor. GLORIA, which was developed by FZJ and KIT, measures with an unprecedented spatial resolution. A second instrument registers signals from satellite navigation systems and determines with great precision the influence of the atmosphere on the travel times of these signals. With this GPS radio occultation, the global temperature distribution can be measured. In addition, a heterodyne spectrometer is used for trace gas measurements at the upper limit of the measurement range.

Scientific Importance
In 2017, the Science Council for the National Roadmap for Research Infrastructures described AtmoSat's scientific potential as "unique." The data provided by AtmoSat will significantly improve medium- and long-term weather and climate forecasts. In particular, AtmoSat is the first to quantitatively capture couplings between the stratosphere and troposphere that affect our regional climate. The project is "highly relevant for further research into fundamental atmospheric dynamics, climate change and measures to prevent it," the Science Council judged. The global atmospheric science community supports AtmoSat.

Strategic Relevance
As a disruptive infrastructure, AtmoSat allows a novel approach to climate-related issues and processes. The data obtained will be highly regarded worldwide. About 80 percent of the users are researchers, for example from the World Climate Research Programme or the Future Earth network. Further users are expected from the field of data assimilation, for example from the Global Climate Observing Systems program and the Copernicus Atmosphere Monitoring Service. AtmoSat significantly expands Germany's role in climate and atmospheric research. FZJ and KIT have the unique scientific-technical expertise for the setup and operation of AtmoSat.

Dates and numbers

Acronym:	**AtmoSat**
Category:	B
Period of realization:	2023 - 2028
Estimated investment in € MM:	165.5
Estimated operating costs per year in € MM:	1
Lead Helmholtz Center:	FZJ, KIT
Other Helmholtz centers involved:	AWI, GEOMAR, GFZ



TERRANET – FROM SENSING TO SUSTAINABLE LAND USE AND MANAGEMENT

Summary

TerraNet is a spatially distributed infrastructure that will automatically collect and aggregate real-time data of the terrestrial system from groundwater to atmosphere, and from coast to mountains. It will enable forecasts and long-term projections. For agricultural areas and forests, as well as for semi-natural spaces in cities, this will allow management strategies to be developed to limit the impact heavy rainfall, droughts and other negative consequences of climate change: either by taking preventive measures or by mitigating the effects. TerraNet also paves the way for digital forecasting products for agricultural and forestry management. In addition, TerraNet data will be released for use by the general public.

Scientific Importance

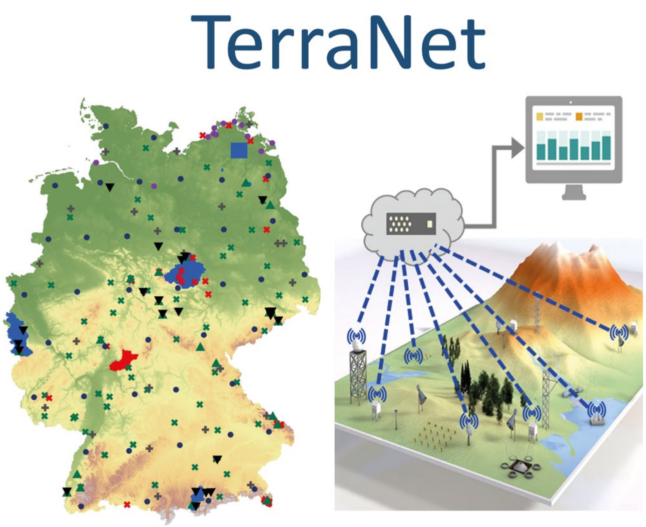
The TerraNet infrastructure brings together current terrestrial observation systems: spatially distributed, stationary sensors (TERENO, ICOS, eLTER, official measurement networks), mobile sensors for recording short-term events and long-term trends in the Earth system (MOSES), and remote sensing. The integrated approach of TerraNet makes it possible for the first time to provide continuous assessments of the consequences of events or measures on the environment – initially on a national, later also on a European and global level. This is possible because TerraNet data can be used to further develop current numerical models for simulating the terrestrial environment, including the climate.

Strategic Relevance

With TerraNet, Germany will assume a pioneering role in environmental forecasting and establish global standards for environmental observation and data-based forecasting. TerraNet is of central importance for national environmental research and forms a significant platform for trans- and interdisciplinary cooperation. The cross-institutional cooperation allows for the first time a Germany-wide standardization of the work flows – from the installation of the measurement technology to the processing, provision and evaluation of the data, the modeling, and product generation. A close connection with the European infrastructure eLTER also makes it possible to help shape the research landscape in Europe in the long term and to make important contributions to European initiatives such as the European Green Deal.

Dates and numbers

Acronym:	**TerraNet**
Category:	B
Period of realization:	2024 - 2028
Estimated investment in € MM:	100
Estimated operating costs per year in € MM:	8
Lead Helmholtz Center:	FZJ
Other Helmholtz centers involved:	AWI, DLR, GFZ, Hereon, KIT, UFZ



GRACE-I – GRAVITY RECOVERY AND CLIMATE EXPERIMENT COMBINED WITH ICARUS PAYLOAD

Summary

GRACE-I consists of a pair of identical satellites and continues the highly successful GRACE and GRACE-FO satellite missions. Extremely precise range measurements between the satellites will allow, at a much lower orbit, the monitoring of mass changes on Earth that depend on the global water cycle with unprecedented accuracy. In addition, the satellites will be equipped with highly stable clocks, gravity reference sensors, or hybrid accelerometers. The gravity field measurements will be complemented by an ICARUS payload for global biodiversity monitoring. GRACE-I is intended as a German contribution to a joint Mass Change (MC) and Surface Biology & Geology (SBG) mission realized together with NASA within the NASA Decadal Survey Program.

Scientific Importance

Numerous scientific studies, applications, and services in hydrology, oceanography, or glaciology have been developed based on past mass transport data. Many Essential Climate Variables rely either entirely (Total Water Storage) or substantially (e.g., Ground Water, Ice Sheets, Glaciers, or Sea Level) on mass transport data. GRACE-I is intended to realize a seamless, multi-decade time series on climate change monitoring.

Strategic Relevance

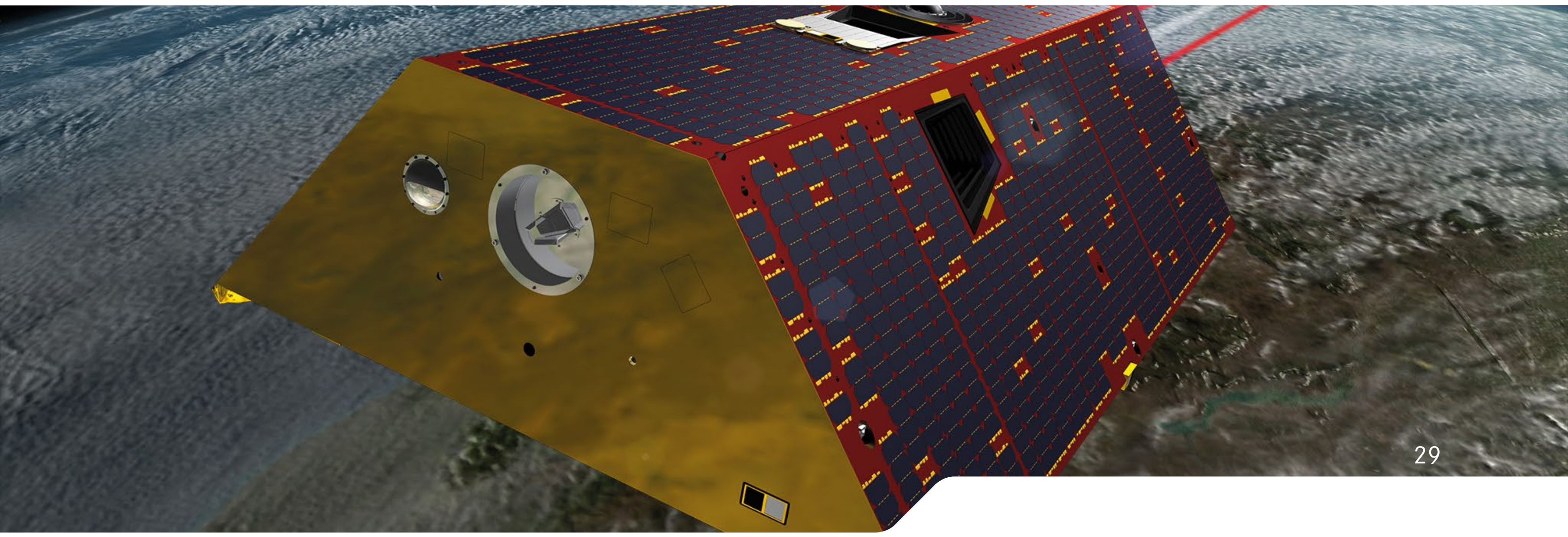
A pair of satellites, once again realized by the U.S. and Germany, with a Laser Ranging Interferometer as the primary ranging instrument, combined with an ICARUS payload and other quantum technology demonstrators, represents a unique technological and scientific opportunity for Germany.

GRACE-I should therefore be jointly realized by the major German research communities such as the Helmholtz Association (gravitational field) and the Max Planck Society (quantum technology, behavioral biology), with DLR space management (overall programmatic management) and GFZ (gravity field data analysis) together with NASA as soon as possible. In addition, to significantly increase the spatial and temporal resolution of future mass transport products, GRACE-I could be combined with a Next Generation Gravity Mission (NGGM) to form a double-pair mission on complementary orbital configurations around 2028/29. Such a NGGM is currently being planned by ESA in the FutureEO program.

Dates and numbers

Acronym:	**GRACE-I**
Category:	C
Period of realization:	2022 - 2032 et seq.
Estimated investment* in € MM:	510.9 (211.5)
Estimated operating costs* per year in € MM:	(18)
Lead Helmholtz Center:	GFZ
Other Helmholtz centers involved:	DLR

*) German share in parentheses..



HEALTH

RESEARCH FIELD HEALTH

Profile

The Research Field Health pursues the goal of making substantial contributions to improving the quality of human life through research and innovation. The focus is on research into the complex causes and mechanisms of common diseases, such as cancer, neurodegenerative diseases, diabetes, cardiovascular diseases, infections, allergies and lung diseases. In addition, innovative methods for precise prevention, diagnostics and treatment are being developed. An integrative and long-term strategy enables cutting-edge research with critical mass. It spans the spectrum from basic research, to translation into clinical applications and transfer to industry and society. As a result, the Research Field Health has become one of the most important biomedical research clusters worldwide and is also a sought-after partner of university medicine, private industry and international networks.

Guided by medical necessity and high societal relevance, the participating centers are thematically focused.

Challenges

An aging population and changes in lifestyle and the environment continue to lead to a sharp increase in common diseases that place an enormous burden on healthcare systems and society.

The dramatic worldwide increase in cancer and its marked biological heterogeneity require further efforts in prevention and personalized therapeutic strategies.

Infectious disease medicine faces global threats, such as emerging and re-emerging infections with pandemic potential, chronic infectious diseases, and increasing antimicrobial resistance.

The complex role of environmental influences in the development but also in the prevention of allergies, asthma, lung diseases, obesity and diabetes is rapidly gaining importance due to climate and global societal changes.

There are no effective treatments for neurodegenerative diseases and industry has largely withdrawn from the development of new drugs. Early clinical trials in stratified patient populations are critical to moving new therapeutic approaches into care.

Diseases often cross the boundaries of individual tissues and organs and have an impact on the whole organism. A cross-organ understanding of the molecular mechanisms of disease and health is therefore essential to prevent disease, diagnose it early, and treat it.

Increasing comorbidities add to the complexity. Last but not least, the potential for prevention of common diseases is far from exhausted.

Strategy

To meet these challenges, the centers of the Research Field are pursuing a highly integrative and translational research strategy. This builds on world-class basic research and expertise across multiple disease areas and leverages interdisciplinarity, critical mass, and high-performance infrastructures and technologies. Breakthroughs in biomedical research are thus driven to combat individual common diseases, such as in the fields of multi-omics analyses, single-cell analysis, high-resolution imaging, CRISP-based genome modification, synthetic biology and artificial intelligence. In addition to technology development and intensive use of integrated data science, common themes include the study of cross-disease aging and metabolic processes, and the role of the immune system in disease pathogenesis and therapy. The centers are significantly involved in large cohort studies such as the NAKO Health Study and the Rhineland Study, and pursue integrated approaches for the prevention of common diseases. Translational centers have been successfully established together with University Medicine to enable highly competitive research for precision medicine and to facilitate patient access to innovations.

Infrastructure Planning

Key factors for success are the high-performance infrastructures, for example for imaging, for omics analyses, for data storage and analysis, for population-based studies, and the translational centers and networks essential for the translational approach. The forward-looking roadmap for the coming years will close gaps regarding key strategic challenges.

The Clinical Research Network for Neurodegenerative Diseases **(KFNE)** forms an important basis for the development and testing of new therapeutic approaches and enables cross-site, early clinical studies in stratified patients with regard to personalized therapies, for example for the various subtypes of dementia.

The 3R Preclinical Cancer Center **(3R PCTC)** employs visionary in vitro models, intercalated with animal experiments according to state-of-the-art 3R principles using cutting-edge technology, thus closing a significant gap between preclinical evaluation and clinical application for personalized therapies.

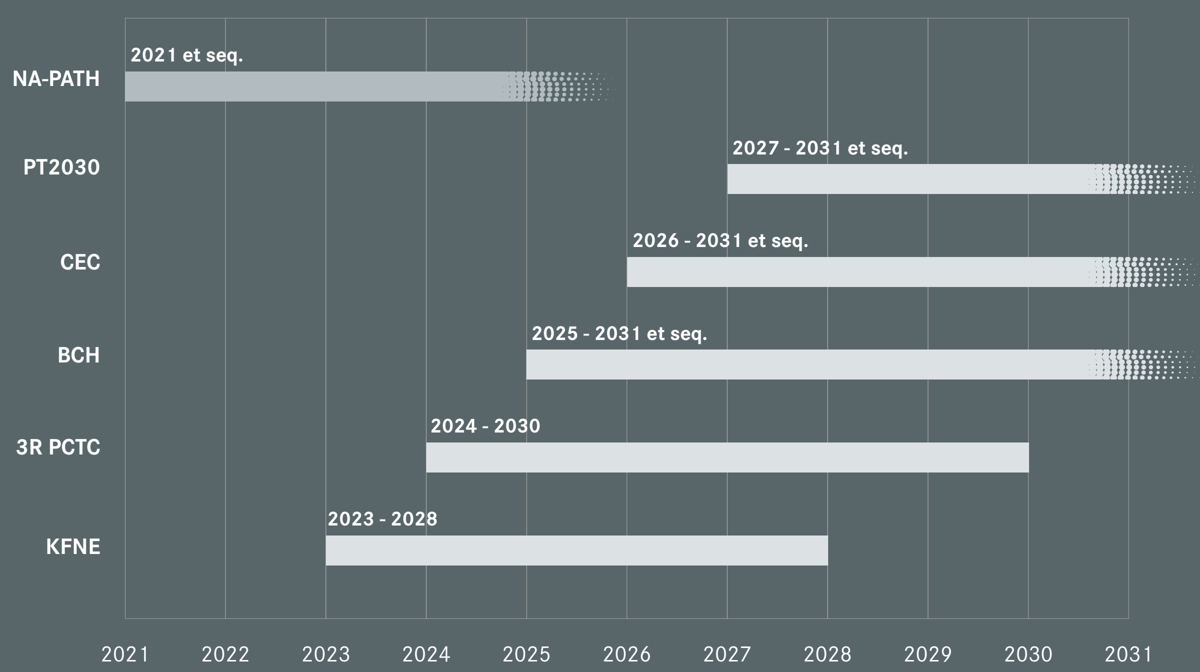
At the Berlin Cell Hospital **(BCH)**, innovative medicine will be developed and applied at the cellular level. This will improve the understanding of the development and progression of diseases, help to predict them at early stages and to treat them innovatively.

The **National Alliance for Pandemic Therapeutics (NA-PATH)** will advance research and development of novel antiviral agents in non-pandemic times (up to early clinical trials) to provide effective therapies much faster in the case of a pandemic.

