Community paper “Optical/IR Facilities”

S. Dreizler, F. Eisenhauer, R. Gredel, A. Kelz, H. Nicklas

Executive summary

During the last two decades, Germany has been extremely successful in the construction of astronomical instruments for the 4- and 10-meter class telescopes. The cooperation between universities, AIP and the Max-Planck institutes enabled them to play a key role here. This German involvement has led to the leadership and the participation in the construction of the majority of instruments for the VLT, the LBT and also 4-meter class telescopes.

During the preliminary studies for the construction of the E-ELT in the period from 2007 - 2010, many instrument concepts and telescope components for the E-ELT have been developed with contributions from Germany. It is important to note that those studies have been made with significant involvement of German high-tech companies from large to medium-sized business. As a result of great success in the previous VLT era, astronomical research institutes in Germany own the leader-ship either in the development or participate strongly in almost all E-ELT instrument consortia. All five instruments of the E-ELT first suite are now fixed and meanwhile contracted by ESO since the first quarter of 2016. The development and construction phase of those five contracted instruments have timelines until 2025 and above, and therefore set the roadmap for Germany in order to participate in the E-ELT project for the next decade and beyond.

The instrumentation projects for the E-ELT meet in an ideal way the funding policy objectives of the BMBF in the field of ground-based astronomy. They are in the scope of international collaborations from institutions within Europe. New concepts in optics, mechanics, electronics and software have been developed for the construction of innovative and complex instruments. The new E-ELT instruments require a close collaboration between consortia and industry on a significantly larger scale than the previous VLT instrument suite. While LBT or VLT instruments could be financed to a large amount within the Max-Planck institutes’ budgets, in combination with very significant contributions from the ‘Verbundforschung’, this approach will become inadequate for E-ELT instruments. To enable Germany playing a major role in the E-ELT instrumentation, tailored initiatives become mandatory for all kind of funding bodies. This could either be accomplished by an increased funding through the ‘Verbundforschung’ or can be achieved via a new funding program in combination with opening up those funding schemes for Max-Planck-Institutes. In order to maintain their long-term competitiveness within Europe, the universities depend totally on substantial and on sustainable funding structures. Only this will allow the participating institutes to maintain the lead and especially the universities to contribute significantly to the subsystems in the construction of the E-ELT instrument suite, which in the end was enabled only through the expertise that was developed and gained in the VLT era.

Within the next decade, the E-ELT development provides the world-wide pole position for European astronomy for gaining significantly deeper insights into fundamental physical questions ranging from the structure and evolution of our universe to life on other planets. Only a long-term and secured co-operation between Max-Planck institutes, the Universities and AIP secures and fosters the gained position of research institutions in Germany at the forefront of science and technology in astronomical research.

1. Introduction

This panel report will concentrate on ground-based astronomy in the optical/IR frequency domain. Space-based observatories and observations of the sun will be addressed in separate dedicated reports.

First, the priorities of astrophysics in the optical/IR spectral range within Germany are addressed, followed by a description of the international landscape of astronomical observatories into which the instrumental development and science observations are embedded. The most prominent observatories (lighthouses) of forefront astronomy in Germany are pointed out. Special emphasis is therefore given to the instrumental developments within Germany, and which role the 'Erdgebundene Verbundforschung Astrophysik und Astroteilchenphysik' plays, both of crucial importance for the participation in world-leading astronomical research on international scale.

Fig.1: Flagship of European astronomy, the 39-meter Extremely Large Telescope under construction.

2. Upcoming Optical/IR Facilities in the coming decade

The clear top priority of ground-based astronomy in Germany is the development of the world-leading European Extremely Large Telescope with its 39-m aperture developed by ESO together with industrial contractors all over Europe and reflects very clearly the federal aspects of this re-search organization. The engagement of Germany to bring this telescope project to a similar success as the VLT did becomes visible through the fact that four (out of five) consortia, building the most advanced E-ELT instrumentation, have German institutions as partners, here listed by project name

(1) ELT-CAM – MICADO
(2) ELT-MIDIR – METIS
(3) ELT-MOS – MOSAIC
(4) ELT-HIRES – Name TBD

of which the first instrument in the list will become the 'First-Light' Camera MICADO that will put this gigantic telescope into operation and which is to the most a German consortium led by MPE in Garching. The road is prepared for developing the other three instruments, which obtained meanwhile signed contracts.

