RDS Strategy Process

Denkschrift 2025: Science and Instrumentation

J. Wilms, M. Kramer, S. Walch-Gassner
for the RDS

2024-October-15

Astronomy Strategy Process

German astronomy: long-term strategy defined by “Denkschrift”-Process

- 1962: path towards ESO, ESA, Effelsberg, Calar Alto
- 1987: centralization of observing towards ESO, funding for VLT instrumentation and exploitation of space experiments: Verbundforschung @ BMBF and DLR
- 2003: ELT, SKA, ESA-missions, neutrino-, gamma- and gravitational wave astronomy; career development
- 2017: dito, plus national computing infrastructure, Big Data, Data-Mining, Virtual Observatory, strategic hiring (exoplanets, Sun, instrumentation), lack of Helmholtz-like central institute for astrophysics

International Context

Europe: Astronet (2007ff; 2023)
(mainly funding agencies)

- Extreme conditions in the cosmos
- Formation and evolution of galaxies
- Formation of stars and planetary systems
- Sun and solar system

Europe:
(mainly fundin

- Extreme
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- Formatic
- Sun and

What is the nature of dark matter and dark energy?

Are there deviations from the standard theories and models (general relativity, cosmological model, standard model of particle physics)?

What are the properties of the cosmic microwave background, first stars, galaxies and black holes in the Universe?

How do galaxies form and evolve, and how does the Milky Way fit in this context?

What are the progenitors of astronomical transients?

What physical and chemical processes control stellar evolution at all stages, from formation to death, and how?

What are the necessary conditions for life to emerge and thrive?
Are we alone?

How do planets and planetary systems form and evolve?

What is the impact of the Sun on the heliosphere and on planetary environments?

What are/were the characteristics and habitability of various sites in the solar system, such as Mars or Jupiter's icy moons?

What is the origin of cosmic rays of all energies?

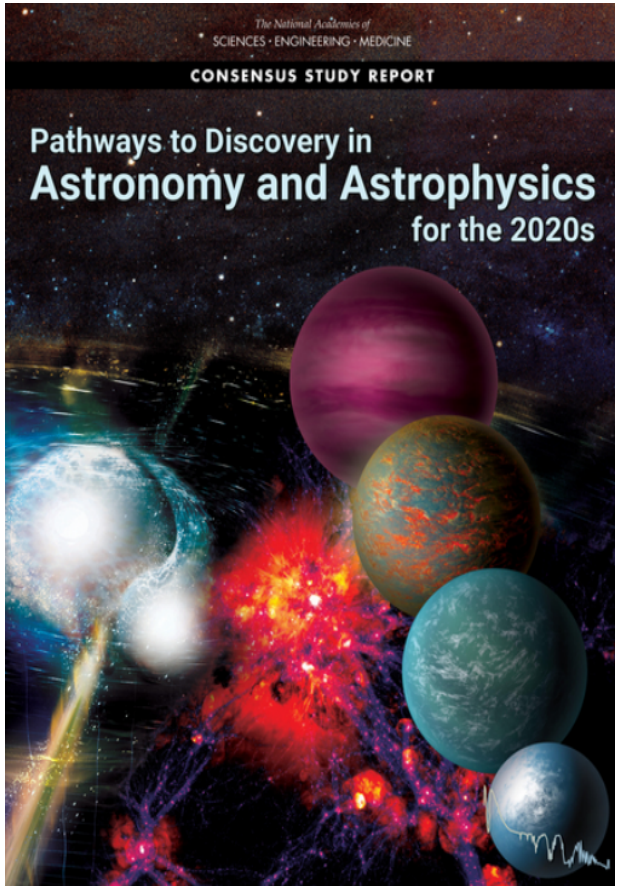
How can extreme astrophysical objects and processes probe new fundamental physics?

International Context

USA: Decadal Reviews
(1964, 1972, 1982, 1991, 2001, 2010, 2021)

Science themes:

- Worlds and Suns in context
  formation and evolution of stars & planets, habitability
- New Messengers and New Physics
  multimessenger and multiwavelength time domain astronomy
- Cosmic ecosystems
  modeling stars, galaxies and their formation and evolution