The interdisciplinary-integrative Comprehensive Environmental Health Exposure Center **(CEC)** will create an environment that will allow a combination of observational and experimental research to investigate the role of complex environmental exposures in health maintenance and disease development.

Furthermore, the Research Field Health is working on a Next Generation Proton Therapy **(PT2030)** project.

Planned Implementation



Legend:

- **A** – Helmholtz projects financed through the Helmholtz Association's competitive procedure for strategic expansion investments (€15 to €50 million).
- **B** – Large national projects of the Helmholtz Association that are included on the national roadmap and funded with additional project funding (> €50 million).
- **C** – Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.

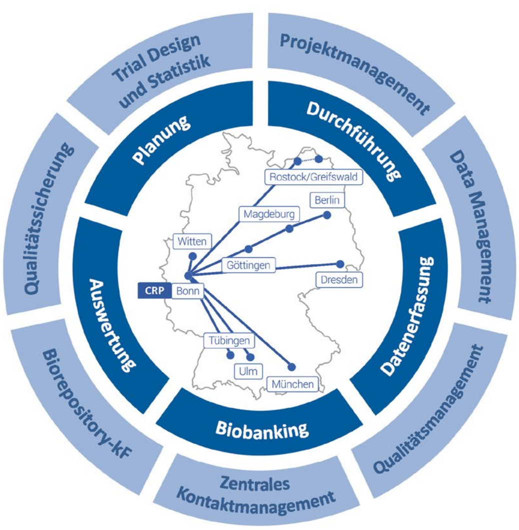
KFNE – CLINICAL RESEARCH NETWORK FOR NEURODEGENERATIVE DISEASES

Summary

Currently, there are no disease-modifying therapies for neurodegenerative diseases. The DZNE Clinical Research Network is designed to rapidly conduct proof-of-principle studies for new drugs in recruited and stratified patient cohorts. In order to conduct these clinical trials, the DZNE requires an infrastructure of clinical trial units at its sites. The units will conduct so-called first-in-human studies, as well as other clinical trials and follow-up studies that require particularly sophisticated protocols. The clinical trial units will be led by specialized clinical study teams.

Scientific Importance

Only symptomatic treatments with limited efficacy are currently available for neurodegenerative diseases. Disease-modifying therapeutic approaches have so far not led to any successes worldwide. Therefore, there is a pressing need to rapidly translate new findings from fundamental research to the clinic. Since the pharmaceutical industry has almost stopped the development of new drugs for neurodegenerative diseases, it is even more important that academic research institutions identify new treatment approaches. So-called investigator-initiated trials, drug repurposing studies and those resulting from strategic collaborations of the DZNE with industry are essential for the development of new drugs. Focused clinical trials in the highly characterized patient cohorts of the DZNE are the basis for future personalized treatments.



Strategic Relevance

The highly characterized patient cohorts of the DZNE allow the targeted definition of patient groups with individual disease profiles. Newly developed compounds from the DZNE pipeline can thus be tested efficiently and across DZNE sites without being tied to the use of the infrastructure of our partner universities, who engaged in normal patient care. The already existing infrastructure at the DZNE sites will be expanded to conduct these innovative clinical trials. The DZNE Clinical Research Network will strengthen the partnership with the university hospitals and will be available to other centers in the Helmholtz Association. The clinical trial units will not only enable innovative proof-of-concept studies and large multicenter trials, but also make extremely valuable contributions to basic research and systems medicine. The availability of large data sets will help to make the DZNE and the Research Field Health an important source of information for health policy and position the DZNE as an attractive partner for the global pharmaceutical industry.

Dates and numbers

Acronym:	**KFNE**
Category:	A
Period of realization:	2023 - 2028
Estimated investment in € MM:	30.6
Estimated operating costs per year in € MM:	7.3
Lead Helmholtz Center:	DZNE
Other Helmholtz centers involved:	None

3R PCTC – 3R PRECLINICAL CANCER TRIAL CENTER

Summary

Through animal models but increasingly also by complex three-dimensional multicellular systems, the results of basic research (through preclinical studies) can be translated into innovative strategies for the treatment, early detection and prevention of cancer. However, current preclinical facilities still fall far short of modern clinical capabilities in this regard. At the 3R Preclinical Cancer Trial Center of DKFZ, visionary in-vitro models are therefore developed in an approach that is unique worldwide and directly intercalated with state-of-the-art animal studies according to 3R principles (Refinement, Replacement and Reduction). In a central trial suite, all clinically relevant cutting-edge technologies for intervention and monitoring, such as imaging, sensor technology and robotics, are further developed for simultaneous use on the various model systems. This will enable multidimensional preclinical studies of unprecedented breadth and depth. The 3R Preclinical Cancer Trial Center (3R PCTC), a unique facility with disruptive potential, will be made accessible to the biomedical community, both within and outside the Research Field Health, for translational research.

Scientific Importance

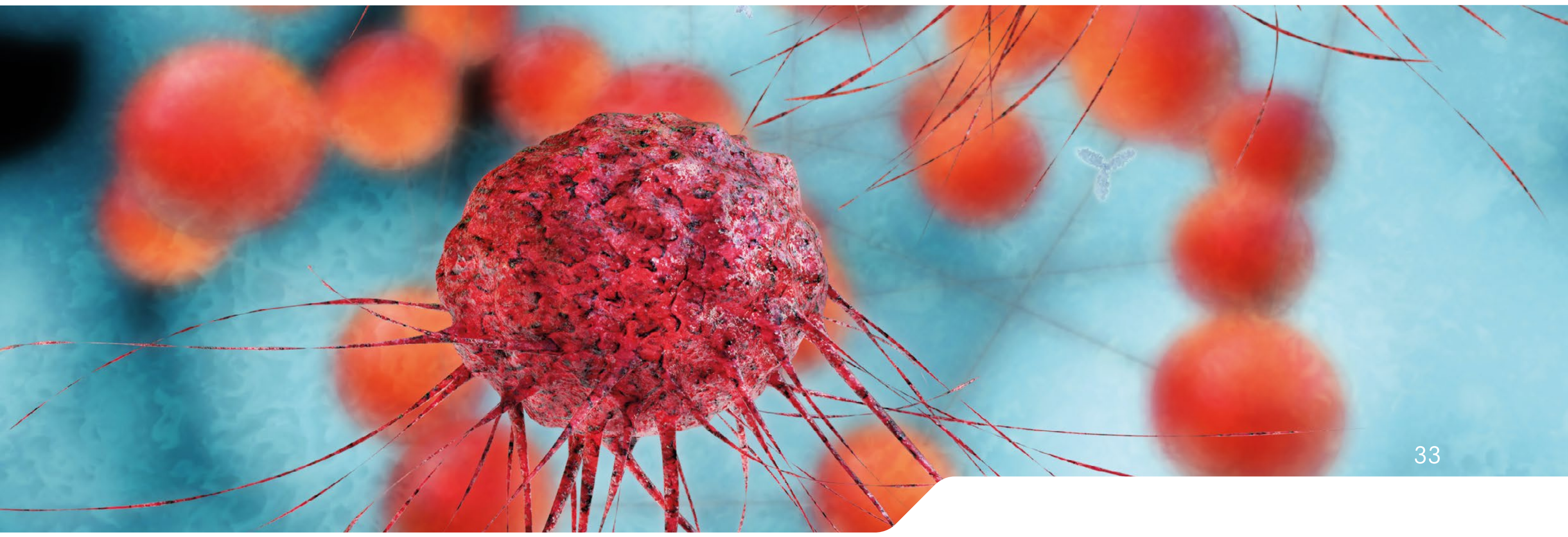
Preclinical studies that accurately reflect the human situation are of rapidly increasing importance for the targeted translation of inventions into innovative strategies for the treatment, early detection and prevention of cancer and other diseases. The 3R Preclinical Cancer Trial Center, through its intercalated structure and use of the most innovative cutting-edge technology, bridges the gap between in vitro systems and animal testing on the one hand, and preclinical evaluation versus modern clinical capabilities on the other. As a result, preclinical translational studies can be performed not only with unprecedented speed and breadth, but also with unique multidimensional depth.

Strategic Relevance

The new, globally unique 3R Preclinical Cancer Trial Center will not only significantly expand the translational research opportunities of DKFZ and its network partners, but also raise them to a new level. This will give decisive impetus to the patient orientated translational strategy of the cancer research program. The disruptive research opportunities of the new center will also promote national and international collaborations with academic partners and industry, thus adding significant value to the network strategy of the cancer research program.

Dates and numbers

Acronym:	**3R PCTC**
Category:	A
Period of realization:	2024 - 2030
Estimated investment in € MM:	35
Estimated operating costs per year in € MM:	1.5
Lead Helmholtz Center:	DKFZ
Other Helmholtz centers involved:	None



BCH – BERLIN CELL HOSPITAL

Summary

The MDC is planning the Berlin Cell Hospital (BCH) to develop and apply innovative medicine at a cellular level (Cell-based Medicine). The pursued aim is to predict the development and progression of diseases at an earlier stage, to better understand and innovatively treat them (Interceptive Medicine). Methods and concepts from basic life and data sciences will be developed, integrated and medically applied. This will be achieved in collaboration with partners within the Helmholtz Association, as well as Berlin research institutions and universities, clinics (Charité), the Berlin Institute of Health (BIH) as translational partner and industry partners. The BCH will build on Virchow's Berlin tradition and develop into an innovation driver for biotechnology and medicine in Berlin with cell-based approaches.

Scientific Importance

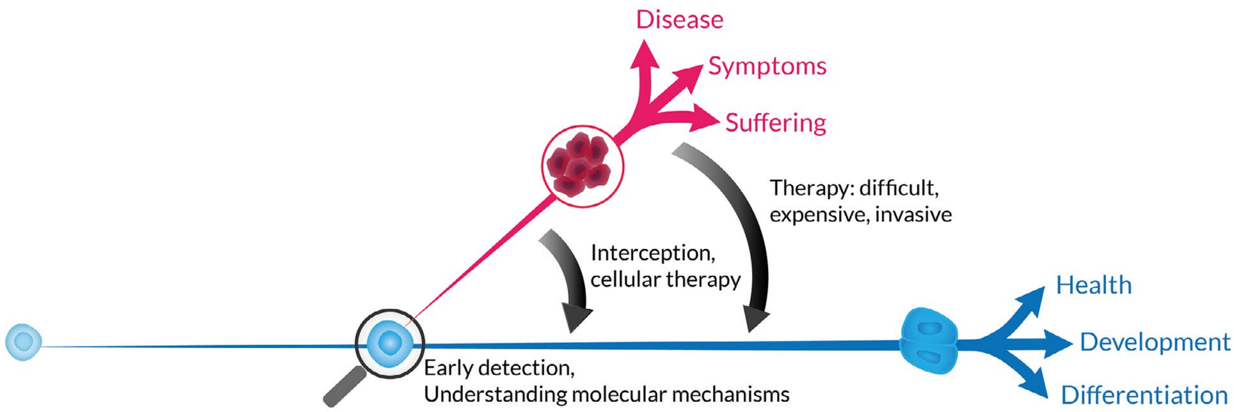
Therapeutic options for major widespread and infectious diseases in their advanced stages are very costly because diagnosis often occurs much later than the onset of the cellular pathology. New methods such as high-throughput single-cell analysis, imaging, and artificial intelligence can be used to detect cell changes and molecular processes that trigger or explain disease progression early on. Other technologies such as CRISPR, humanized model systems, opto- and nanotechnology, etc., are also being developed, combined, and applied to understand the molecular causes and mechanisms of early disease progression or the emergence of resistance, for example to immunotherapies. With the Cell-based Interceptive Medicine approach, targeted diagnostic and intervention methods are developed to eventually therapeutically treat cells and tissues at an early stage.

Strategic Relevance

The BCH integrates key strategic goals of the MDC PoF program Systems-wide and Cardiovascular Diseases and existing infrastructures such as the Optical Imaging Center, with the focus areas of BIH, MDC and Charité, single-cell technologies for personalized medicine and translational vascular biomedicine. At the same time, the BCH realizes the medical vision of the LifeTime Initiative, the MDC-coordinated, pan-European consortium with more than 200 research institutions and 80 companies. In this way, the BCH fulfills an important national and international scientific and strategic function in health research and establishes a network with relevant national and international institutions and consortia (NCT and DZGs (DKTK, DZHK, DZKJ) as well as international initiatives and consortia (among others LifeTime, Human Cell Atlas, Chan Zuckerberg Initiative, ELIXIR, RESTORE). Innovations in technology and medicine will lead to spin-offs and company collaborations in the areas of biotechnology, pharmaceuticals and bioinformatics, also beyond the borders of Berlin.

Dates and numbers

Acronym:	**BCH**
Category:	A
Period of realization:	2025 - 2031 et seq.
Estimated investment in € MM:	48
Estimated operating costs per year in € MM:	2
Lead Helmholtz Center:	MDC
Other Helmholtz centers involved:	None



Cell-based interceptive medicine

CEC – COMPREHENSIVE ENVIRONMENTAL HEALTH EXPOSURE CENTER

Summary

Today's common diseases result from the interaction of environmental stressors and individual genetic makeup. Rapid global climate and lifestyle changes add to the urgent need for action. The Comprehensive Environmental Health Exposure Center (CEC) aims to uncover common mechanistic principles of the development and progression of allergy and asthma, as well as infectious and chronic lung diseases. This includes studies of metabolic and epigenetic programming as well as aging processes. By means of integrated approaches from epidemiology, genetics, immunology and exposomics, key mechanisms of protective environmental influences are to be made available as treatments. Close cooperation with national and international partners creates synergies to elucidate the effect of environmental influences on other diseases.

Scientific Importance

The multidisciplinary research at HMGU initiated a paradigm shift in the study of gene-environment interactions: While environmental stressors can induce the above-mentioned diseases, protective environmental influences have a preventive effect. Understanding molecular mechanisms of individual environmental interactions is critical in the development of personalized prevention and treatment strategies based on these findings. Translational studies will focus on exposure, as well as molecular, cellular, and organ barrier structures. Thus, key processes in tolerance, immunity, disease development and regeneration can be deciphered. Networking with the HMGU Topics will enable integration of the latest bioengineering, AI and digital health technologies.

Strategic Relevance

Genetic and environmental factors play a crucial role in all major common diseases. Therefore, research into their influence on disease development or health maintenance is of central importance. The HMGU builds on its leading expertise in large preclinical population- and patient-based cohorts, and also conducts environmental research at the interface with human health. This unique interdisciplinary integrative approach combines observational and experimental research. We anticipate findings with transformative potential for prevention and treatment solutions to address the major health challenges of our time.

Dates and numbers

Acronym:	**CEC**
Category:	A
Period of realization:	2026 - 2031 et seq.
Estimated investment in € MM:	35
Estimated operating costs per year in € MM:	1.5
Lead Helmholtz Center:	HMGU
Other Helmholtz centers involved:	None

PT2030 – NEXT GENERATION PROTON THERAPY: ONLINE ADAPTIVE

Summary

For the first time, real-time adaptive proton therapy will be realized — enabled by a closed, fully automated and AI supported feedback loop of imaging, treatment verification and adaptation in real time. This will bring the clinical advantage of proton therapy to its physical maximum, improve patient survival and/or reduce side effects, and furthermore enlarge the PT-eligible tumor entities. A worldwide unique research-clinic hybrid proton facility will be built where, for the first time, innovative software and hardware components and their interaction will be integrally tested, further developed, and finally enabled for clinical application. Close cooperation partners are the University Hospital Dresden, the medical technology industry, and CASUS.