MICADO and METIS aim for a tremendous improvement in spatial resolving power by a factor of about five (linear) in combination with an increase in light collection power of the factor of twenty. Thus, completely new and fundamental questions of astrophysics can be tackled. The other two instruments, MOSAIC and ELT-HIRES, run currently through their phase A study, which will define their top level requirements and performances adequate to multiple-object and high-resolution spectroscopy in the ELT era. All of them became real projects through signed ESO contracts for Phase-B (1 and 2) and Phase-A (3 and 4) developments, respectively.

Beside these E-ELT developments with the highest priority in the German community, the other observatories including the ESO/VLT ask for progressive and state-of-the-art instrumentation.

- ESO/VLT 3rd Generation instruments; GRAVITY, 4MOST, ERIS, MATISSE
- Next generation instruments for LBT
- CAHA/Spain extended access and follow-up instrumentation
- SALT/South Africa and HET/Texas follow-up instrumentation
- Wendelstein/Bavaria instrumental upgrade

The following two tables map the coverage of the landscape in instrumental development for astro-physical research institutions in Germany. Only instruments at the level of international competition are taken into account. Both graphs picture the engagement and the capacities of German institutions on a large scale that urges stable and sustainable funding structure.

Obser-vatory	Facility	PI Institute	AIP Potsdam		IAG Göttingen		KIS Freiburg		MPE Garching		MPIA Heidelberg		MPIfR Bonn		TLS Thür.Landes.		RUB Bochum		Universität Hamburg		Universität Kiel		Universität Köln		Universität Potsdam		USM München		ZAH Heidelberg	
ESO	ELT-CAM Micado	D MPE			2015	2030			2015	2030	2015	2030															2015	2030		
	ELT-IFU Harmoni	UK UO																												
	ELT-MIDIR Metis	NL NOVA									2016	2030																		
	ELT-MOS Mosaic	F GEPI	2016	2030	2016	2030																								
	ELT-HIRES	I INAF	2016	2030	2016	2030									2016	2030			2027	2030									2016	2030
	VLTI Gravity	D MPE							2015	2016	2015	2030											2015	2016						
	VLT MUSE	F CRAL	2015	2017	2015	2017																								
	VLT CRIRES +	D TLS			2015	2017									2015	2018														
	VLT Moons	UK ROE																												
	VISTA 4MOST	D AIP	2015	2020					2015	2020	2015	2020							2021	2030					2023	2030			2015	2020
	VLT Eris	D MPE							2015	2017																				
	VLTI Matisse	F INSU									2015	2017	2015	2017							2015	2017								
HET	HETDEX Virus	US Texas	2015	2016	2015	2016																			2017	2020	2015	2016		
LBT	Lucifer 1&2	D ZAH							2015	2015	2015	2015					2015	2015											2015	2015
LBT	Linc-Nirvana	D MPIA									2015	2016											2015	2016					2015	2016
LBT	Pepsi	D AIP	2015	2015																										
CAHA	Carmenes	D ZAH			2015	2016									2015	2016													2015	2016
USM	Wendelstein	D USM																									2015	2030		
OdT	VTT/GREG./ATST	D KIS					2015	2030																						
OdT	STELLA	D AIP	2015	2017																										
TLS	Tautenb.Schmidt	D TLS													2015	2030														
MPG	2.2m	D MPIA									2015	2018																		
US/ZA	MONET N&S	D IAG			2015	2017																								
2015		2016	2017		2018		2019		2020		2021		2022		2023		2024		2025		2026		2027		2028		2029		2030	

Table 1: Map of the instrumental landscape where German institutes took the leadership or participate in collaborations for instrumental development, restricted to the period 2015-2030. Indicated is start/end of running or upcoming instrument projects for the consortia members within Germany.