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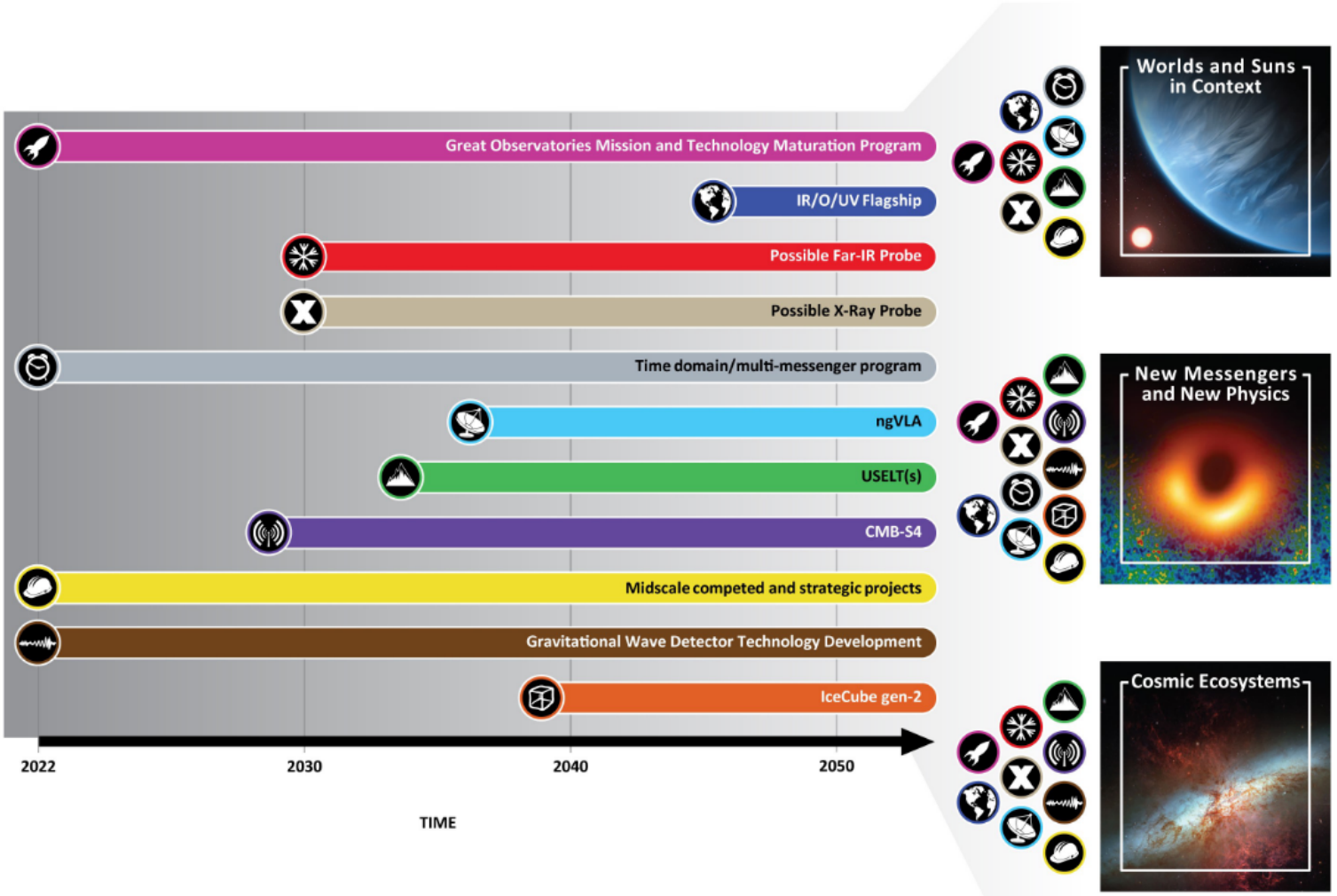
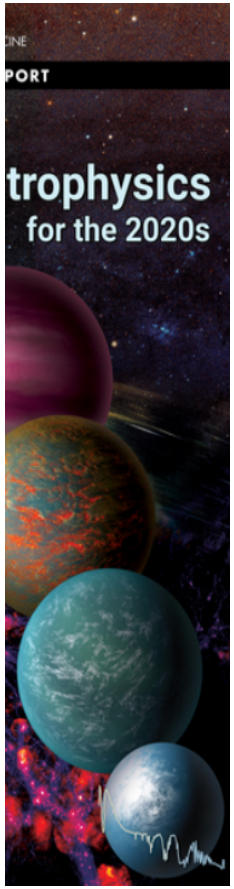




Timeline

Status of work on update of existing Denkschrift:

- Process started September 2023 at AG-meeting Berlin
- Coordination: S. Walch, M. Kramer, *J. Wilms*
- Formation of *Science Working Groups*
- Jan/Feb 2024: Science and Instrument Working Group Inputs received
- March 2024: First condensing of SWG input
- April: Distribution of Science and Instrumentation *draft* to community
- 29/30 April 2024: Community meeting, Telegrafenberg (Potsdam)
- Sept 2024: RDS/AG Meeting: Science close to convergence

Science and Infrastructure Working Groups

- Stellar Astrophysics
  (coord: Geier/Roth)
- Planetary Systems and Habitability
  (coord Rauer/Reiners/Poppenhäger)
- Circuit of Cosmic Matter
  (coord: Sasaki/Wolf)
- Milky Way and Local Group
  (coord: Walcher et al.)
- Galaxies and AGN
  (coord: Kadler/Förster-Schreiber)
- Cosmology, Large Scale Structure, and young universe
  (coord: Reiprich/Komatsu)
- Extreme conditions in the cosmos, fundamental astrophysics
  (coord:Tjus et al.)

- Instrumentation (led by F. Eisenhauer)
  - Radio/mm
  - Optical/IR (incl Sun)
  - UV
  - TeV
  - Space (all wave bands)
  - Time-Domain Astronomy (all wave bands)
  - Multimessenger Facilities

Progress on Denkschrift

Status of work:

- Science Text close to done
- Recommendation on instrumentation, theory, e-science formulated

Original plan: finish Sept 2024

- not feasible - not enough time available in RDS exec
- science case / instrumentation: have good draft (78pp.)
- working on astronomy and society

ferent instruments will provide the necessary synergy to constrain the chemical composition and evolution of planet-forming disks, and ultimately their potential link to the origin of life.

The complexity of planet formation requires extensive simulations, observational analysis, and sophisticated large-scale simulation tools. Rapid growth in exoplanet knowledge demands continuous technology development. Retaining research expertise and high-performance computing availability are bottlenecks, especially for universities. Overcoming these challenges in a concerted effort is crucial to fully exploit results from major instrumentation projects with German participation.

Observing planet formation in star-forming regions leads to a general understanding, while studies of Solar System minor bodies, such as the ESA mission to comet 67P/Churyumov-Gerasimenko, are increasingly important. Laboratory investigations of dust properties, dust agglomeration, collisions, and planetesimal formation by pebble cloud collapse are key components of planet formation studies in Germany.

German institutions had a central role in the success of the VLT/VLTI and its instrument suite and play a major in providing first-light instruments for the ELT. Ensuring the continuity of this German participation in VLTI and E-VLTI is key to maintaining the leadership of German scientists in the field of planet formation and ultimately probe disk scales down to Hill radius scales.

ALMA2030 WSU will extend the existing capabilities of ALMA. The VLT/VLTI, with the MATISSE, MUSE, ERIS, SPHERE, GRAVITY and GRAVITY+ instruments, is making a major contribution, building up to observations with the Extremely Large Telescope (ELT). Ensuring the continuity of this German participation in VLTI is key to maintaining the leadership of German scientists in the field of planet formation and ultimately probe disk scales down to the radius at which individual planetary bodies exert their gravitational influence.