Scientific Importance

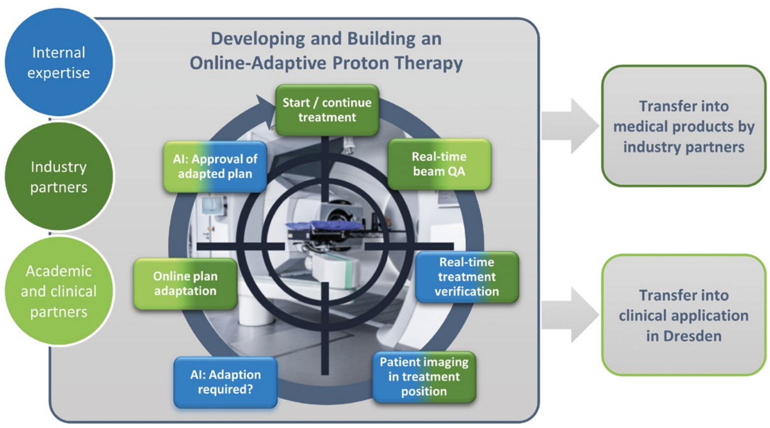
The goal of next-generation proton therapy (PT2030) is to develop the best physically possible radiation therapy for patients: The advantage of tissue-sparing dose distribution of protons will be combined for the first time with the advantages of adjusting the irradiation in real time. This currently exists only in the dosimetrically inferior photon therapy. The research focus is on further development and integral translation of preclinical, prototype innovations, techniques, and algorithms into patient application. This will result in improved treatment success rates, in particular for patients with highly changing or moving tumors who could benefit more from proton therapy. Research is still focused only on the isolated component development in the laboratory — the interaction and automated decision-making is yet to be integrally tested and thus made ready for actual application.

Strategic Relevance

Successful implementation of the translational project would make the site the world‘s leading center for online adaptive proton therapy. In the field of proton therapy translation research, it would rank among the top five centers and thus also support the BMBF initiated Decade against Cancer. For the healthcare systems of industrialized nations, the project would have a double effect: cancer therapy would be improved and, at the same time, costs would be reduced in the long term due to the highest level of automation. Thanks to collaborations with leading international medical technology companies, the innovations will be made usable for patient care.

Dates and numbers

Acronym:	**PT2030**
Category:	A
Period of realization:	2027 - 2031 et seq.
Estimated investment in € MM:	35
Estimated operating costs per year in € MM:	2.9
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	None



NA-PATH – NATIONAL ALLIANCE FOR PANDEMIC THERAPEUTICS

Summary

The current SARS-CoV-2 pandemic demonstrates the devastating impact that emerging, uncontrolled spread of infectious agents can have. As new major human infectious disease outbreaks are expected to continue in the future, improved preparedness for future pandemics is imperative. Targeted agents adapted to the respective infection events are one of the essential components for successful pandemic management. Against this background, the HZI together with the German Center for Infection Research (DZIF) proposes the establishment of a novel strategic alliance of academic science, industry, regulatory authorities and politics: the so-called National Alliance for Pandemic Therapeutics (NA-PATH). This alliance will carry out the necessary research and development of active substances in non-pandemic or pre-pandemic times, right up to the first clinical trials. In this way, effective therapies can be made available much more quickly in the event of a crisis. The focus will be on pathogen groups with high pandemic potential and will include therapeutics with cross-pathogen efficacy, platform technologies and approaches for symptomatic therapy.

Scientific Importance

The core element of NA-PATH is the decentralized platform of scientific disciplines and technologies to explore and optimize novel small molecules and biologic agents. From the platform emerges a portfolio of promising preclinical development candidates for future therapeutics. Additional advanced candidates can be added to the portfolio at any stage of development. When the final clinical phase IIa (proof-of-concept) is reached, intellectual property rights can be licensed to the biotechnology and pharmaceutical industry or serve for spin-offs, strengthening the connectivity for NA-PATH product candidates.

Strategic Relevance

The National Alliance for Pandemic Therapeutics is designed to ensure the necessary paradigm shift in response management to future pandemic pathogens. The overarching mission is to develop broadly effective antiviral therapeutics to treat emerging viral pathogens. This should help to reduce the burden of disease and contribute to the early control and containment of future pandemics. To this end, under the leadership of HZI and DZIF, the research and development potential of leading German academic infectious disease research centers is specifically focused on key innovation areas in drug discovery and development. This means NA-PATH relies on collaborations between academic research centers with highly relevant infrastructures and expertise in the field of infection research, university hospitals, the pharmaceutical industry, as well as regulatory authorities and politics.

Dates and numbers

Acronym:	**NA-PATH**
Category:	B
Period of realization:	2021 et seq.
Estimated investment in € MM:	105
Estimated operating costs per year in € MM:	25
Lead Helmholtz Center:	HZI
Other Helmholtz centers involved:	None

INFORMATION

RESEARCH FIELD INFORMATION

Profile

The Research Area Information addresses the opportunities and challenges of the digital transformation as an interdisciplinary, method- and technology-oriented enabler and shaper. To this end, scientific principles of representation, storage, transfer and processing of information in natural and technical systems are explored. They form the basis for high-performance and secure information systems, for which we develop innovative technological solutions as well as fundamental concepts, methods, algorithms and software tools, and demonstrate their capabilities on challenging scientific and technical problems. Digital and digitized research infrastructures, such as exascale computers, quantum computers, multi-method platforms for materials development, or data management and software systems are simultaneously research objects and research infrastructures. The value creation potential of our research results is demonstrated together with our partners and reflected in its societal context. Both material science and neuroscience are geared towards the consistent use of digital technologies with regard to both the research process and its products. They are therefore constitutive in two respects: both form the foundation and application field for future information technologies. A central task of our work is the translation and transfer of our findings into the economy and health care system.

Challenges

Enabling considered and informed action in a society increasingly shaped by digitalization forms the framework for the work of the Research Field, from which a wide range of challenges will be derived over the next ten years:

- New information and communication technologies, most notably more powerful classes of computing and storage technologies, must be developed, demonstrated and implemented.
- Highly scaling, (hybrid) simulation and data science methods and their intergration in (partially) automated workflows are both research objects and tools of digitally driven R&D processes.
- Instrumental innovations, e.g. in NMR and microscopy, as well as analyses of large data sets, contribute decisively to breakthroughs in (neuro- and material) sciences.
- Technological and clinical innovations are achieved through a cross-scale, quantifiable understanding of the biological information processing, function, and dysfunction of the brain.
- Automated processes of efficient and accelerated material development open up new opportunities, for example for information and medical technologies. Bridging the gap from the atom to the component, and an integrated approach to the material life cycle will lead to sustainable products with new functionality.

Strategy

By means of computers of the highest performance class, data storage and analysis, as well as the modular integration of promising technologies of quantum and neuromorphic computing in supercomputers, the Research Field Information will provide the basic tools for digital transformation to interactively analyze complex problems. These include processes in the human brain, cross-scale and digital development of material systems, severe weather phenomena, as well as complex traffic logistics and epidemiological processes. In addition, technological development and brain research are linked via innovative digital research infrastructures in order to draw on new technological and clinical potential. New infrastructures will be made accessible by researching and developing basic algorithms, methods, tools and concepts for handling information and data. This leads to direct application, for example, in high-resolution, high-throughput methods coupled with real-time analysis, or in Earth system research where exascale computing capabilities and petabyte data management are required. In addition, the combination of novel analytical methods with much more precise data from microscopy, NMR, neutron probes, and synchrotron radiation will serve to take materials systems development to a new level with dynamic digital twins.

Infrastructure Planning

The planned research infrastructures are essential for the implementation of the scientific program of the Research Field. They are also open to external users and contribute to the implementation of national and international strategies.

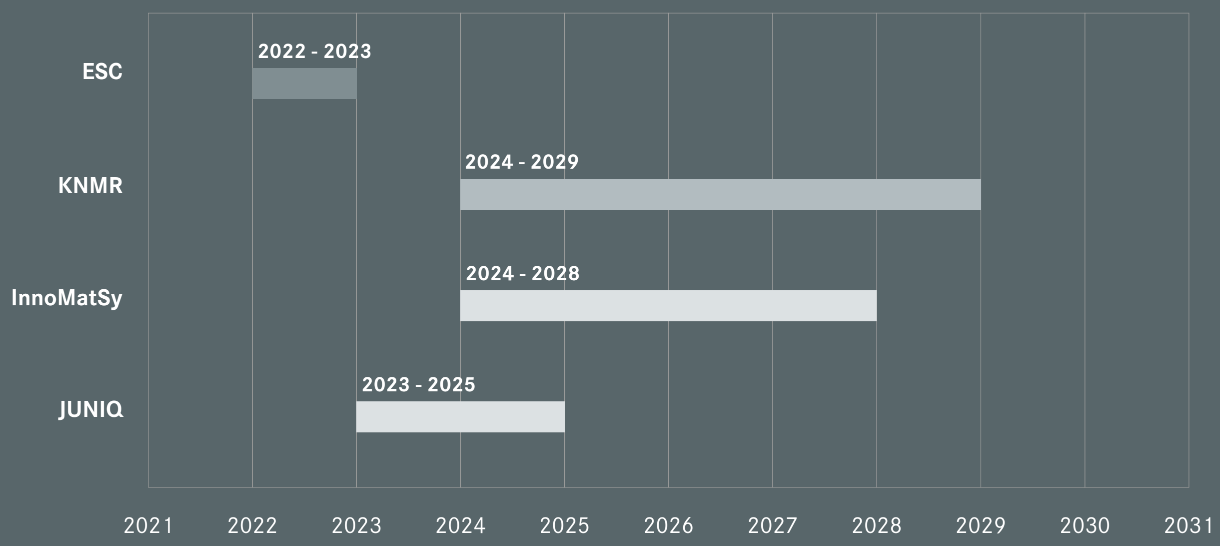
The Exascale Supercomputer **(ESC)** extends the existing supercomputing infrastructure and will herald the next generation. Simulations and data analysis on supercomputers are the link between theory and experiment, becoming ever more important as problems become more complex. Universally applicable and modularly adaptable exascale systems will create synergies between communities. The Jülich UNified Infrastructure for Quantum Computing **(JUNIQ)** provides access to quantum computers, simulators and annealers, as well as HPC-based emulators for European scientific and industrial communities via a unified cloud platform, including user support and training. It provides an environment to advance algorithms, software tools and applications in collaboration. It is closely linked to the Helmholtz Quantum Center, whose portfolio ranges from quantum materials to quantum computing. **InnoMatSy** is a modular multi-method infrastructure spanning materials, functions and applications, which for the first time ever allows in situ, in operando and in vivo analyses of sample bodies in equal measure. In this way, a wide variety of states and processes in both the object and its environment can be understood and virtualized.

The Karlsruhe Nuclear Magnetic Resonance facility **(KNMR)** is an application and technology research center for nuclear magnetic resonance that will implement correlative material characterization including in-operando observation and life cycle management using a concrete example. It has some of the strongest superconducting NMR magnets in the world.

Both KNMR and InnoMatSy will represent milestones in the digitization of materials science and will strengthen the strategy of the Research Field. They will also complement the existing infrastructures under development, such as the Karlsruhe Center for Optics and Photonics, and the Ernst Ruska Center 2.0.

In Terra-Lab, an infrastructure for observing the terrestrial system, the Research Field Information is supporting the Research Field Earth and Environment in the joint development of a secure information infrastructure for data processing on distributed computing systems.

Planned Implementation



Legend:

A – Helmholtz projects financed through the Helmholtz Association's competitive procedure for strategic expansion investments (€15 to €50 million).

B – Large national projects of the Helmholtz Association that are included on the national roadmap and funded with additional project funding (> €50 million).

C – Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.

JUNIQ – THE JÜLICH USER INFRASTRUCTURE FOR QUANTUM COMPUTING

Summary

The Jülich UNified Infrastructure for Quantum Computing (JUNIQ) will provide European science and industry with access to quantum computing technologies of various types and levels of technological maturity. This access to quantum computers, quantum simulators and quantum annealers, as well as emulators of such systems on supercomputers, will be provided via a unified, user-friendly cloud platform. Furthermore, JUNIQ offers support, training and collaboration opportunities to the user. It will also see the development of software tools, modeling concepts, algorithms and prototype applications. In order to make practical use of quantum technologies in scientific computing, they must be integrated into high-performance computing infrastructures. At the Jülich Supercomputing Centre (JSC), the necessary modular architecture of hardware and software elements has already been realized meaning that JUNIQ systems can be integrated.

Scientific Importance

Advances in the development of quantum computers will allow for completely new applications, for example in machine learning, solving difficult optimization problems, and for (material) simulations. Second-generation quantum technologies are expected to have an impact on all areas of science, from energy and climate research to life sciences. The properties of the quantum world open up new avenues for solving previously unsolvable problems.

Strategic Relevance

Quantum technologies and quantum computing receive considerable attention at the highest levels of research and economic policy, both nationally and internationally. JUNIQ is expected to play the leading role in the use of quantum computing hardware in the Helmholtz Association, in Germany and in Europe. It will open these technologies to user communities in science and industry and offer opportunities for joint research and development projects, for example on methods, algorithms and software tools arising from concrete practical problems. The practical application of quantum technologies requires hybrid computing, using both classical supercomputers and quantum computers. Thus, JUNIQ has taken over the coordination of the pilot project <HPC|QS> on the integration of supercomputing and quantum simulation, which is funded by the EuroHPC JU.

Dates and numbers

Acronym:	**JUNIQ**
Category:	A
Period of realization:	2023 - 2025
Estimated investment in € MM:	25
Estimated operating costs per year in € MM:	0.6
Lead Helmholtz Center:	FZJ
Other Helmholtz centers involved:	None

INNOMATSY - IN-SITU INNOVATION PLATFORM FOR MULTIFUNCTIONAL MATERIAL SYSTEMS

Summary

With the In-situ Innovation Platform for Multifunctional Material Systems (InnoMatSy), scientists will study samples that are under constant change in a realistic environment. They will simultaneously obtain information at the highest spatial and temporal resolution by combining one analytical technique, which requires a large-scale instrument, with other analytical techniques. In order to process the acquired experimental data in real time and to generate dynamic digital twins, the respective InnoMatSy instrument is combined with data storage systems, real-time software tools and Big Data strategies. Tomography with synchrotron radiation at DESY's PETRA III storage ring serve as the pilot method and reveal changes in metabolic functions situated close to degradable metallic implants.

Scientific Importance

InnoMatSy is an infrastructure that spans materials, functions and applications, allowing the characterization of continuously changing samples. Through such an infrastructure, researchers can investigate a wide variety of states and processes, both in the object and in its environment. Many areas of science benefit from this, such as research on photocatalytic hydrogen synthesis, battery materials, polymer biomaterials and magnetic textures, and the release and interaction of pollutants in water.

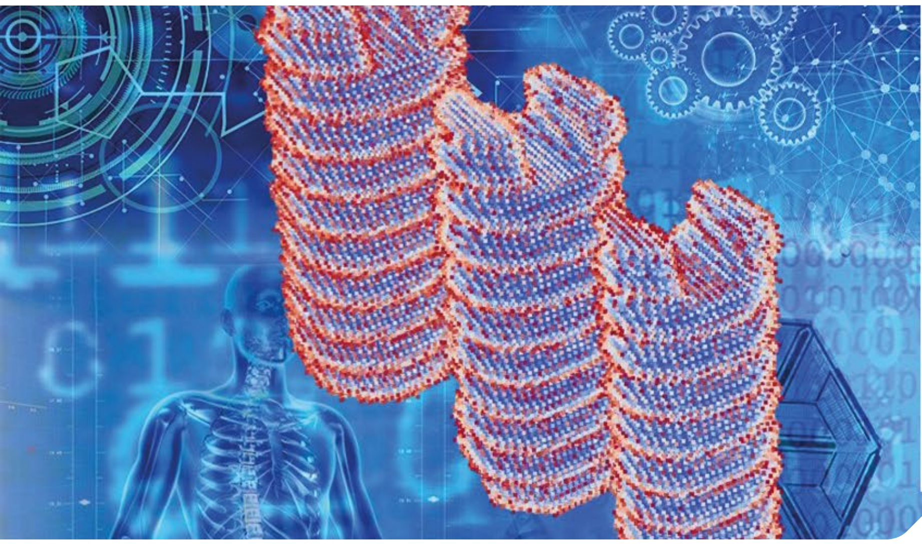
Among other things, the pilot application has allowed the observation of feedback phenomena that trigger tissue regeneration, but remain misunderstood. This could be meaningful for the treatment of cancer.