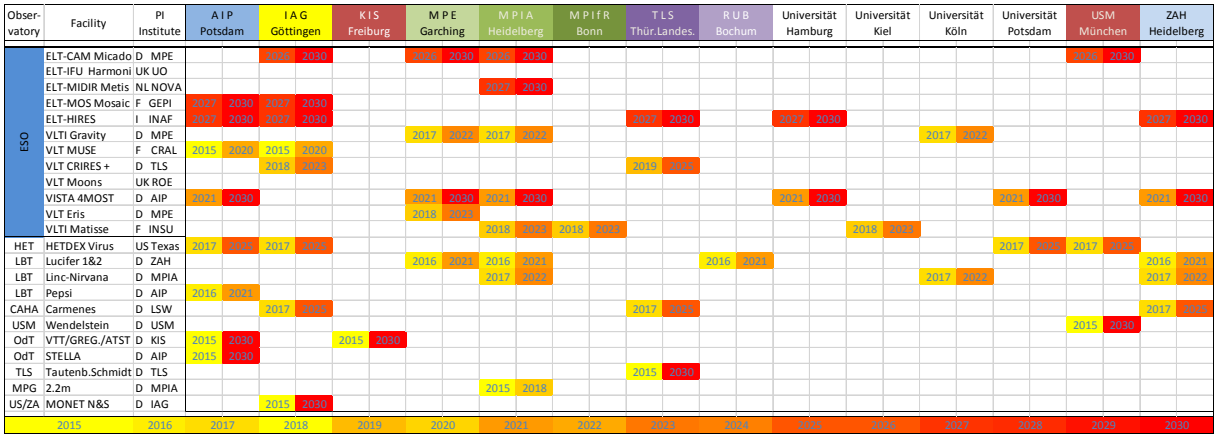

Table 2: Map of astrophysical research institutions in Germany that are engaged in GTO observations and data reduction as the science return for instrumental developments of the previous table.

3. Main achievements in the past decade

3.1 The European Southern Observatory – ESO

The backbone for astronomical research from the ground in Europe and in Germany is undoubtedly the European Southern Observatory ESO with its three observational sites in Chile and the headquarter in Garching. Founded in the 1960s, it supports at the moment the national astronomical communities of 15 countries in Europe and two in South America. Germany's annual contribution to the organization is currently about 24%.The return in observing time amounts roughly to 25% and is thus fairly balanced. Major industry in Germany was and still is involved in developing the sites, both telescope VLT and E-ELT, and instrument subsystems for astronomical observations, such as Dornier, Heidenhain, Krupp Industrietechnik, MAN-GHH, MT Mechatronics, Schott, Zeiss and many other small and mid-size companies in opto-mechanics, glass technology, electronics and other industrial fields.

The VLT is the greatest success for the European ground-based optical/IR astronomy. With its appearance Europe stepped into the 10-Meter class astronomy, and thus became able to catch up with the greater astronomical observatories in the US. In order to set the benchmark for the next decades, Europe planned in due time the largest telescope in the world, shortly after commissioning the VLT, which maintains Europe's competitiveness. This step into the near future will no longer follow the old fashioned law of doubling the aperture of the primary mirror, it is aiming for a about 20-times larger light collecting power.

Germany is the largest net contributor to the ESO (contribution proportional to GDP) and represents about 500 possible ELT users. Considering the return of funds for the ELT telescope and instrument construction, Germany benefits the most.

The development of appropriate techniques within these international consortia enables the German astronomical community to participate in other collaborations that are mentioned in the following. These partnerships in competitive consortia is to a large extend to credit the 'Verbundforschung'.

3.2 International Observatories

Astronomical research institutions in Germany – covering universities, Max-Planck-Society and Leibniz institutes – are engaged in a lot of international observatories, which are list here not comprehensively and without ranking:

- Mount Graham Obs., US/Arizona
- Obs. del Teide, Spain
- Calar Alto Obs., Spain
- McDonald Obs., US/Texas
- South African Astron. Obs., South Africa

The German engagement in those observatories is twofold. Part of the operations costs is covered, but also instrumental developments are taking place.

3.3 National Observatories

The international engagements above find a support through observatories that are operated on a national basis that are

- MPG/ESO 2.2m at La Silla Observatory, Chile
- Thüringer Landessternwarte, Tautenburg
- Wendelstein Observatorium, Bayern
- The robotic telescopes
    - STELLA, OdT Spain
    - TIGRE, La Luz, Mexico
    - MONET, North/South, Texas and South Africa

The developments that are required to operate these national observatories are manifold in terms of knowledge base, technological R&D in

- Back-focal instrumentations
- Software for telescopic, instrumental control
- Data reduction techniques
- Telescope operations and maintenance
- Project management

The expertise gained through these smaller facilities and their requirements in operation and technical developments forms to some extend the basis to apply successfully in large instrument consortia, especially in the huge consortia building the large and most complex E-ELT instrumentation.

4. Particular role and strength of Optical/IR instrumentation and technology

Germany has an astronomical instrumentation program that is not easily to beat. It looks back in his-tory on a long tradition. We concentrate us here on the time after inventing the 16-Meter VLT. The rise of the VLT put new and large requirements on the astronomical community in Europe, so on instrumental developers in Germany. A new level of complexity and of quality had to be entered in or-der to fulfil the required demands on VLT instrumentation. This leap into developing adequate instrumentation looks back now for 25 years and is of a great success, which comprise the following not comprehensive list.