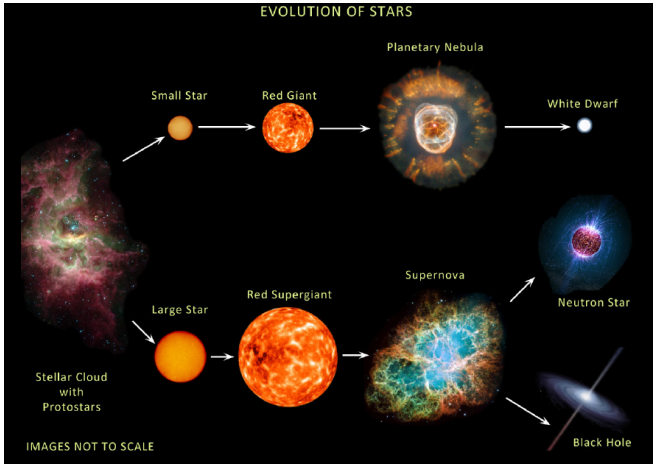
2.3 Cycle of Cosmic Matter

Galaxy evolution is heavily influenced by star formation and stellar evolution. Stars produce elements heavier than hydrogen and helium, contributing to chemical enrichment and ionization through UV photons and stellar winds. Massive stars end in explosions, dispersing these elements into the interstellar gas, which can be ejected into the circum-galactic medium and later cool and rejoin the galaxy. This enriched gas and dust form the next generation of stars (see Fig. 2.5).

Figure 2.5: The cosmic matter and energy cycle (Credit: HABEX Report, The Habitable Exoplanet Observatory Study Team).

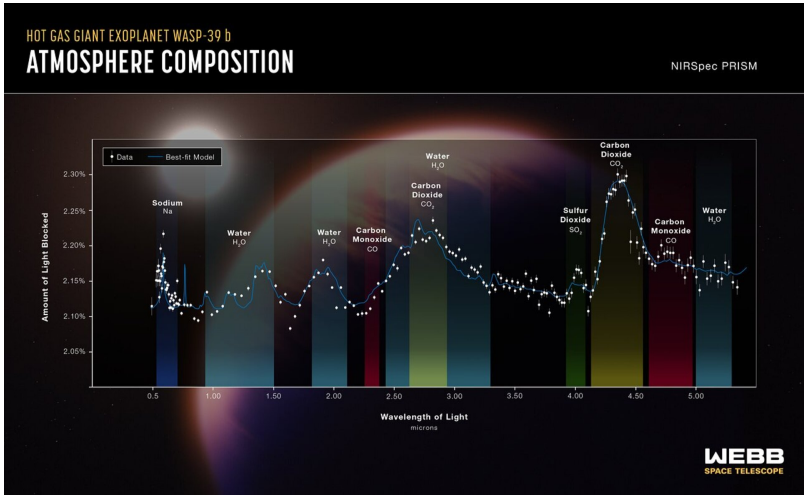
Stellar Astrophysics: Stars and the Sun

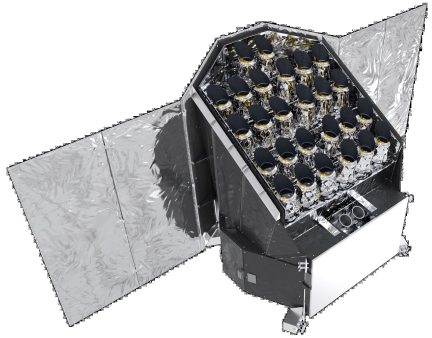
- How does the Sun work and impact us?
- How do stars evolve?
- How do stars end their lifes?
- How do stars influence their environment - their planetary systems and galaxies



Solar System, Planetary Systems, and Habitability

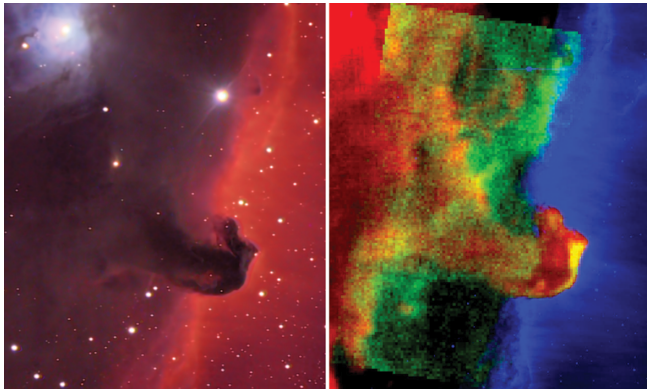
- How do planets form?
- Is our solar system representative of other planetary systems?
- Is there life on other planets?