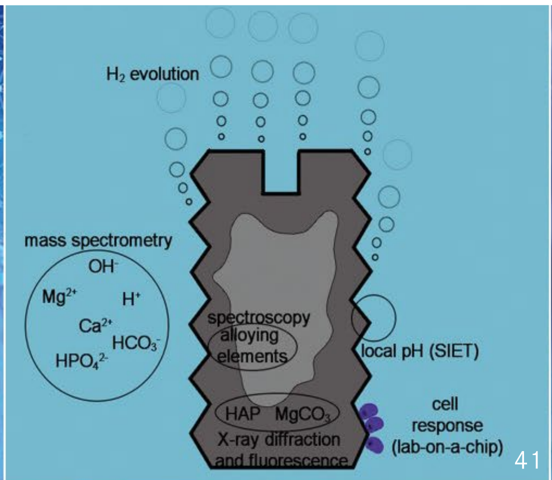
Strategic Relevance

Information-guided development of innovative material systems is a key element of future scientific and engineering research and development. Dynamic digital twins open up an entirely novel approach. Among other things, they can be used to optimize manufacturing processes for material systems very efficiently from a computer. The methodology for obtaining and processing experimental data, as developed for the pilot application, can also be transferred to other analysis methods, such as NMR, electron microscopy, soft synchrotron radiation, positron spectroscopy, as well as to other large-scale facilities, for example KMNF, ER-C, BESSY II, EPOS@ELBE.

Dates and numbers

Acronym:	**InnoMatSy**
Category:	A
Period of realization:	2024 - 2028
Estimated investment in € MM:	27
Estimated operating costs per year in € MM:	3
Lead Helmholtz Center:	Hereon
Other Helmholtz Centers involved:	DESY, FZJ, HZB HZDR, KIT





KNMR – THE KARLSRUHE NUCLEAR MAGNETIC RESONANCE FACILITY

Summary

The Karlsruhe Nuclear Magnetic Resonance facility (KNMR) will be the leading German NMR center for key applications and technology research. It includes devices whose superconducting NMR magnets are among the most powerful in the world. Two of these instruments have a permanent field strength of over 28 Tesla. The instruments are used for high-resolution spectroscopic characterization of novel materials. The KNMR is also home to the HiT-NMR high-throughput NMR facility, which is currently under construction. Another component of the KNMR is a laboratory for correlative analysis of materials by combining NMR spectroscopy with other spectroscopic and imaging techniques. Spectroscopic NMR imaging, a technique that combines NMR spectroscopy and MR imaging is also used.

Scientific Importance

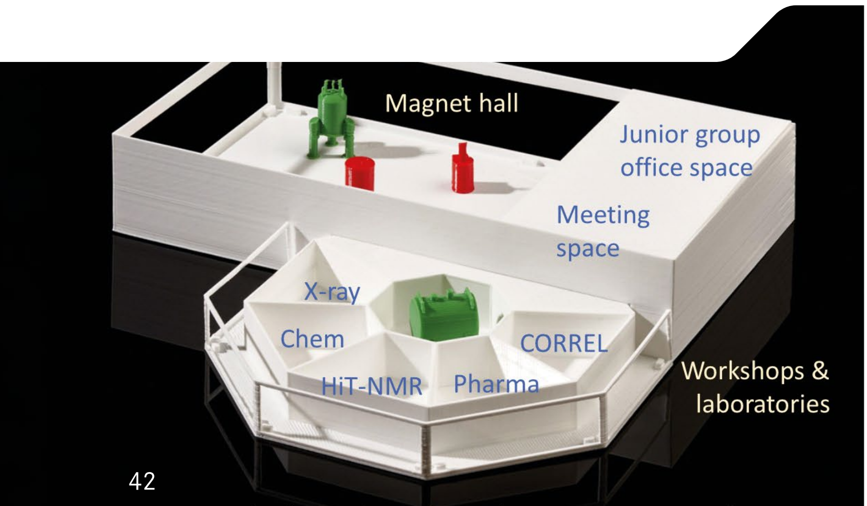
Especially when correlated with IR, UV, Raman or other detectors, NMR spectroscopy is the most chemically specific tool to obtain information from materials with high accuracy and on a large scale. The KNMR will host state-of-the-art NMR instruments combined with different types of detectors and a machine learning environment, as well as large amounts of data storage. This will result in a high throughput of materials being studied. Thus, a comprehensive digitization of materials science is possible, combined with numerical prediction, synthesis, characterization, in-operando observation, and life-cycle management – all of which are embedded in a closed-loop machine learning system.

Strategic Relevance

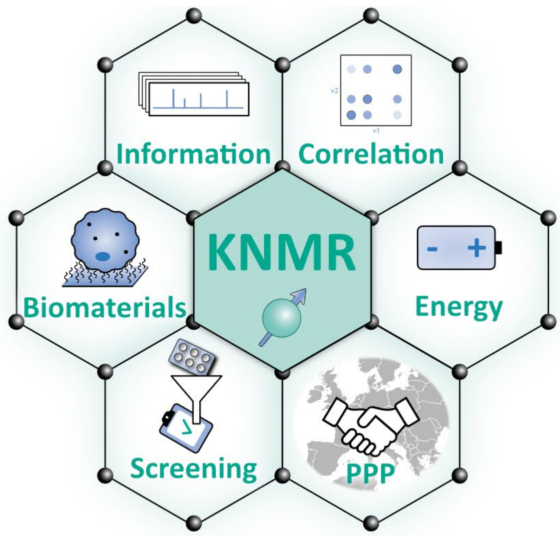
KNMR will provide information-based characterization of materials at the highest possible resolution and throughput to researchers in the Helmholtz Association and beyond. It is thus an essential part of a materials discovery platform that benefits society as a whole and contributes to a future of sustainable materials in Germany. It is a complementary partner in the German NMR infrastructure together with the FZJ and HMGU centers. Internationally it is establishing itself as a center for the study of materials and the extraction of information from molecules. As an open access facility, KNMR provides resources for research in the fields of materials science, process technology, pharmacy, biology, food technology, energy science, as well as for industry.

Dates and numbers

Acronym:	**KNMR**
Category:	B
Period of realization:	2024 - 2029
Estimated investment in € MM:	93
Estimated operating costs per year in € MM:	3
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	None



High throughput/correlative NMR rotunda



ESC – EXASCALE SUPERCOMPUTER

Summary

The Exascale Supercomputer (ESC) of the Jülich Supercomputing Centre (JSC) will be a world-leading supercomputer for science. Computers with a performance of more than a quintillion computing operations per second (exaflop/s) will form the next generation of supercomputers. The ESC will enable simulations that have not been feasible until now due to their complexity or the amount of data to be processed. In the research fields of climate, environment, energy, life, materials and technology, among others, it will deliver results of a higher spatial and temporal resolution whilst also helping to significantly advance artificial intelligence (AI). Overall, the ESC contributes significantly to addressing the grand societal challenges of our time.

Scientific Importance

Simulations and data analysis on supercomputers are the bridge between theory and experiment. Exascale systems suggest significant scientific breakthroughs, which the Partnership for Advanced Computing in Europe (PRACE) has outlined in its Scientific Case 2018 - 2026.

Because the modular ESC can be used universally, it creates enormous synergies between numerous fields of science and application. Simulation and data sciences will continue to align with one another. The Jülich infrastructure of supercomputers offers researchers in Europe a world-leading simulation platform, with excellent support available to scientists from all disciplines using the supercomputers.

Strategic Relevance

FZJ has achieved a leading position in Europe by expanding its infrastructure for supercomputing and data exchange, and it has co-designed European supercomputer technology and helped shape PRACE.

With the exascale expansion, science will make crucial developments. The ESC planned in Jülich is the leading system of Europe's the Tier 0 centers. It is based on FZJ's innovative modular supercomputer architecture, which will integrate the latest technologies such as quantum and neuromorphic computing for the first time.

Dates and numbers

Acronym:	**ESC**
Category:	C
Period of realization:	2022 - 2023
Estimated investment* in € MM:	277 (0)
Estimated operating costs* per year in € MM:	31 (0)
Lead Helmholtz Center:	FZJ
Other Helmholtz centers involved:	None

*) Helmholtz Association share in parentheses.

RESEARCH FIELD AERONAUTICS, SPACE AND TRANSPORT

Profile

The Research Field is divided into three programs: Aeronautics, Space and Transportation. They each combine basic research with concrete applications up to market maturity and the transfer of technologies to the market. In the Aeronautics program, the researchers aim to develop safe, efficient and environmentally compatible air traffic, and to digitize aviation as a whole. In the Space program, scientists are not only researching the formation of planets, the solar system and the universe, but are also providing important infrastructures for modern life on Earth, for example for communication, navigation, and monitoring the Earth and climate. New approaches and innovative solutions for a sustainable transportation system that benefits the economy, society and the environment alike are being developed within the Transportation program of the Research Field.

These three programs are linked by the cross-cutting theme of digital transformation, which runs through all areas. Together with the Research Field Information, the Research Field Aeronautics, Space and Transport uses quantum technologies and artificial intelligence methods for its analyses. As a new spin-off strategy, the “Innovation Hub” is intended to strengthen technology transfer and bring technological advances into application.

Challenges

Climate, mobility and technology are changing globally and the Research Field uses its expertise to develop solutions to these challenges. Its programs explore the earth and the universe, and develop technologies for a sustainable future. In this way, it is helping to strengthen Germany as a center of knowledge and business.

The overarching, long-term goal of the Aeronautics program is to achieve climate-neutral air transport in the second half of this decade – supported by a technologically leading, competitive, national and European industry. Activities will focus on increasing the efficiency, safety and environmental compatibility of air transport systems and strengthening social acceptance. To this end, in addition to traditional technologies and processes, new areas are also being intensively researched in terms of their potential for application and development. These include, for example, digitization and electrification as well as increasing automation, combined with computing and analysis methods from new fields of information and engineering sciences.

Space travel and the use of space remain indispensable for meeting the long-term challenges of the 21st century. DLR‘s space program continues to make critical contributions to this effort. Its mandate is to advance research and development, promote education, innovation and growth, create highly skilled jobs and improve the quality of life. It also aims to contribute to planetary protection, security and defense, and international cooperation. DLR space research is therefore of strategic importance to Germany.

A central challenge in transport research is future ground-based mobility. The aims of climate protection and mobility should be reconciled through research into efficiency, emissions, safety, use and cost-effectiveness. Overcoming these challenges is the goal of DLR transport research. The topics central to DLR‘s Strategy 2030 (Germany as a business location, mobility, sustainability, digitization and safety) are also addressed in a variety of ways within the Research Field, alongside current references to the COVID 19 pandemic, among other things.

Strategy

Regular midterm assessments of the need for the maintenance and expansion of research infrastructures ensure that DLR has a portfolio of facilities that is geared to the challenges in a timely manner and that the operation of the infrastructures is secure. This is done in alignment with the overall strategic but also with the programmatic goals of DLR, and the goals of the Helmholtz Association. With regard to the available budgets, it is particularly important to evaluate the needs of the existing facilities and to maintain them, yet they should also be expanded proportionally in response to new topics. The planning of research infrastructures is thus closely linked both to current and future research priorities, and to national and international strategies and roadmaps. At DLR the operation and provision of the relevant research infrastructures takes place along a certified process system that is managed centrally and across the board by an independent organizational unit.

Infrastructure Planning

The planned Campus for Medicine and Informatics in Aerospace **(CMI)** at the DLR site in Cologne supports the digitization strategy of the German government and DLR. In cooperation with national and international partners, a structure is to be created that will make key technologies such as artificial intelligence, high-performance computing, virtual reality and robotics available for medical applications both in aerospace and on Earth. The backbone of DLR's airborne atmospheric research and remote sensing is the sophisticated Falcon 20E research aircraft, which has been in operation for over 40 years. It serves questions of high global, social and economic relevance, such as the influence of humans on the climate and environment.

With **ASTAR** (Atmospheric and Remote Sensing Test and Research Platform), the research platform for atmospheric research, replacement of this unique infrastructure is now planned. This will serve to maintain DLR's capacities and at the same time provide scientific support for the German government's hydrogen strategy.

The powerful radar satellite mission **Tandem-L** is based on previous, internationally recognized technological developments in German SAR remote sensing. It will enable tremendous progress in the exploration of processes in the bio-, cryo- hydro- and geosphere. The data from Tandem-L will help find solutions to the challenges faced by society, such as climate change, population growth and resource management.

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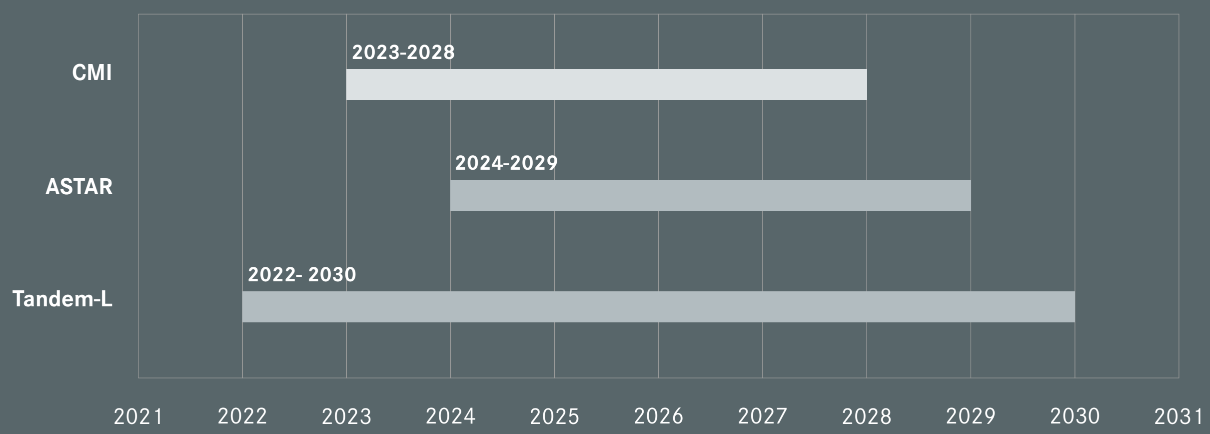
Planned Implementation



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TANDEM-L - SATELLITE MISSION FOR MONITORING DYNAMIC PROCESSES ON THE EARTH'S SURFACE

Summary

Tandem-L consists of a space segment with two radar satellites in formation flight, and a ground and user segment. The latter controls the satellites, receives the data, processes them into higher-quality information products and makes them available to the user groups. Tandem-L's data will contribute significantly to finding solutions to the challenges of climate change, population growth, and resource management, and will enable major advances in the study of the environment and the dynamic processes in the biosphere, cryosphere, hydrosphere, and geosphere. The innovative data products will not only advance the analysis, modeling, and understanding of the diverse processes in the different Earth spheres, but will also synergistically reveal their interrelationships.

Scientific Importance

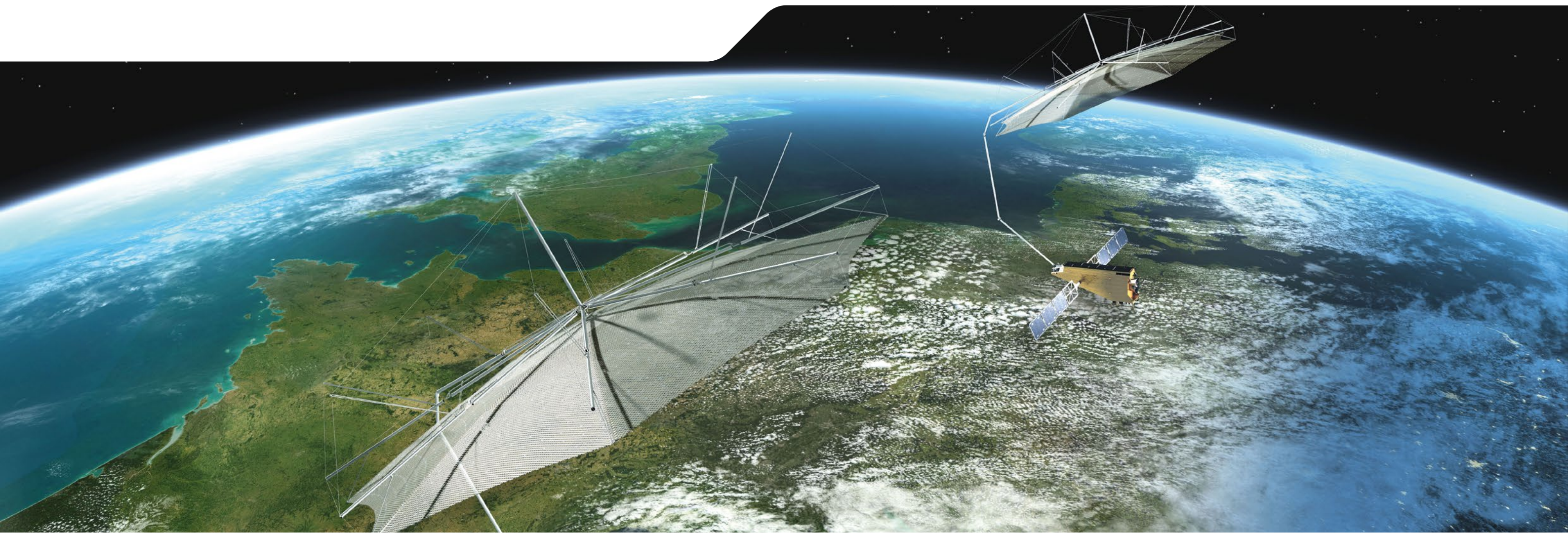
Tandem-L will contribute significantly to climate, environmental, and Earth system research. Examples include global forest biomass measurements for a better understanding of the carbon cycle, the millimeter-scale recording of Earth deformations for earthquake research and risk analysis, the quantification of glacier movements and melting processes in the polar regions for a better understanding of climate change and its impacts, and the fine-scale measurement of variations in near-surface soil moisture for a detailed analysis of the water cycle. Tandem-L provides a unique observatory for continuous monitoring of the Earth and the environment, comparable to the network of weather satellites.

Strategic Relevance

This innovative mission builds on the internationally recognized expertise of DLR and German industry in the field of high-resolution radar. Tandem-L will maintain and expand Germany's leading position in the long term and help it become a forerunner in global Earth system, climate and environmental research. The mission sends a signal of strong commitment to climate protection and opens up new opportunities for international cooperation. Tandem-L will provide information that has been missing until now in the discussion on the extent and impacts of climate change. This will enable the development of better forecasts and recommendations for sociopolitical action.

Dates and numbers

Acronym:	**Tandem-L**
Category:	B
Period of realization:	2022 - 2030
Estimated investment in € MM:	771
Estimated operating costs per year in € MM:	14
Lead Helmholtz Center:	DLR
Other Helmholtz centers involved:	AWI, FZJ, GFZ, UFZ



ASTAR - RESEARCH PLATFORM FOR ATMOSPHERIC RESEARCH

Summary

The Falcon 20 is an established platform and has been the backbone of DLR‘s internal airborne atmospheric research for decades. After 45 years in service, the aircraft is burdened with rapidly increasing risks of failure and deployment costs due to its age. Its retirement can only be postponed by a few years beyond the previously planned year of 2024. This unique piece of infrastructure will be replaced with a new atmospheric research platform ASTAR (Atmospheric and Remote Sensing Test and Research Platform) based on a twin-engine jet (payload 2 t, flight altitude 14 km, range 6000 km). The cabin will be prepared for the installation of scientific instruments and can be configured flexibly. The aircraft will be modified in order to meet this purpose with fuselage apertures, external attachments, additional systems and sensor technology, ensuring universal scientific usability.

Scientific Importance

In order to fulfill the programmatic tasks of atmospheric research at DLR, a dedicated jet-powered research aircraft remains indispensable. The successor to the Falcon 20 will be used primarily for aeronautics and space research, covering a mission and utilization profile that cannot be served by HALO. These include flexible access for DLR users and flight-mechanical and structural properties that are crucial, for example, for tracking flights in the near field of large commercial aircraft. In the international environment, this is intended to maintain DLR‘s outstanding role in this field and ensure flexible deployment in exceptional situations.

Strategic Relevance

DLR occupies a leading position in international atmospheric and environmental research, based on the operation of an exclusive, sophisticated fleet of research aircraft. Climate change and sustainability in aviation will increase in importance. A DLR-owned, future-oriented platform that can, among other things, accompany the scientific side of the German government‘s hydrogen strategy has central strategic importance and an important influence on the international positioning of DLR and Germany. Research into the influence of humans on climate and the environment is of high global, societal and economic relevance (e.g. measurement of corona-induced pollutant changes in the atmosphere).

Dates and numbers

Acronym:	**ASTAR**
Category:	B
Period of realization:	2024 - 2029
Estimated investment in € MM:	76
Estimated operating costs per year in € MM:	5
Lead Helmholtz Center:	DLR
Other Helmholtz centers involved:	None

CMI - CAMPUS FOR MEDICINE AND INFORMATICS IN AEROSPACE

Summary

The Campus for Medicine and Informatics in Aerospace (CMI) brings together DLR's technology research with medical and life science expertise at DLR's Cologne site. In cooperation with leading national and international partners, a structure is being created to make key technologies such as artificial intelligence, high-performance computing, virtual reality and robotics available for medical applications, both in aerospace and on earth. In addition to a modern DLR FAB Lab as a direct interface between medicine and technology, a DLR Venture Studio will translate scientific innovations into commercial applications and company start-ups.

Scientific Importance

Extreme conditions in aerospace lead to psychological and medical challenges corresponding to similar problem areas on Earth, such as loss of muscle and bone mass, reduced performance, and feelings of isolation. Technologies such as AI-assisted and data-driven medicine or virtual environments help solve these, as do globally unique think tanks in conjunction with simulation facilities for human studies (:envihab, Lunar Habitat), which enable highly controlled proof-of-concept studies. The close link to practical aerospace medicine enables translation into application. Findings from spaceflight, such as environmental data from Earth observation, are made usable for medical questions and risk prediction.

Strategic Relevance

Medical innovations are of utmost importance for aviation and human spaceflight. The conditions are excellent at the Cologne site (DLR, ESA, Air Force, Lunar Habitat). Collaborations with universities, agencies, and industry offer globally unique opportunities for feedback between science and practical application, and for building attractive career programs at the interface of medicine and technology. Because of its transferability to healthy living and aging on Earth, there is societal relevance beyond aerospace. Opportunities are opened up for new products and company start-ups, as well as for strengthening the economy and creating attractive jobs.

Dates and numbers

Acronym:	**CMI**
Category:	A
Period of realization:	2023 - 2028
Estimated investment in € MM:	43
Estimated operating costs per year in € MM:	8
Lead Helmholtz Center:	DLR
Other Helmholtz centers involved:	None

RESEARCH FIELD MATTER

Profile

The scientific mission of the Research Field Matter is to decipher the structure and function of all forms of matter, from the quantum universe to new artificial and biological materials and agents. In the Research Field Matter, the Helmholtz Association combines several competencies at once: the study of matter, the construction and operation of complex large-scale research facilities for basic research and applied sciences (especially materials and drug research), and the development of key technologies, such as new concepts for accelerators, detectors and data management systems.

The tripartite program structure promotes cooperation between different disciplines. With its world-leading research infrastructures and its strategic collaborations in major international research projects, the Research Field makes a significant contribution to the mission of the Helmholtz Association and also strengthens Germany's role as a science hub. The Research Field also offers universities and the institutes of the Alliance of Science Organisations in Germanyand beyond, as well as industrial partners, and, in particular, young scientists a unique and internationally leading infrastructure for carrying out their research projects.

Knowledge and technology transfer, as well as cooperation with industry are key components of the Research Field's future strategies. One focus is on the targeted opening of research infrastructures for external users from industry.

Challenges

The Research Field has formulated the fundamental challenges and major questions of the next ten years into three key questions:

- How can we gain better insights into the structures of the visible and the dark universe, from elementary particles and their forces to galaxy clusters, and how can we better understand the nucleo-synthesis of elements?

- How can electronic and molecular processes be better understood and controlled at all relevant length and time scales, enabling the development of novel functional materials and better-tuned drugs?

- How can high luminosity and compact particle accelerators, novel detectors and sensors be developed, and how can their data be effectively used for research and industry?

The Research Field will focus both its research and infrastructures towards solving major societal challenges, such as the design of novel materials or the development of vaccines and drugs.

Strategy

The Research Field has a multidisciplinary program structure that fosters collaborations across research centers, divisions, and disciplines: In the Matter and the Universe program, particle, astroparticle and nuclear physicists work in close cooperation with one another. The program From Matter to Materials and Life bundles activities in the field of condensed matter, both in basic and applied research. Research and development activities for key technologies such as accelerators and detectors, as well as on new Big Data concepts, are handled in the Matter and Technology program.

In addition, cross-discipline collaborations have been initiated for the above-mentioned materials and drug research, as well as in quantum technology and radiation research. In the future, AI-supported concepts are to be increasingly applied in the handling of large amounts of data. The Research Field Matter is also applying its expertise to the implementation of a forward-looking digitization strategy.

For the big questions that arise with regard to the quantum universe, answers are to be found through large international cooperations in the proven manner. Among others, CERN is an important partner of the Research Field. The Research Field also aims to find answers and solutions to the above-mentioned challenges in the quantum world, which is experimentally and theoretically difficult to access. For this reason, the further development of the large-scale research equipment required for this purpose is indispensable.

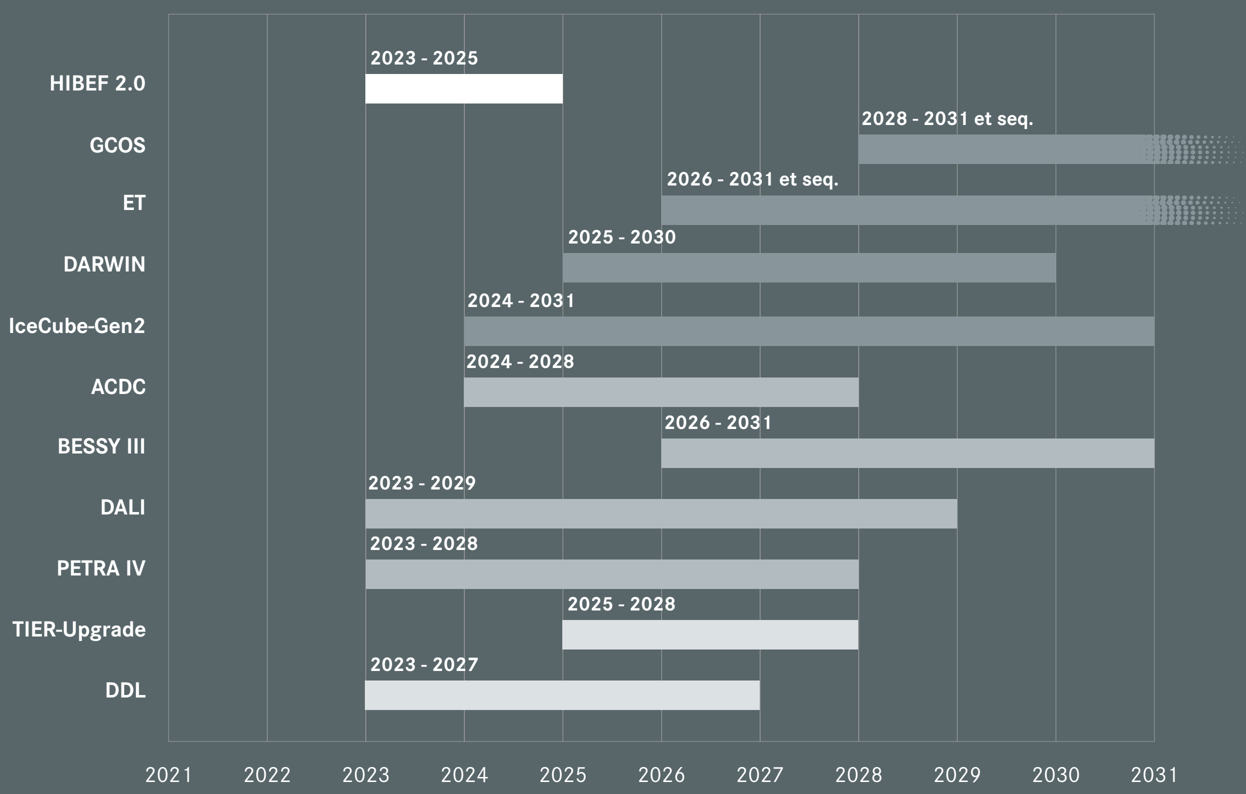
Infrastructure Planning

In view of the urgent challenges faced, the Research Field has set clear priorities for the research infrastructure measures that will be required in the future. The highest priority focus is on upgrading the accelerator-based photon sources (to **PETRA IV, BESSY III and DALI**). These are essential for condensed matter research and for the future molecular design of new materials and active substances. A detailed strategy document outlines both the need for these measures and their benefits, as well as their staggered implementation. These three infrastructures represent the central contribution of the Research Field to the update of the National Roadmap. Another contribution is the upgrade of the Ion Beam Center IBC to **ACDC**. Here, the aim is to open up an ion beam energy range of accelerator-based mass spectrometry for geo, environmental and climate research, as well as for industrial applications in the field of microelectronics and electromobility.

In the pipeline of medium-scale projects in category A, two technology projects have high priority: First, the establishment of a national detector laboratory **(DDL)**, a distributed infrastructure in which detector and sensor technologies will be developed for application in all future research areas. Furthermore, the necessary upgrade of the GridKa, IDAF and Green IT Cube data centers is planned in preparation for the high luminosity operation of the LHC **(TIER upgrade)**. The High Brilliance Source Project (HBS-P) will be taken off the list of strategic upgrade Investments. This means that it will be withdrawn from the currently ongoing process of the Helmholtz Association Roadmap and, assuming a revision during the fourth program period, may be reintroduced at a later date.

In the international arena, the Research Field has initially prioritized two international projects in which German participation is sought: the upgrade of the IceCube detector at the South Pole **(IceCube-Gen2)** and the **DARWIN** project, which deals with the direct search for dark matter. The Research Division also suggests that Germany should consider participating in the Einstein Telescope **(ET)**, the European gravitational wave project. However, any possible German involvement should not compete with the prioritized upgrade of accelerator-based photon sources. Finally, at the end of the decade, the Global Cosmic Ray Observatory **(GCOS)** is to be established.

Planned Implementation



Legend:

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- **C** – Helmholtz participation in international research infrastructures that are transferred to the ESFRI list via the national roadmap, via the national representatives, or include other international participation.
- **A*** – The construction of HIBEF 1.0 at the European XFEL is almost complete, but the withdrawal of the Chinese cooperation partner means a replacement investment is necessary.

MATTER

DDL – HELMHOLTZ DISTRIBUTED DETECTOR LABORATORY

Summary

The Helmholtz Distributed Detector Laboratory (DDL) is an infrastructure for the construction and development of high-tech components for detectors. It will be set up as a distributed facility with the core competencies strategically distributed across the participating centers. This will enable maximum efficiency and best possible use of resources. Investments will be made in three priority areas:

- Access to technologies for highest resolution sensors, especially in the field of superconducting detectors.
- Installation of a dedicated facility to adapt semiconductor sensors to a specific application, for example the detection of extremely low-energy X-rays.
- Expansion of test beam facilities and diagnostic capabilities.