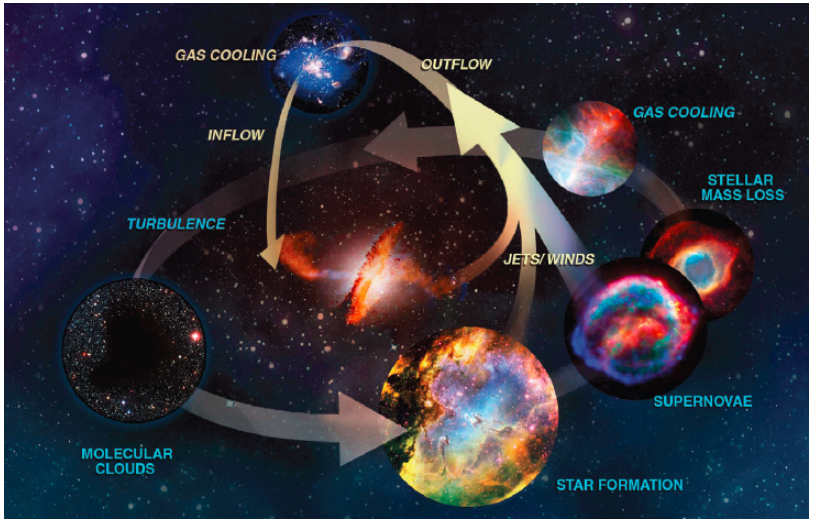


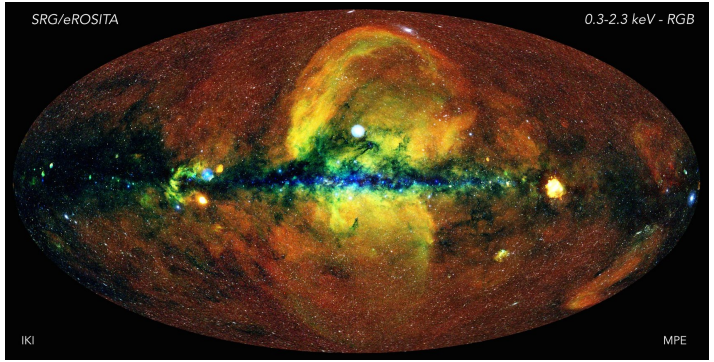


Cycle of cosmic matter

- What are the constituents of cosmic matter and what is their physics?
- How is matter transported and transformed in the Galaxy and beyond?

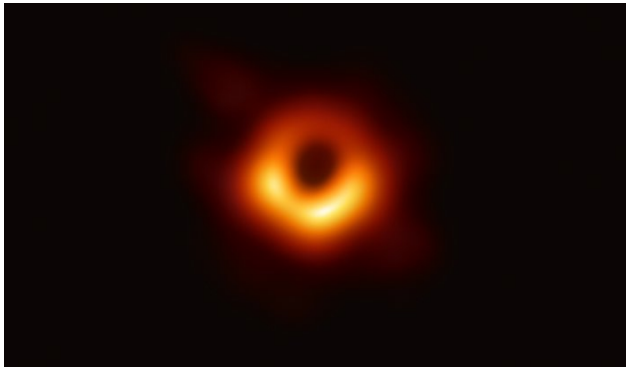


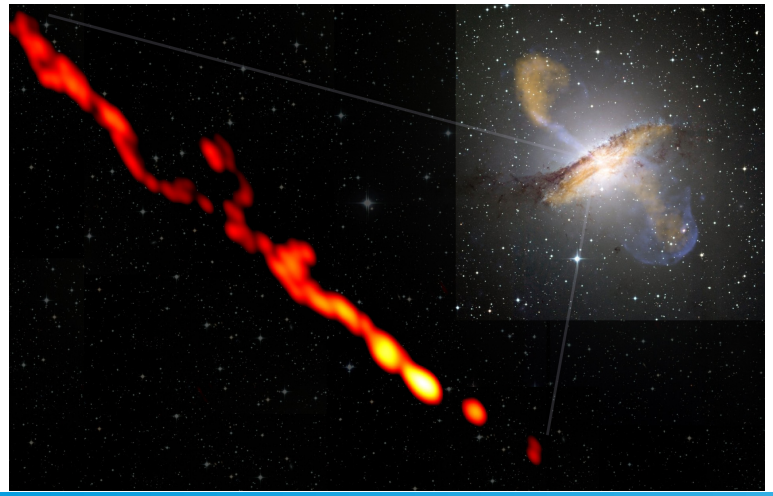




Galaxies and AGN

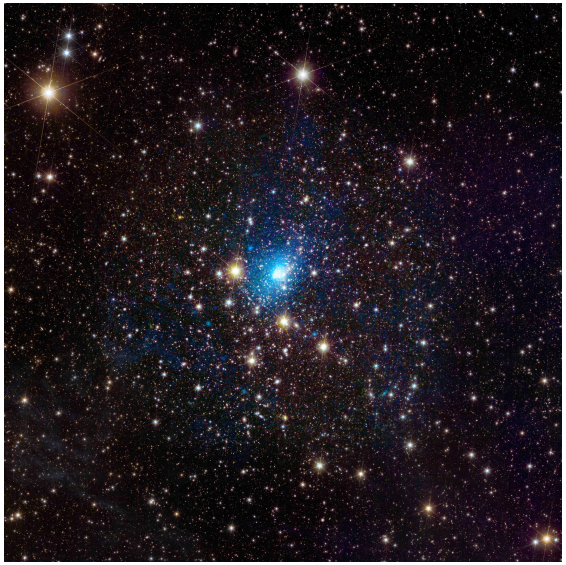
- How do galaxies form, evolve, and interact?
- How do supermassive black holes in galaxies evolve and how do they influence their environment?