Scientific Importance

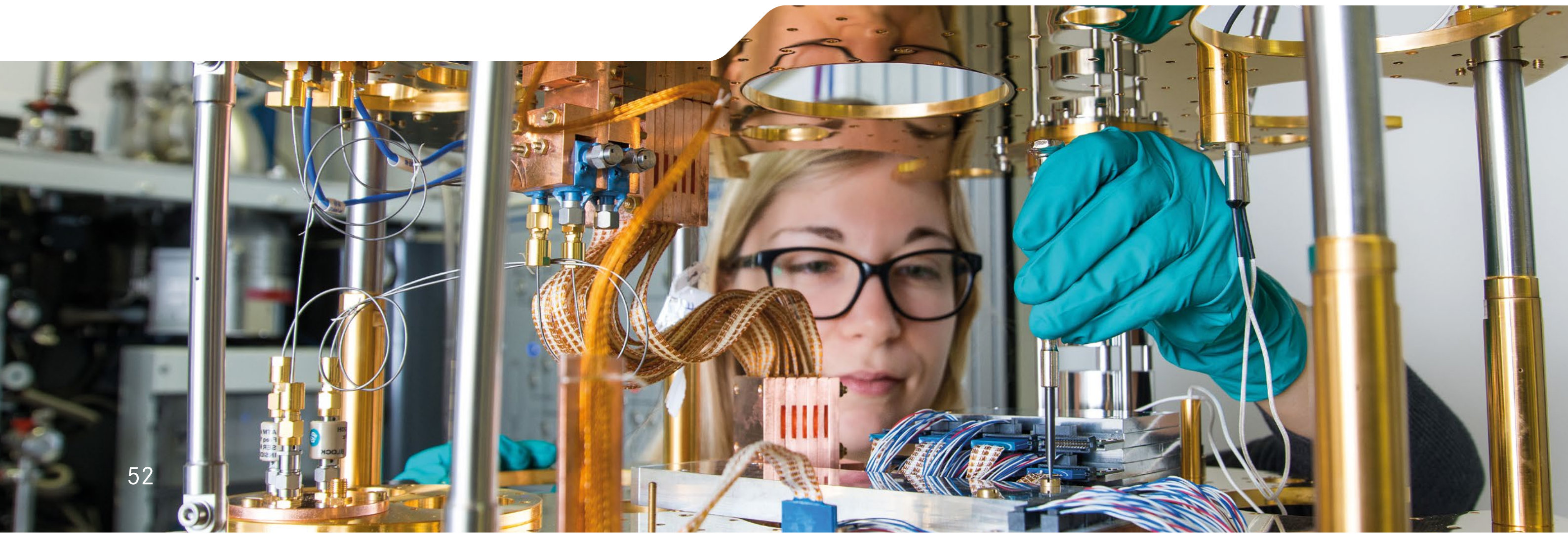
Detector technologies are crucial for successful research in the Research Field Matter. Experiments in Matter require increasingly complex and powerful detectors. DDL significantly increases access to promising new technologies. The main focus areas are strategically selected to address the key challenges of experiments in the Research Field. By being configured as a distributed infrastructure with organized user operations, the DDL will have a very large impact in many areas, both within the Helmholtz Association and beyond. With the broad range of supported technologies and the wide variety of potential application fields (such as satellite missions, medicine, metrology, nuclear safety engineering, and many more), the DDL will be a unique focal point of detector research worldwide.

Strategic Relevance

A pillar of success of research in the Research Field Matter is the quality of the detector systems used. Access to state-of-the-art technologies is therefore an essential strategic building block. The establishment of the DDL is expected to significantly improve the availability of key technologies that are commercially unavailable or very difficult to access. By distributing them over several centers, it will be possible to access a much broader range of technologies. From the very beginning, an open access policy will deepen the cooperation between Helmholtz centers, universities and non-university institutions. An important task of the DDL will be to intensify and further develop cooperation with industry in this area, so there will be a dedicated workpackage established within the DDL.

Dates and numbers

Acronym:	**DDL**
Category:	A
Period of realization:	2023 - 2027
Estimated investment in € MM:	31.6
Estimated operating costs per year in € MM:	3
Lead Helmholtz Center:	DESY
Other Helmholtz centers involved:	HZB, GSI (HI Jena), KIT



TIER-UPGRADE - GRID COMPUTING CENTRES FOR THE HL-LHC (UPGRADE)

Summary
The High Luminosity LHC accelerator at CERN poses completely new challenges for digitization, data analysis and data management (TIER upgrade). Only if these are adequately addressed, new discoveries and insights will be possible at the HL-LHC. Accordingly, high-performance data and analysis centers in Germany are mandatory as part of the worldwide LHC computing infrastructure (WLCG). Only in this way German high-energy and nuclear physics can most effectively participate in the scientific discoveries made at the HL-LHC. With the Tier-1 and 2 computing centers at KIT (GridKa) and DESY (part of IDAF), GSI (in the GreenCube), respectively, Germany is a cornerstone of the worldwide WLCG. According to the requirements of the HL-LHC, these centers are to be further developed.

Scientific Importance
The LHC accelerator will be further developed for operation with ten times increased luminosity (HL-LHC) starting in 2024, in order to investigate known mechanisms with even greater precision and to discover new, very rare physical phenomena. This results in a more-than ten-fold increase in data volume. A multi-pronged approach is needed to process this volume: On the one hand, experiment software and computing technologies need to be optimized (e.g., scalable, energy-efficient, highly optimized software and systems for computing in high-energy physics). On the other hand, data storage and analysis capacities need to be significantly expanded.

Strategic Relevance
Extraction of knowledge from data is a fundamental part of modern science. For decades, the Research Field Matter has been a pioneer of digitization and handling of large amounts of data, for example in the context of international experimental communities in particle, astroparticle, nuclear and hadron physics, in which the Helmholtz Program Matter and Universe is also involved. The goal of the HL-LHC is to gain insights into fundamental physics. In addition, the innovations around the HL-LHC have impact on socially relevant topics, from medicine to the energy transition. In this context, the German Tier-1/2 computing centers at KIT/DESY, GSI are a cornerstone of the worldwide LHC Computing Grid (WLCG) and currently (2021) contribute about one tenth of the worldwide computing resources. For the HL-LHC phase, the outstanding position of the participating German science organizations must be consolidated and further developed. Cutting-edge technology in computing and data management is a “conditio sine qua non” for the scientific success of the HL-LHC.

Dates and numbers

Acronym:	**TIER-Upgrade**
Category:	A
Period of realization:	2025 - 2028
Estimated investment in € MM:	33
Estimated operating costs per year in € MM:	13
Lead Helmholtz Center:	KIT
Other Helmholtz centers involved:	DESY, GSI

PETRA IV – UPGRADE OF THE SYNCHROTRON RADIATION SOURCE PETRA III

Summary

PETRA IV comprises the upgrade of the synchrotron radiation source PETRA III at DESY to a source with ultra-small emittance, which will reach the physical limits of the focusability of synchrotron radiation in the photon energy range up to 10 keV. This will make PETRA IV the ultimate X-ray microscope for biological, chemical and physical processes under realistic conditions, enabling their study on length scales from atomic dimensions to millimeters, and on process-relevant time scales. As a result, it allows new, groundbreaking investigations in many areas of science and industry, and thus important contributions to the major societal challenges in health, energy, earth and environment, transport and information technology.

Scientific Importance

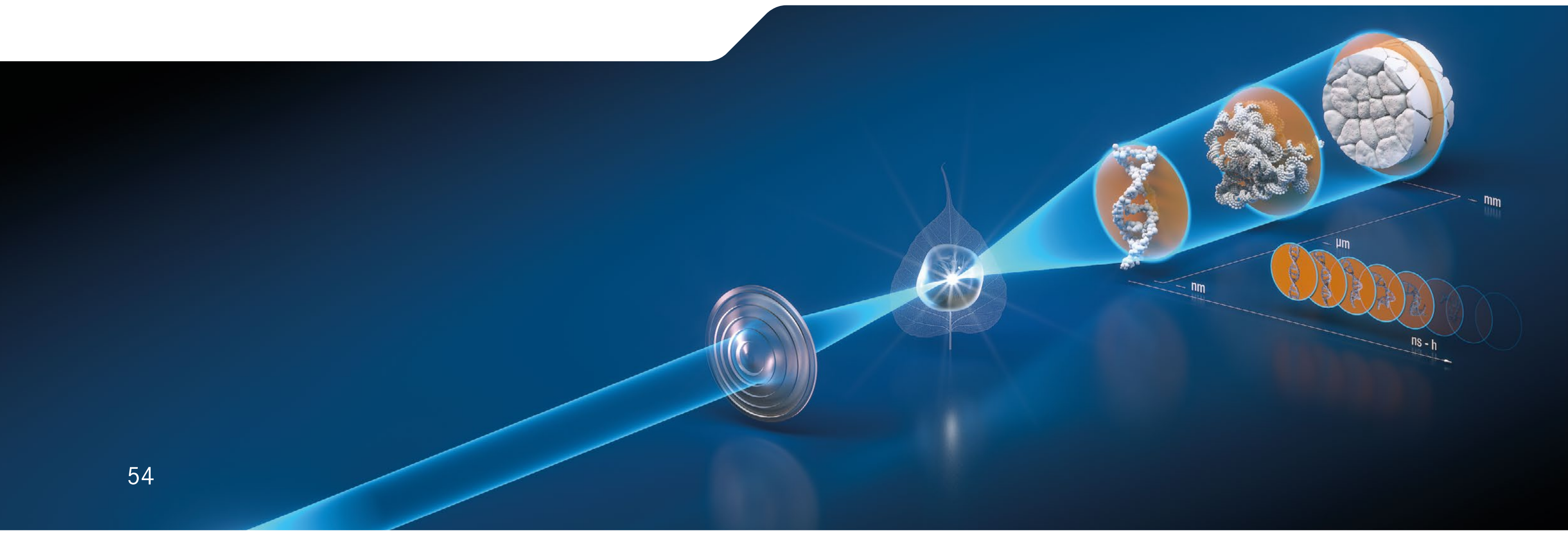
In order to meet future societal challenges in areas such as health, earth and environment, energy, mobility and information, the development of novel materials with tailored functions down to the atomic level is essential. This, in turn, is only possible with suitable diagnostic tools. PETRA IV enables the investigation of microscopic heterogeneous samples and biological, chemical and physical processes under realistic in-situ/operando conditions, from the atomic scale to the macroscopic range and on all process-relevant time scales. This is required for the knowledge-based design of next-generation active agents and multifunctional materials.

Strategic Relevance

Developing, building and operating large-scale facilities for science is an important part of the Helmholtz Association's mission. To this end, DESY operates state-of-the-art accelerator facilities for photon science. These serve as unique tools for studying the structure, dynamics and function of matter, and are made available to a broad national and international academic and industrial scientific community. New developments in accelerators are currently fueling a revolution in synchrotron radiation worldwide. Due to its circumference, PETRA IV can make optimal use of these new technologies and thus further strengthen its outstanding position in cutting-edge photon research within DESY, the Helmholtz Association and Germany.

Dates and numbers

Acronym:	**PETRA IV**
Category:	B
Period of realization:	2023 - 2028
Estimated investment in € MM:	670.8
Estimated operating costs per year in € MM:	70.5
Lead Helmholtz Center:	DESY
Other Helmholtz centers involved:	Hereon



DALI – DRESDEN ADVANCED LIGHT INFRASTRUCTURE

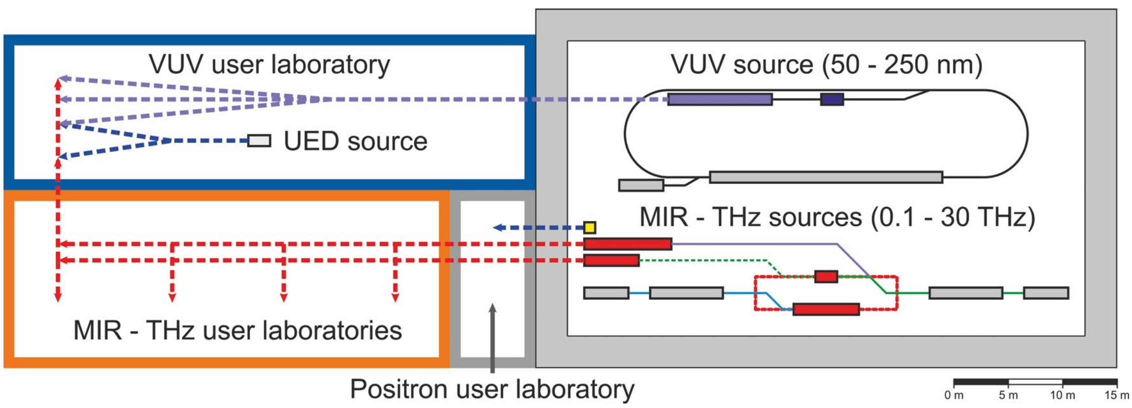
Summary
The Dresden Advanced Light Infrastructure (DALI), based on superconducting electron accelerators, is comprised of a high-field radiation source for the terahertz (THz) spectral range and the mid-infrared, as well as a free-electron laser for wavelengths in the vacuum ultraviolet (VUV), a combination which is unique worldwide. As successors to the ELBE radiation source, these sources allow the experimental investigation of dynamic processes with femtosecond time resolution at extremely high pulse energies and repetition rates. In combination with positron secondary radiation, a system for ultrafast electron diffraction, and dedicated user laboratories for physics, materials science, chemistry, biology, and medicine, DALI creates the conditions for excellent cutting-edge research and will attract national and international user groups from various scientific disciplines.

Scientific Importance
Intense THz/infrared radiation sources enable the modification and targeted control of functionally relevant electronic states in solids, especially in nanostructures and high-temperature superconductors. They are crucial for understanding the role of water in life processes, triggering switching processes in cell membranes, and controlling chemical reactions. Intense positron radiation allows the highly sensitive determination and dynamic study of defects in crystalline solids, for example CMOS circuits, and of porous materials on nm scales. The planned intense VUV radiation source promises to improve microscopic understanding of chemical reactions, particularly in catalysis, combustion, atmospheric physics, and astrochemistry.

Strategic Relevance
DALI would be the largest research infrastructure in the new states of Germany outside Berlin, as well as the world‘s largest user facility for THz radiation, the world‘s most powerful positron source, and also the world‘s most powerful VUV laser - making it a regional and national flagship project with international appeal. This assessment was shared by the reviewers for PoF IV when they spoke of the THz revolution that DALI will launch. They made a clear recommendation for its implementation in PoF IV. DALI would substantially increase the attractiveness of the Dresden research area as a science location. DALI would significantly strengthen the HZDR‘s leading international position in the application of superconducting accelerator technologies and, at the same time, would be a point of attraction for leading scientists from all over the world to achieve revolutionary scientific and technical breakthroughs in this facility.

Dates and numbers

Acronym:	**DALI**
Category:	B
Period of realization:	2023 - 2029
Estimated investment in € MM:	200
Estimated operating costs per year in € MM:	20
Lead Helmholtz Center:	HZDR



BESSY III - BERLIN ELECTRON STORAGE RING FOR SYNCHROTRON RADIATION III

Summary

With its optimization for spectroscopic methods, the synchrotron radiation facility BESSY III will enable the characterization and knowledge-based discovery of highly efficient materials and material systems that are required to solve major societal challenges. The scientific focus is on the conversion, storage and use of energy as well as energy-efficient information technology. With this in mind, BESSY III will provide unique insights into the transport of electrons and ions through interfaces, as well as into catalytically supported chemical reactions. In combination with dedicated laboratory and sample environments, BESSY III allows in-situ and in-operando investigations from the nano to the macro scale, and from extremely short time scales to steady states.

Scientific Importance

The knowledge-based development of new materials lays the foundation for solving major societal challenges such as sustainable energy supply, quantum technology, energy-efficient information technology and health. The methods for detailed spectroscopic and microscopic characterization provided by BESSY III will enable significant insights across all relevant energy, size and time scales, from the function and control of processes on the atomic scale, to the origin of the macroscopic properties of materials. This will allow a paradigm shift away from pure observation to targeted control of functionality.

Strategic Relevance

BESSY III is located in Germany‘s largest technology park, Berlin-Adlershof. Synergies will emerge from the interaction of HZB‘s materials research and external use by leading international research groups and industry, accelerating the development of materials for new technologies. Of particular importance for HZB is the close collaboration with Berlin‘s excellent universities, national research institutions and technology companies. PTB will also use BESSY III for metrological investigations on behalf of industry and as a European radiation standard. As an international beacon for materials research, BESSY III will thus promote the further development of Germany as a technology location in the long term.

Dates and numbers

Acronym:	**BESSY III**
Category:	B
Period of realization:	2026 - 2031
Estimated investment in € MM:	550
Estimated operating costs per year in € MM:	50
Lead Helmholtz Center:	HZB

ACDC – ACCELERATOR-DRIVEN MULTIPURPOSE ION BEAM COMPLEX

Summary

The ACelerator-Driven multipurpose ion beam Complex (ACDC) complements the ion energies available in Germany (HZDR: low energies; GSI: highest energies) by occupying the medium energy range. The extension of the available ion energies and the provision of neutrons with ACDC strengthens the focus of the center on important questions of society. With the development of unique high-energy accelerator mass spectrometry, current questions of climate change and environmental protection are addressed. In addition, the research portfolio will be expanded to include the field of radiation biology and, with the use of ion post-acceleration, extended to radiation medicine. In the field of materials research, new processes for low-loss high-performance components for electromobility and smart grids are being further developed.