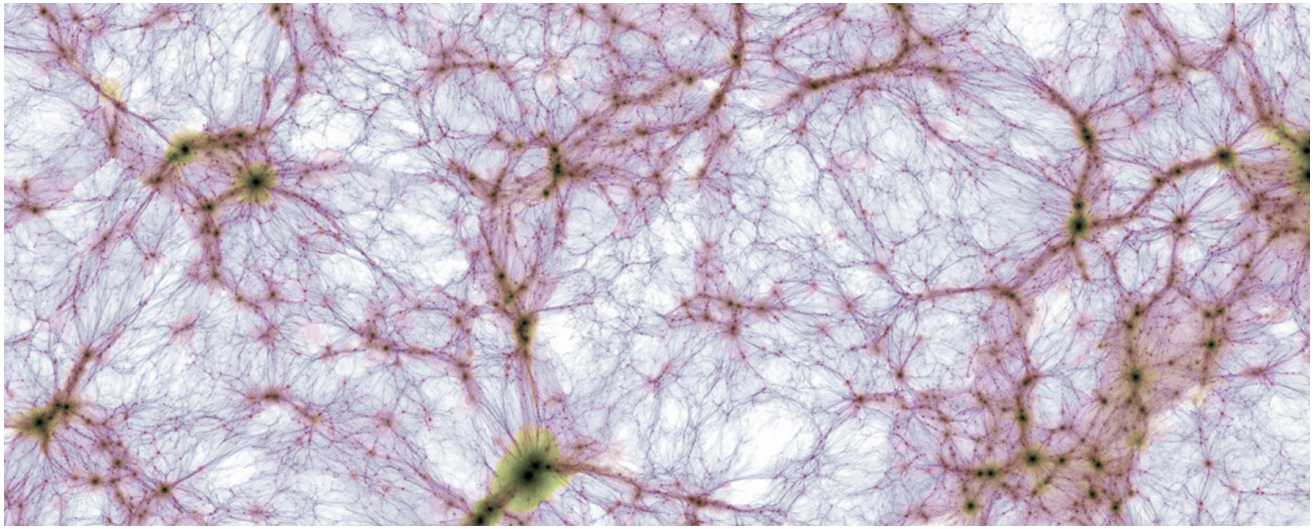




Cosmology, Large Scale Structure, Early Universe

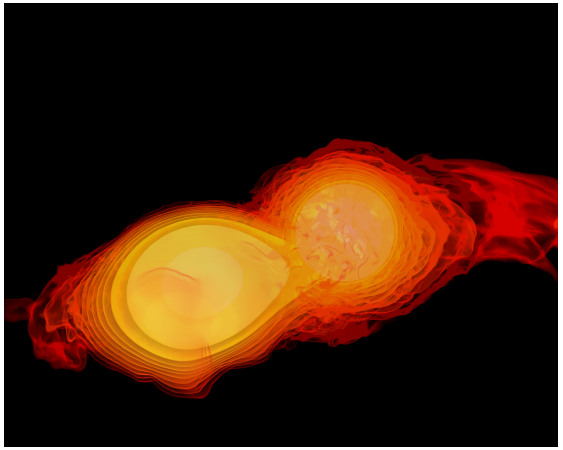
- What is the Universe made of and why?
- How did the Universe evolve into what we see today?
- What is the physics of the early Universe?

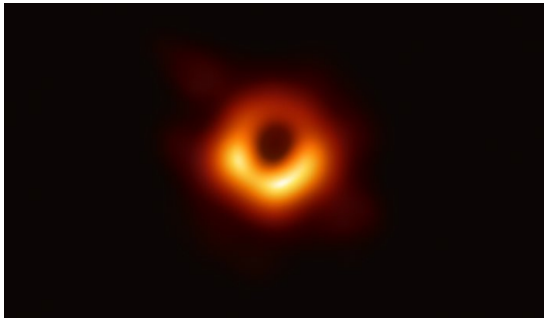




Extreme conditions in the cosmos, fund. physics

- What are black holes?
- What are the properties of matter under extreme conditions not accessible in the laboratory on Earth?
- Is General Relativity our last word in understanding gravity? What are Dark Matter and Dark Energy?
- What are the astrophysical sources of gravitational waves, cosmic rays, and neutrinos?



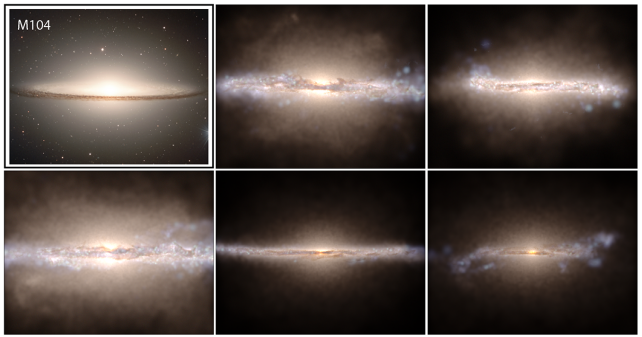


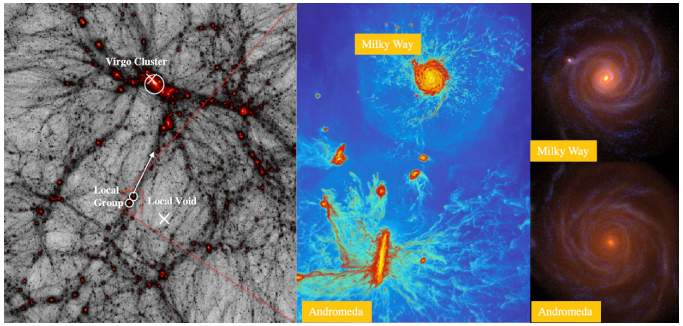
High Performance Computing / e-science

Helps to answer ALL previous questions -> cross sectional

Selected example questions:

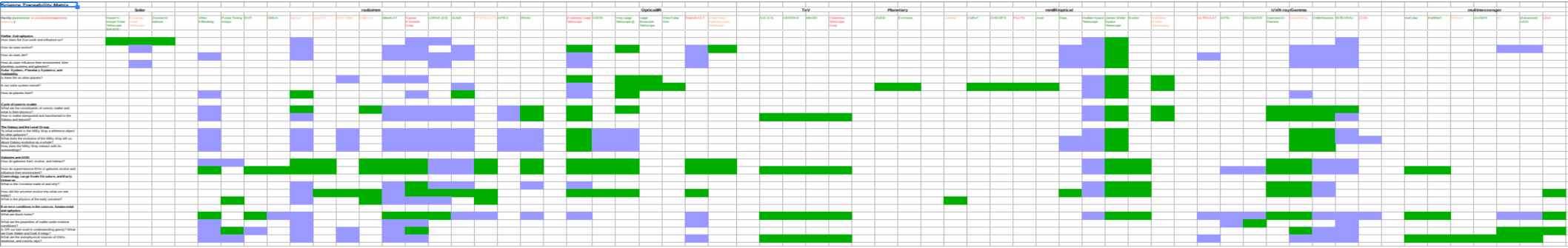
- How can we deal with the increasingly complex and exponentially growing datasets?
- Can numerical simulations reproduce the properties of the solar corona?
- Will 3D-models of rotating stars describe the observed stellar properties?
- Can we simulate the Milky Way?
- What discoveries/breakthroughs are made possible by artificial intelligence?





Observational Facilities

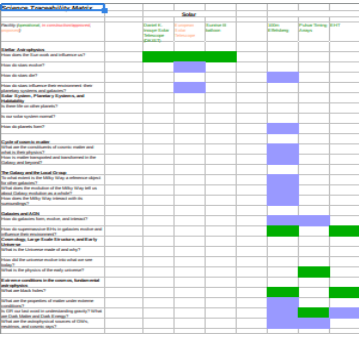
Recommendations: Instrumentation



Recommendations: led by Science Traceability Matrix:

- Which instrument addresses which science question?
- How can we maximize scientific return?

Recommendations: Instrumentation



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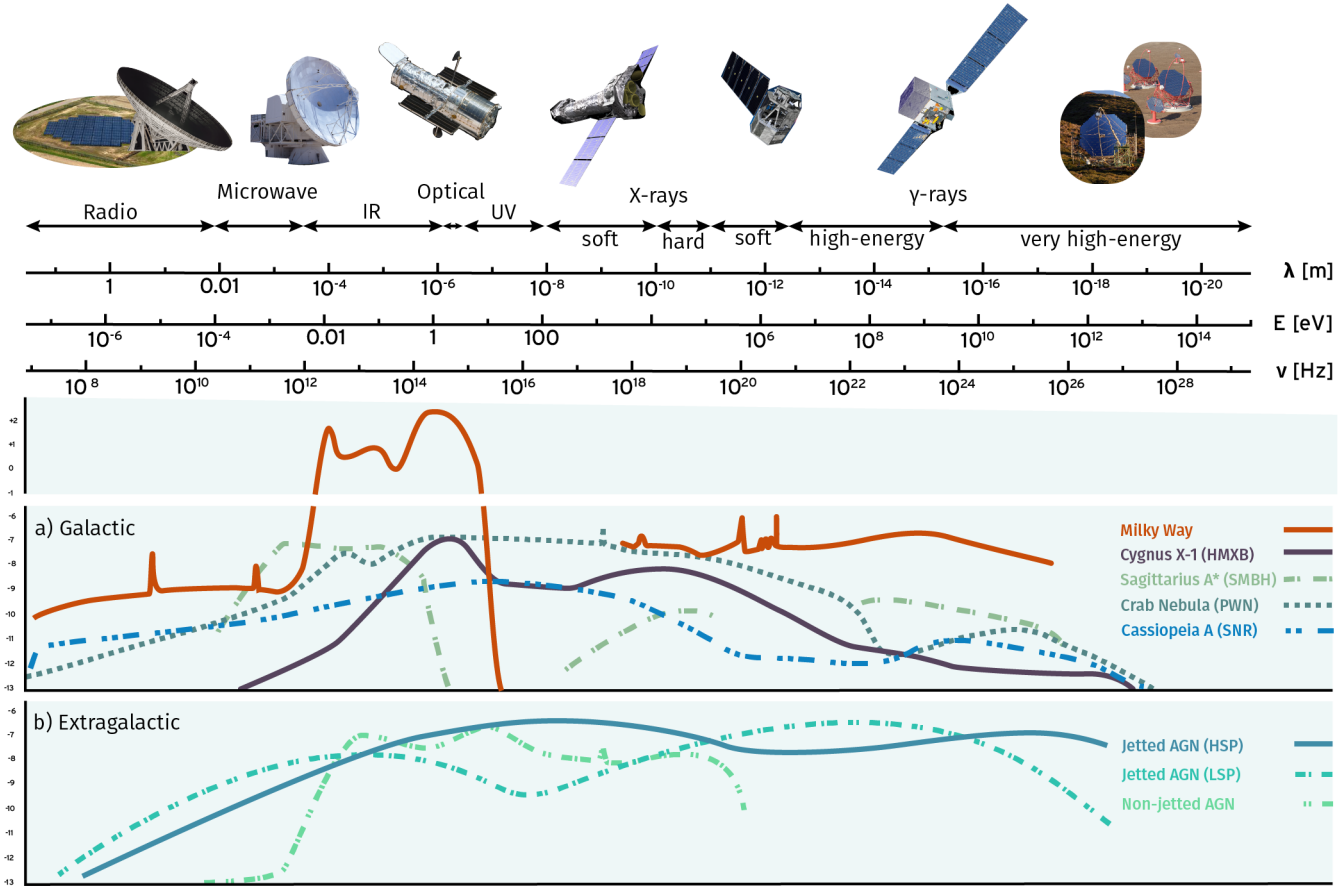

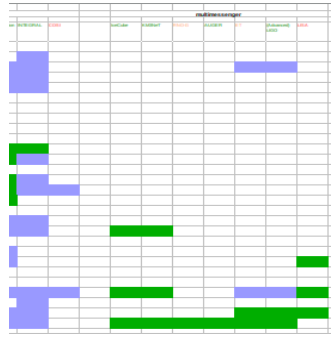

Science Traceability Matrix

TeV

Facility (operational, in construction/approved, proposed)	H.E.S.S.	VERITAS	MAGIC	Cherenkov Telescope Array
Stellar Astrophysics				
How does the Sun work and influence us?				
How do stars evolve?				
How do stars die?				
How do stars influence their environment -their planetary systems and galaxies?				
Solar System, Planetary Systems, and Habitability				
Is there life on other planets?				
Is our solar system normal?				
How do planets form?				
Cycle of cosmic matter				
What are the constituents of cosmic matter and what is their physics?				
How is matter transported and transformed in the Galaxy and beyond?				
The Galaxy and the Local Group				
To what extent is the Milky Way a reference object for other galaxies?				
What does the evolution of the Milky Way tell us about Galaxy evolution as a whole?				
How does the Milky Way interact with its surroundings?				
Galaxies and AGN				
How do galaxies form, evolve, and interact?				
How do supermassive BHs in galaxies evolve and influence their environment?				
Cosmology, Large Scale Structure, and Early Universe				
What is the Universe made of and why?				
How did the universe evolve into what we see today?				
What is the physics of the early universe?				
Extreme conditions in the cosmos, fundamental astrophysics				
What are black holes?				
What are the properties of matter under extreme conditions?				
Is GR our last word in understanding gravity? What are Dark Matter and Dark Energy?				
What are the astrophysical sources of GWs, neutrinos, and cosmic rays?				