Scientific Importance

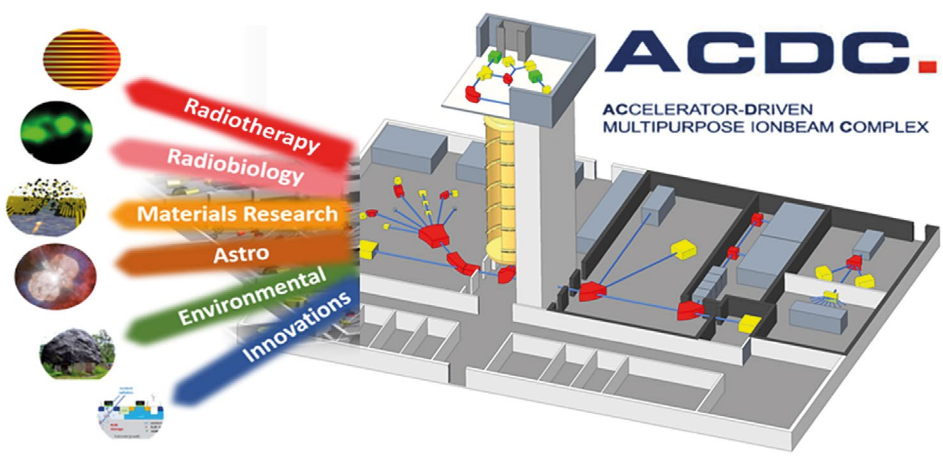
Because of its unique ion beam capability and its interdisciplinary and broad focus, ACDC can break new ground in a wide variety of research areas. In the field of radiation biology and medicine, it is the only facility in the world with conventional and laser-assisted irradiation concepts that can comparatively evaluate the effectiveness of so-called minibeam and flash concepts at a single location. With these high ion energies available for accelerator mass spectrometry, new nuclides become usable and thus new areas of application in the field of environmental and geological research become accessible for the first time. Furthermore, important questions in the field of nucleosynthesis and the impact of near cosmic events on the Earth‘s biosphere will be addressed.

Strategic Relevance

The Ion Beam Center IBC of the HZDR is Europe‘s largest and most successful user facility in the field of materials research with ions. With the spin-off of HZDR Innovation GmbH, it has sustainably expanded its activities in technology transfer and industrial service. With ACDC, the HZDR is now implementing the expert recommendation for PoF IV to substantially expand the IBC. ACDC will open up new user communities and make decisive contributions to all societal challenges identified by the EU (Horizon Europe Missions). With the establishment of ACDC, activities in the Research Field Health will be complemented and bridges will be built to the Research Fields Energy as well as Earth and Environment. The semiconductor production site in Dresden will be further strengthened by the industrial use of ACDC.

Dates and numbers

Acronym:	**ACDC**
Category:	B
Period of realization:	2024 - 2028
Estimated investment in € MM:	94
Estimated operating costs per year in € MM:	6
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	GSI



ICECUBE-GEN2 – THE NEUTRINO OBSERVATORY

Summary

The Neutrino Observatory IceCube-Gen2 will be the world‘s leading experiment for measuring high-energy neutrinos from the universe. The detection of the first high-energy astrophysical neutrinos in 2013 was a fundamental breakthrough which lead to neutrino astronomy being established as a new field of research. The 1 km³ IceCube detector at the South Pole was completed in 2010 by an international collaboration of twelve countries ($280 million construction cost) and has been collecting data continuously since then. By 2024, IceCube will undergo an expansion (IceCube Upgrade) to provide increased sensitivity to low-energy neutrinos. After that, IceCube-Gen2 will establish high-energy neutrino astronomy. In the future, IceCube-Gen2 will be a key observatory for global multi-messenger astroparticle physics.

Scientific Importance

In 2018, the first high-energy neutrino source was identified by coincidence measurements with gamma-ray observatories. The proposed IceCube-Gen2 instrument will increase the rate of discoveries tenfold by significantly increasing neutrino sensitivity. Multi-messenger astroparticle physics relies on the Pierre Auger Observatory, Cherenkov Telescope Array (CTA), IceCube-Gen2, and the future gravitational wave experiment Einstein Telescope for detecting the four cosmic messengers from the universe (cosmic rays, neutrinos, gamma rays, gravitational waves). Only with their sensitivity the questions about the highest-energy processes in the universe can be answered.

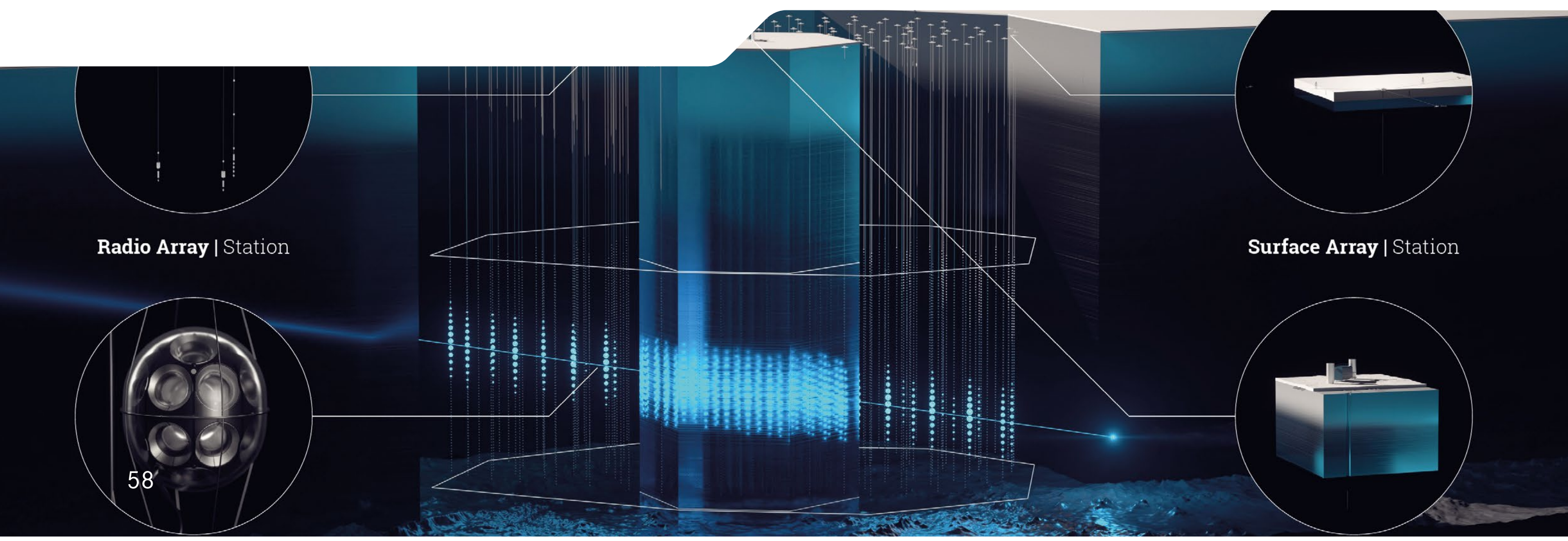
Strategic Relevance

High-energy astroparticle physics research with IceCube is a key pillar of the Matter and the Universe program. IceCube-Gen2 ensures that the Helmholtz Association maintains and expands its global visibility in the research area. After the USA, Germany (DESY, KIT, nine university groups) is the second strongest partner in the collaboration. A large part of the recorded data will be made available for open use, partly in real time. IceCube-Gen2 will become a central instrument not only for multi-messenger astroparticle physics, but also in the search for heavy dark matter and the determination of neutrino properties.

Dates and numbers

Acronym:	**IceCube-Gen2**
Category:	C
Period of realization:	2024 - 2031
Estimated investment* in € MM:	285 (40)
Estimated operating costs* per year in € MM:	8 (1)
Lead Helmholtz Center:	DESY
Other Helmholtz centers involved:	KIT

*) German share in parentheses.



DARWIN – DARK MATTER WIMP SEARCH WITH LIQUID XENON

Summary

DARWIN addresses one of the central questions of the Research Field Matter: What is the nature of dark matter (DM)? The goal is to build the ultimate detector for direct detection of DM, with a sensitivity limited only by the irreducible neutrino background, for a projected exposure of 200 ton-years. An underground laboratory will house a time projection chamber operated with 50 tons of liquid xenon. DARWIN - Dark Matter WIMP Search with Liquid Xenon will investigate the experimentally accessible parameter space for WIMPs as DM candidates over a wide mass range. As a multi-purpose observatory, DARWIN will also contribute to ultra-precise measurements of solar neutrinos, detection of supernova neutrinos, and search for physics beyond the Standard Model, such as neutrinoless double beta decay.

Scientific Importance

DARWIN will be the world's leading observatory for rare-event astro-particle physics. Therefore, DARWIN not only has a realistic chance of revealing the nature of DM, but will also be able to study its properties, such as mass or even interaction strength and type. In addition the observatory's unprecedentedly low background rate makes it ideal for studying the structure of the weak interaction and extremely rare processes. It will as well open up other interesting physics channels, such as the search for solar axions.

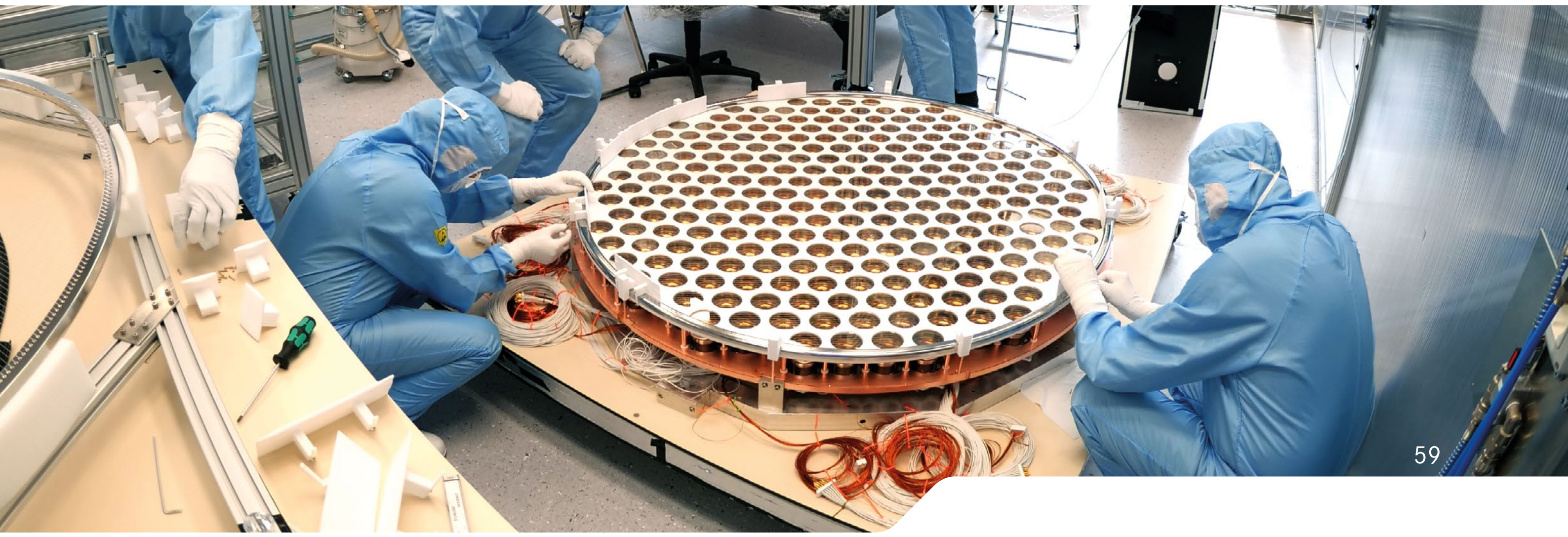
Strategic Relevance

Low-energy astroparticle physics is an important component of the Helmholtz Association's Matter and the Universe program as it addresses the question of the composition of our universe. With DARWIN, the Helmholtz Association is involved in a key experiment with the potential for revolutionary discoveries, thereby sustainably strengthening the high-tech expertise at KIT. As the successor of the highly successful XENON detector line, DARWIN is a technologically unique large-scale international research project. Currently, collaboration partners from 13 countries (EU, USA, Asia) are involved, including eight groups from Germany (Helmholtz Association, Max Planck Society, university groups). One possible location is the Laboratori Nazionali del Gran Sasso (LNGS) in Italy.

Dates and numbers

Acronym:	**DARWIN**
Category:	C
Period of realization:	2025 - 2030
Estimated investment* in € MM:	175 (44)
Estimated operating costs* per year in € MM:	0.8 (0.2)
Lead Helmholtz Center:	KIT

*) German share in parentheses.



ET - THE EINSTEIN TELESCOPE

Summary

The Einstein Telescope (ET) is a planned third generation gravitational wave interferometer. Possible sites are the border triangle Germany/Netherlands/Belgium or Sardinia (Italy). Gravitational wave astronomy with ET promises groundbreaking new insights for astroparticle physics, astrophysics, particle physics and cosmology.

Scientific Importance

Detection of gravitational waves (GW) from the merger of black holes or neutron stars was achieved in 2015 with the LIGO interferometers (USA) and in 2017 with LIGO and Virgo (Italy), respectively. In 2017, Barry Barish, Kip Thorne, and Rainer Weiss received the Nobel Prize “for decisive contributions to the LIGO detector and to the observation of gravitational waves.” The most important Earth-based future project is the European Einstein Telescope (ET). ET is designed as a laser interferometer with a side length of 10 km. Through numerous technological developments, the Einstein Telescope will achieve a sensitivity that will allow many sources of gravitational waves of various types to be detected from deep into the universe. This will also lead to new insights into extreme states of nuclear matter, allow tests of general relativity in the presence of strong gravitational fields, and, via the integration of gravitational waves into multi-messenger astroparticle physics, expand knowledge of the highest energy processes in the universe.

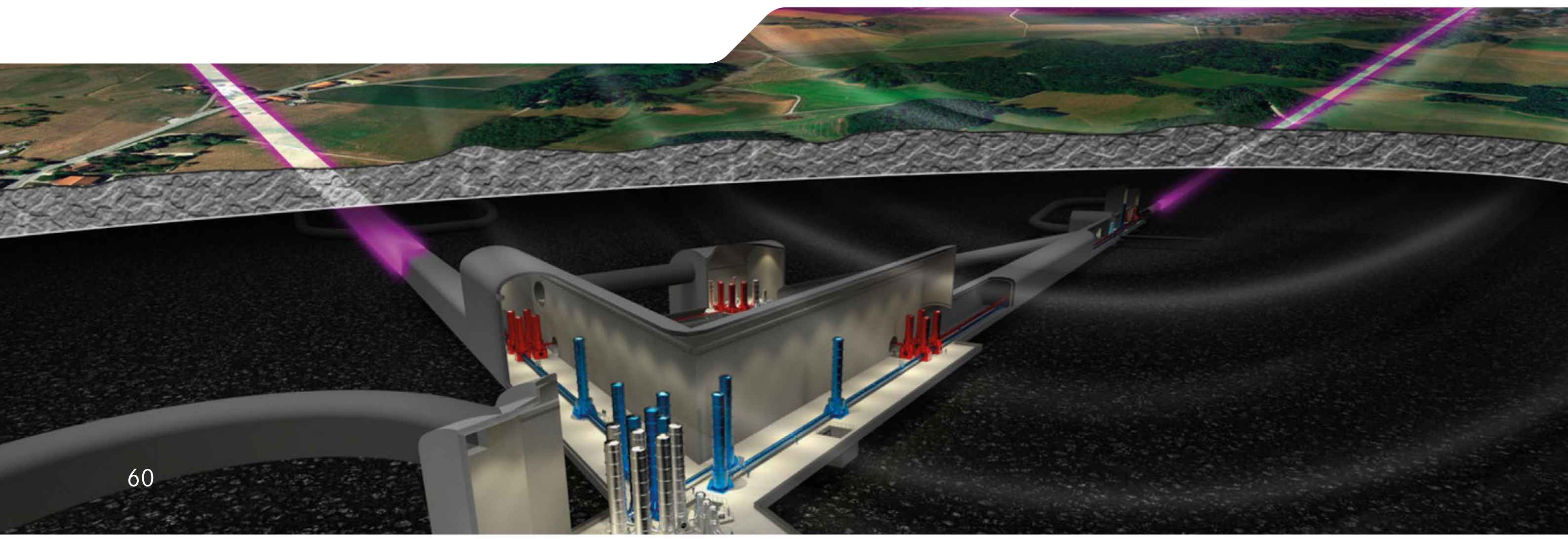
Strategic Relevance

The Einstein Telescope secures a leading role for Europe in the study of the universe. ET will be a central instrument for astroparticle physics in the 2030s to the 2050s and thus a great opportunity for the scientific landscape in Germany and Europe. ET can only succeed with significant participation by Germany. It will require and generate enormous progress in numerous fields: in addition to fundamental physics, among others, in mathematics, AI-based sensor field evaluation, seismo-geodesy, vacuum and laser technology, cryogenic detectors, and quantum measurement methods. Among the German universities and research institutions, the Research Field Matter of the Helmholtz Association with the primarily participating centers KIT and DESY is particularly influential. The expected findings cannot be achieved in the foreseeable future by any other method.

Dates and numbers

Acronym:	**ET**
Category:	C
Period of realization:	2026 - 2031 et seq.
Estimated investment* in € MM:	1736 (n. a.)
Estimated operating costs* per year in € MM:	37 (n. a.)
Lead Helmholtz Center:	DESY
Other Helmholtz centers involved:	HZDR, KIT

*) German share in parentheses.



GCOS – THE GLOBAL COSMIC RAY OBSERVATORY

Summary

If the sources of the ultrahigh-energy cosmic rays can be identified with measurement data from the Pierre Auger Observatory, these sources will be scrutinized with greater precision by the Global Cosmic Ray Observatory (GCOS). In this way, acceleration mechanisms, particle propagation, and the strength and course of cosmic magnetic fields can be studied. With a total instrumented area of more than 90,000 km^2, evenly distributed among different sites in several countries, the observation of the entire sky with the necessary particle statistics becomes possible. Each of the sub-observatories of GCOS is available for a variety of multidisciplinary and large-scale investigations as an expandable sensor network, such as for climate and earth sciences.

Scientific Importance

The GCOS data will form one of the four pillars of modern multi-messenger astroparticle physics and will provide fundamental insights into the highest-energy processes in our universe. It will determine the energy, direction of origin, and type of cosmic particles with great statistics to characterize their sources. GCOS will also provide an alternative approach to the search for New Physics beyond the Standard Model, for example, the search for extra dimensions, Lorentz-invariance violation, and the study of hadronic interactions. GCOS will also have very high detection sensitivity for ultra-high energy neutrinos and photons.

Strategic Relevance

The development and construction of GCOS, which will include the Pierre Auger Observatory as a central building block, will continue the Helmholtz Association‘s global leadership in the field of high-energy cosmic ray measurements. High-energy astroparticle physics is an important pillar of the Matter and Universe program and contributes significantly to the progress and global visibility of multi-messenger physics. In addition, the project offers great potential for technological developments, for example, in terms of robust as well as environmentally friendly particle detectors, smart networks, and renewable energy. With its distributed sensor network, it will also contribute to climate and geospatial research.

Dates and numbers

Acronym:	**GCOS**
Category:	C
Period of realization:	2028 - 2031 et seq.
Estimated investment* in € MM:	390 (40)
Estimated operating costs* per year in € MM:	15 (1.5)
Lead Helmholtz Center:	KIT

*) German share in parentheses.

HIBEF 2.0 – HELMHOLTZ INTERNATIONAL BEAMLINE FOR EXTREME FIELDS 2.0

Summary

Using the latest developments in laser technology, HIBEF 2.0 will for the first time combine an XFEL source with high-power lasers of the kJ class. These laser pulse energies are more than an order of magnitude above the capabilities of all internationally comparable facilities. This will allow the opening up of new fields of science, in particular the investigation of states of matter at pressures around and above 1 TPa (10 Mbar) as well as precision experiments on the nature of the quantum physical vacuum. To this end, we will construct:

- A high-energy optical laser system at the European XFEL, providing both nanosecond kJ pulse energies and sub-picosecond petawatt powers with repetition rates of about one laser shot per minute.
- A nanosecond high-energy laser (approx. 200 J pulse energy) at HZDR for developing sample environments at European XFEL and for separate experiments.

Scientific Importance

The behavior of matter at pressures above 400 GPa is almost unknown. HIBEF 2.0 will allow detailed insights into material structures at pressures up to 30 TPa for the first time. In addition to being of great importance for the interior of planets (esp. super-earths and gas giants), novel materials are predicted at pressures above 1 TPa, which in metastable form under normal conditions may allow breakthrough applications. The petawatt option will significantly increase the sensitivity to measure the birefringence predicted by quantum electrodynamics in vacuum for the first time, greatly expanding HIBEF's ability to achieve this flagship goal. Other fields include detailed studies of matter under the influence of magnetic fields in the kT range and laser-matter interactions at extreme conditions. Findings from these would have great application potential, for example in materials processing or medicine.

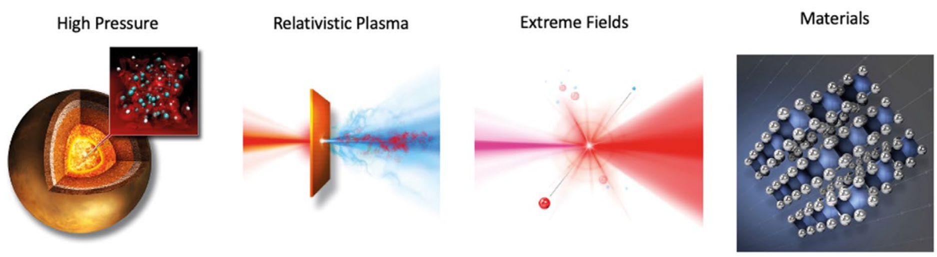
Strategic Relevance

The proposed infrastructure is unique worldwide and will further strengthen HIBEF's internationally leading position at the European XFEL. The strategic partnership with GSI, which will take the leading role in the development of the sub-picosecond option of HIBEF 2.0, will provide indispensable preliminary work for the planned high energy laser systems at FAIR (planned GSI contributions: Femtosecond front-end, compressor, and beam transport components). At the same time, the proposed compressor laser at HZDR will support and extend the science program at the existing laser user facilities of the Helmholtz Association.

Dates and numbers

Acronym:	**HIBEF 2.0**
Category:	A*
Period of realization:	2023 - 2025
Estimated investment in € MM:	28
Estimated operating costs per year in € MM:	3.9
Lead Helmholtz Center:	HZDR
Other Helmholtz centers involved:	GSI

A*) The construction of HIBEF 1.0 at the European XFEL is almost complete, but, the withdrawal of the Chinese cooperation partner means replacement investment is necessary.



HiBEF2.0

MATTER

THE HELMHOLTZ SYMPOSIUM
A SUMMARY

On June 28, 2021, the Helmholtz Association‘s symposium to present the newly planned research infrastructures (RI) in each of the six research fields was held in the Spreepalais by the Berlin Cathedral. The idea was to get feedback on the proposals from the science community. The symposium consisted of a panel discussion in the format of a talk show, which was published via live stream and watched by more than 1,200 viewers.

> **"At the symposium we learned that stakeholders from the different science communities can successfully talk to one another about research ideas on large-scale scientific devices. It is interesting to see how much interaction this induces between the Research Fields of the Helmholtz Association.**
>
> Rolf-Dieter Heuer, CERN

New planned ventures were presented and discussed during three two-hour sessions and a one-hour closing session. The event was opened by President Otmar D. Wiestler, who was also a participant in the sessions that followed. The discussion was moderated by Rolf-Dieter Heuer (former CERN and member of the Helmholtz Association Senate), alongside Sara Arnsteiner (Helmholtz Association Office). In tandem, the vice presidents presented the plans for their research areas and then discussed them with two to three representative guests from the user community and strategic partnerships.

The initial questions were about the focus, priorities and possible gaps in the planning. In particular, the discussions addressed the unique selling points in comparison to existing research facilities, what characterizes the operator/user relationship, and the role of the planned RI in encouraging young scientists and recruitment. For example, how will the different needs of the science community and industry be best taken into account? What technology transfer is possible or expected in connection with the new RI? What could generate a boost in innovation? Furthermore, the role of the Helmholtz Association and its RI in the German science system was examined, as well as the development towards large RI in Germany and worldwide. Last but not least, the discussion focused on the question of how the selection processes for future RI will be organized.

The discussion, in which numerous viewers participated via chat, was very inspiring. Critical views were also openly addressed, for example why certain projects do not appear on this roadmap on this occasion. It was fascinating to see how stimulating it was to discuss the RI projects with one another across research fields and science communities. Impressive state-

ments were made regarding the high level of system competence for the development, construction and operation of large RI, noting that this is a special feature of the Helmholtz Association - at all working levels and trades. The RI are a magnet for young people in particular, the President commented, making them especially valuable for talent recruitment. The interaction between the research areas through appropriate cross-cutting activities was agreed to be essential by the panel, as was the call for new directions to be taken in interdisciplinary planning. For excellent research at the RI, a holistic approach is crucial, in which the entire system of a question is taken into consideration. The same is true for the acceptance of RI projects outside the science community, which is why science communication is so important for RI. The panel underlined the catalytic effect of RI for research and development in general.

For knowledge and technology transfer, a systemic approach was suggested to address the close interplay between basic research and innovation. The development of startups and entrepreneurship must therefore be considered from the outset when planning the new RI. In general, the opening of the RI beyond the science system, i.e. the integration of industry, is considered an essential criterion for success. It was undisputed among the panel that digitization, especially the management and manageability of the enormous data sets, was a key topic in the planning of all six research areas. Moreover, questions of sustainability are becoming increasingly important.

In their concluding statements, Rolf-Dieter Heuer and Otmar D. Wiestler stated that the Helmholtz Association, as the operator of large-scale RI, is fundamentally well positioned in the German science system – in association with the universities, the Max Planck Society, the Fraunhofer Society and the Leibniz Association. The focus of the Helmholtz Association's new RI plans is on basic research, which is the driving force behind research and development. However, this should not obscure the great transfer potential of these facilities. In their summary, both emphasized that excellent in-house research at the RI is an essential prerequisite both for the successful operation of the user facilities and for fruitful collaboration with the external user community. Overall, the discussion showed that the range of R&D activities at the current and planned RI of the Helmholtz Association is appreciated by the guests, and that a great networking potential between the science organizations is in sight. It was repeatedly noted that the research centers of the Helmholtz Association are characterized by an extraordinarily high level of system competence in the development, construction and operation of large RI. The President concluded by pointing out that, against the backdrop of this fruitful discussion and in view of the dynamic development in the field of large-scale RI at both national and international level, it would be advisable to regularly review the planning of the roadmap for new RI and thus define a flexible but guiding framework for the coming years. For Germany as a research location, the RI are of outstanding importance.

"Excellent RI are focal points and links for the science system. Researchers come from science organizations and institutions all over the world. They meet there, get to know each other, work closely together and are trained in systemic thinking. The RI form a magnet for young people in particular, which makes the facilities especially valuable for talent recruitment.

Otmar D. Wiestler, Helmholtz Association

The event is available online as a video at:
→ https://www.helmholtz.de/fis-symposium21

THE USER FACILITIES OF THE HELMHOLTZ COMMUNITY

The Helmholtz Association operates a large number of research infrastructures as user facilities for research within Germany and from abroad. More than half of the available measurement time is also available for external users. Applications are evaluated on the basis of a peer review process by independent panels of experts according to criteria of strategic relevance and scientific quality. As operators of the research infra-structures the Helmholtz Centers support the researchers in the execution of the experiments within the framework of their user service. Currently, the Helmholtz Association operates almost two dozen facilities for dedicated user operation (with more than 50 % use by external parties), which are thus available to scientists from Germany and from around the world.

Research Field Earth and Environment

The centers of the Helmholtz Association operate large research vessels currently in user operation: **Polarstern** and **Heincke** (AWI) as well as **ALKOR** (GEOMAR). They are among eight German ships specially designed for marine research and equipped for work in biology, geology, geophysics, glaciology, geochemistry, oceanography and meteorology. In addition to the research vessels, the Helmholtz Centers operate the research stations on Helgoland and Sylt (AWI), the **Neumayer Station** for German Antarctic research (AWI), the Arctic long-term observatory Frontiers in Actic Marine Monitoring **FRAM**, and the GFZ‘s Modular Earth Science Infrastructure, or **MESI**, to provide scientific infrastructure services in the geosciences. In addition, the research aircraft Polar 5 and Polar 6 (AWI) are currently deployed in inaccessible, ice-covered areas of the Arctic and Antarctic.

Research Field Health

For individual risk assessment and development of personal prevention strategies, the Helmholtz Association has initiated a nationwide health study, the **National Cohort** (DKFZ, HMGU, HZI, MDC), which is based on specific infrastructures in addition to logistics. The long-term study on the health of the population is being set up and operated by Helmholtz together with universities, the Leibniz Association and institutes of the federal government‘s departmental research in order to establish the causes of widespread diseases, identify risk factors, point out ways of effective prevention, and identify possibilities for the early detection of diseases.

Research Field Matter

A central task of the Research Field is the development, construction and operation of large-scale scientific equipment and research infrastructures. About half of the nearly two dozen current user facilities – with thousands of external users – are located in this Research Field. The Helmholtz Association provides numerous research infrastructures to study the structures and dynamic processes of, and in, matter, materials, and their modes of operation. Four of them are accelerator-based photon sources: the free-electron laser facility in Hamburg **FLASH**, the X-ray radiation source **PETRA III** at DESY, and the Berlin electron storage ring for synchrotron radiation **BESSY II** from HZB. Three years ago, the **European XFEL** at DESY was added. It is internationally operated and currently the world‘s largest accelerator-based light source. Neutron sources can be used via the Jülich Centre for Neutron Research **JCNS** at FZJ, and also via the German Engineering Materials Science Centre **GEMS** at Hereon, which is a central user platform for complementary research with both photons and neutrons. Low-energy ion beams are available at the Ion Beam Centre **IBC** of the HZDR. Furthermore, subcomponents for the high-energy ion acceleration of the Facility for Antiproton and Ion Research **FAIR** at GSI are already temporarily in user operation. The **ELBE** radiation source at HZDR provides a primary electron beam of high luminosity and low emittance, as well as photons and particle beams as secondary beams for experiments. The Dresden High Field Magnetic Laboratory **HLD** at HZDR provides the highest pulsed magnetic fields for materials research. Finally, three research centers in this field participate in the Worldwide LHC Computing Grid in international collaboration: The Grid Computing Centre Karlsruhe **GridKa** at KIT, as well as the **Tier II Centers** at DESY and at the **Green IT Cube** of GSI for the advanced data analysis of the experiments at the Large Hadron Collider (LHC) at CERN.

Research Field Information

For research in the area of micro- and nanostructures, the Karlsruhe Nano Micro Facility **KNMF** (KIT) offers access to state-of-the-art technologies for structuring, microscopy and spectroscopy as well as characterization, among others by means of synchrotron radiation of the Karlsruhe Research Accelerator (KARA). Supercomputing in the research area at FZJ is also used intensively by external parties, as well as the Jülich-based European Facilities in Electron Microscopy (**ER-C**).

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Abbreviations used:

AWI
Alfred Wegener Institute
Helmholtz Centre for Polar and Marine Research

DESY
Deutsches Elektronen-Synchrotron DESY

DKFZ
German Cancer Research Center

DLR
German Aerospace Center (DLR)

DZNE
German Center for Neurodegenerative Diseases

FZJ
Forschungszentrum Jülich

GFZ
Helmholtz Centre Potsdam
German Research Centre for Geosciences GFZ

GSI
GSI Helmholtz Centre for Heavy Ion Research

GEOMAR
GEOMAR Helmholtz Centre for Ocean Research Kiel

Hereon
Helmholtz-Zentrum Hereon

HMGU
Helmholtz Zentrum München
German Research Center for Environmental Health

HZB
Helmholtz-Zentrum Berlin für Materialien und Energie

HZDR
Helmholtz-Zentrum Dresden-Rossendorf

HZI
Helmholtz Centre for Infection Research

KIT
Karlsruhe Institute of Technology

MDC
Max Delbrück Center for Molecular Medicine
in the Helmholtz Association

UFZ
Helmholtz Centre for Environmental Research - UFZ

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