Science Traceability Matrix

multimessenger

Facility (operational, in construction/approved, proposed)	IceCube	KM3NeT	RNO-G	AUGER	ET	(Advanced) LIGO	LISA
Stellar Astrophysics							
How does the Sun work and influence us?							
How do stars evolve?							
How do stars die?							
How do stars influence their environment -their planetary systems and galaxies?							
Solar System, Planetary Systems, and Habitability							
Is there life on other planets?							
Is our solar system normal?							
How do planets form?							
Cycle of cosmic matter							
What are the constituents of cosmic matter and what is their physics?							
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Cosmology, Large Scale Structure, and Early Universe							
What is the Universe made of and why?							
How did the universe evolve into what we see today?							
What is the physics of the early universe?							
Extreme conditions in the cosmos, fundamental astrophysics							
What are black holes?							
What are the properties of matter under extreme conditions?							
Is GR our last word in understanding gravity? What are Dark Matter and Dark Energy?							
What are the astrophysical sources of GWs, neutrinos, and cosmic rays?							

Recommendations: Caveat

RDS Exec: set of recommendations on instrumentation, informally approved at September RDS meeting.

Three areas for recommendations:

1. ground based instrumentation
2. space based instrumentation
3. computing, e-science, theory

Note: further recommendations will come out of “astronomy and society” process (e.g., sustainable astronomy, funding structure, hiring, status of community,...)

Recommendations: Boundary Conditions

Boundary conditions:

- ESO and ESA budgets receive substantial German contributions

  Our instrumentation contributions produce the knowledge to maximize their science return
- Astrophysics requires multiwavelength approach
- Fiscal realities are dire and should not be ignored:
  - flat budgets will be a success (Ukraine, Art 109 GG [Schuldenbremse],...)
  - BMBF: danger of additional FAIR cost overruns
  - ESO procurement approach has increased costs for member states
  - WissZeitVG adds significant uncertainty for keeping expertise around

Recommendations: Ground Based

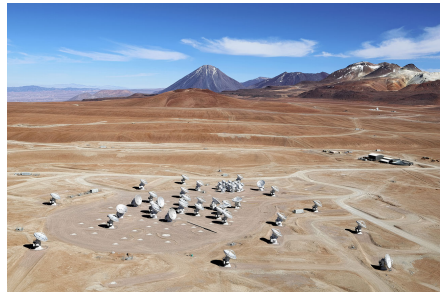
Recommendation 1: Contributions to the ESFRI infrastructure ELT

The active German contribution to the construction of the flag ship of European astronomy, the 39m European Extremely Large Telescope on the Cerro Armazones, and its instrumentation is essential for astronomical research in the coming decades. German groups have significant involvement in the instrumentation, also in leading roles. Funding for the first set of instruments should have the highest priority.

Recommendations: Ground Based

Recommendation 2: Continued development of the La-Silla-Paranal-Observatory and of ALMA as world-leading observatories:

With the VLT(I) the La-Silla-Paranal-Observatory will remain one of the most important optical observatories, while the antenna array ALMA on the Chajnantor plateau represents an unique observatory in the mm- and submm-range. RDS recommends continued funding for the third generation of sensors, receivers, and spectrographs for these facilities in order to ensure internationally competitive conditions on a broad range of astrophysical key questions, as well as access to the smaller telescopes on La Silla.



Recommendations: Ground Based

Recommendation 3: Contributions to SKA

RDS recommends that the German membership in SKA as one of the most important international projects in astronomy be funded in a way that ensures appropriate access to SKA for the whole German community.

Recommendations: Ground Based

Recommendation 4:

Ensure way to continue access to Northern hemisphere activities:

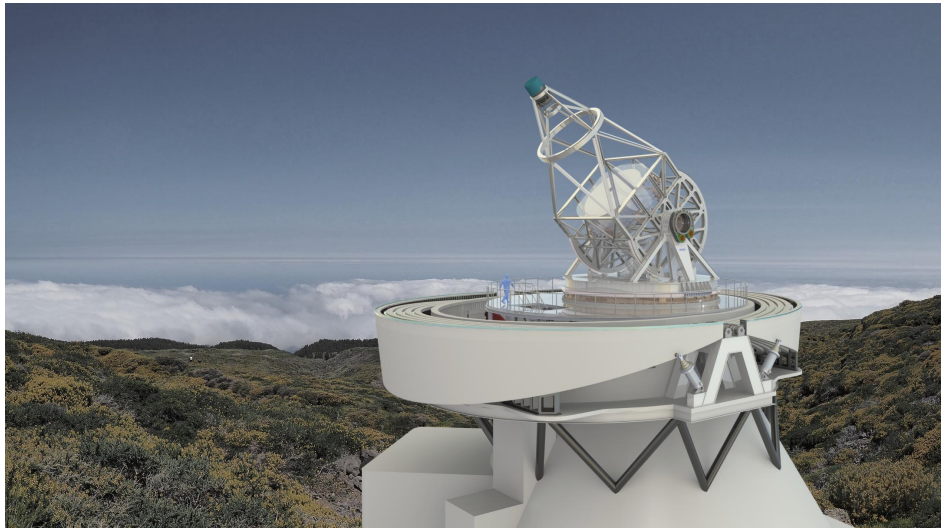
- ensure some OIR access to Northern hemisphere
- ensure continued operation and evolution of radio facilities (LOFAR, Effelsberg, IRAM, and international collaborations)

(full phrasing not yet decided)

Recommendations: Ground Based

Recommendation 5: Contributions to the solar telescope EST

EST will be the central facility for solar research in the next decades, and will also be of significant utility for stellar astrophysics. RDS recommends funding of hardware contributions to ensure the continued leadership of the German community in solar science instrumentation and research.



Recommendations: Ground Based

Recommendation 6: Future ESO facilities

As part of its strategy process, ESO has initiated the process to identify the next large infrastructure under ESOs coordination to be developed after the ELT is finished. In order to maintain the world-leading role German groups have in the development and exploitation of state-of-the-art OIR facilities, RDS supports participation of German groups in this process.

Recommendations: Ground Based

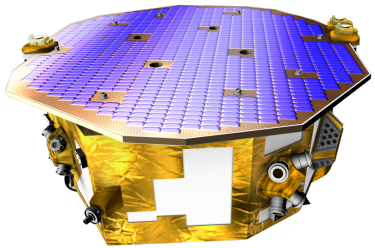
Further comments on ground based recommendations:

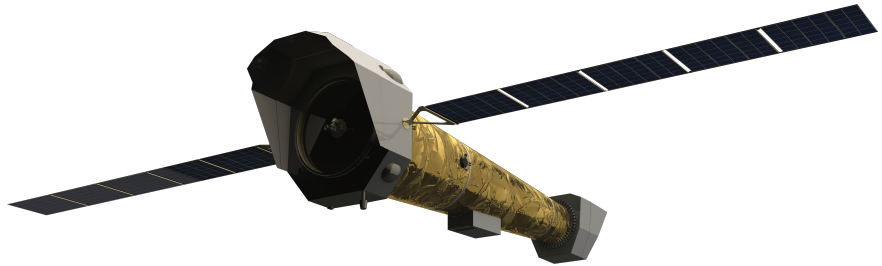
- Support CTA as ESFRI infrastructure, and German contributions to IceCube, KM3NeT, and RNO-G neutrino observatories
- Acknowledge efforts for Germany to contribute to ET as 3rd generation gravitational wave detector. EM follow up to GW signals is central to understand the astrophysics of GW sources, and therefore crucial for ET. Facilities recommended by RDS are well suited for this task.
- Verbundforschung ground based astronomy and astroparticle physics is mandatory to enable university contributions (avoid offloading these activities to DZA - need healthy community *with* DZA)

Recommendations: Space Based

Recommendation 1: ESA L- and M-class missions

The main priorities are the German contributions to the gravitational wave experiment LISA (launch ~2032) and the X-ray telescope NewAthena (launch ~2035), as well as continued support for the development of M-class missions in implementation. RDS also supports funding the participation of German groups in future M-class missions as well as for studies for future Voyage 2050 missions.





Recommendations: Space Based

Recommendation 2: National and Bilateral Missions

A continuation of the funding of national and bilateral missions is crucial for ensuring German capabilities in space instrumentation, especially when considering the very long timescales for flag ship missions. In the next decade this especially includes funding German participation in a NASA Probe mission (in the infrared or X-rays) and HabEx, but may also include missions led by France, Japan, India, and other nations.

Recommendations: Space Based

Recommendation 3: Small-scale instrument development

RDS recommends funding contributions to small satellites with fast turn around times in the microsatellite and minisatellite range. RDS also emphasizes the need to enable German contributions to long duration balloon flights that could replace and complement space experiments, e.g., to close the gap in IR-astronomy left by the end of SOFIA.

Recommendations: Space Based

Further comments on space based recommendations:

- RDS endorses funding of instrumentation for in situ studies of bodies in the solar system

Additionally:

- also include similar statement for other small bodies, and for plasmas in solar system,
- express very strong support for the Verbundforschung space based astronomy,
- study possibilities of doing astronomy on the Moon.

Recommendations: HPC/e-science

Recommendation 1: Verbundforschung Theorie & Simulation

RDS recommends the establishment of a dedicated funding line (e.g., “Verbundforschung Theorie und Simulationen”, a virtual research institute on simulations, or something similar) to ensure long-term, sustainable strategic code development that enables the German community to maintain its world-leading position in astrophysical simulations.

Recommendations: HPC/e-science

Recommendation 2: Cross-sectional data analytics laboratories

To make use of the opportunities associated with the very large, rich, and unrestricted astronomical data sets in particular for novel machine learning methods, RDS recommends the formation of cross-sectional data analytics laboratories in which researchers from the fields of astrophysics, mathematics, data science, and computer science jointly develop novel algorithms for various applications.

Recommendations: HPC/e-science

Recommendation 3: Data Center

RDS supports the creation of a Germany wide structure of data centers from large-scale observing facilities and their analysis that complements and/or uses the software and procedures developed, e.g., within Nationale Forschungsdateninfrastruktur (NFDI) initiatives or international activities such as the Virtual Observatory Alliance. Depending on the specific nature of the data, distributed data centers or a central facility will be the most efficient means to ensure access for the whole community.

Next Steps:

- Release next iteration of science text, which incorporates comments from AG meeting in Cologne
- Prepare Astronomy and Society topics:
  - Green Astronomy (sustainable science)
  - Transfer of Knowledge (“Technology Transfer”)
  - Astronomy and STEM education
  - Astronomy and the Public
  - Protection of the electromagnetic spectrum
  - Careers
- Discuss relationship to other fields
  will address lab astro (there or in science part), plus, e.g., chemistry, optics, geosciences, history...
- Summarize main structural challenges for German astronomy in the next decade
- Collect statistical data on German astronomy

=> Many of these points also important for KAT, collaborate as much as possible!