- ESO-VLT: FORS 1&2, (NAOS)-CONICA, SINFONI, OmegaCAM, KMOS, MUSE, SPHERE
- ESO-VLTI: AMBER, MIDI, PRIMA
- LBT: LUCIFER 1&2, LINC-NIRVANA, PEPSI, ARGOS
- HET: HETDEX/VIRUS
- CAHA: CAFOS, PMAS, CARMENES

All the ESO instruments above, those were developed under German leadership and contributions, have been extremely successful in the sense that they have enabled ground-breaking world-class scientific results especially for the astronomical community in

Germany. Among those are the instruments dubbed the workhorses of the VLT and their founding set the foundation for the story of the great success of the 'Erdgebundene Verbundforschung Astrophysik und Astroteilchenphysik'.

The role of the 'Erdgebundene Verbundforschung Astrophysik und Astroteilchenphysik' for developing state-of-the-art and competitive instruments can not be overestimated. It plays a crucial role for Germany to participate in forefront and international instrument teams. Eventually it supports and enlarges thus the scientific return through guaranteed observations with the most modern and advanced world-class telescopes.

The engagement of German research institutions in the forefront instrumentation (including the university institutes) led to a very high degree of professionalism in R&D of technical solutions, but also in managing either the project in total or locally at their node. Those invented for instance most modern Product Lifecycle Management systems, that is state-of-the-art only in large industrial companies, which put them in a strong position when applying for a major role in upcoming large international instrumental consortia.

The total in instrumental achievements through German consortia or participations is the backbone of optical and IR facilities worldwide. They all together guarantee a high degree in GTO observations and the scientific return for both, for the involved consortia and for the astronomical community in Germany and (in case of ESO instruments) in Europe as a whole.

5. Technology transfer effects

It's a technological challenge but also an opportunity for European companies to build world-leading observatories with turn-key telescopes at forefront astronomy such as the VLT and the E-ELT. Technologies that are involved and gain leading positions in know-how through the development of those astronomical telescopes and instruments are:

- Glass technology; elasto-mechanical behaviour of mirror blanks, optical filtering etc.
- Mirror technology; huge monolithic disks or mass production of 1-meter optics
- Structural design and construction; most modern design and analysis software tools
- Production of large series in optics, mechanics and electronics in instrumental developments, too numerous for institute consortia workshops
- Machining of large, heavy and high-precision instrumental structures, either too large for institute workshops or made out of high-tech materials with exotic properties
- Product and quality assurance; ensuring the investments
- Data-base-management systems; professional state-of-the-art storage of documentation, procurement, manufacturing drawings and processes etc.
- Project management; organize complex work-flows and huge logistics etc.

Numerous companies within Germany did participate in the construction of the telescopes and observatories of the last decades. The effect can be observed in the most recent telescope design, the construction of the E-ELT, where elements from earlier developments of German companies can be found again, and which will lead to the corresponding contracts. Also the industrial part in the instrumental development will become larger due to the requirements in handling more complex, larger and massive instrument components. Thus, the link between industry and research institutions and universities becomes much more intensified.

6. Summary and conclusion

During the last two decades, Germany has been extremely successful in the construction of astronomical instruments for the 4- and 10-meter class telescopes. The cooperation between Max-Planck institutes, the Universities and AIP enabled them to play a key role here. This German involvement has led to the leadership and the participation in the construction of the majority of instruments for the VLT, the LBT and also 4-meter class telescopes.

During the preliminary studies for the construction of the E-ELT in the period from 2007 - 2010, many instrument concepts and telescope components for the E-ELT have been developed with contributions from Germany. It is important to note that those studies have been made with significant involvement of German high-tech companies from large to medium-sized business. As a result of great success in the previous VLT era, astronomical research institutes in Germany own the leader-ship either in the development or participate strongly in almost all E-ELT instrument consortia. All five instruments of the E-ELT first suite are now fixed and meanwhile contracted by ESO since the first quarter of 2016. The development and construction phase of those five contracted instruments have timelines until 2025 and above, and therefore set the roadmap for Germany in order to participate in the E-ELT project for the next decade and beyond.

The instrumentation projects for the E-ELT meet in an ideal way funding policy objectives of the BMBF in the field of ground-based astronomy. They are in the scope of international collaborations from institutions within Europe new concepts in optics, mechanics, electronics and software developed for the construction of innovative and complex instruments. Those E-ELT instruments require a close collaboration between consortia and industry on a significantly larger scale than the previous VLT instrument suite. While LBT or VLT instruments could be financed to a large amount within the Max-Planck institutes' budgets, in combination with very significant contributions from the 'Verbundforschung', this approach will become inadequate for E-ELT instruments. To enable Germany playing a major role in the E-ELT instrumentation, tailored initiatives become mandatory for all kind of funding bodies. This could either be accomplished by an increased funding through the 'Verbundforschung' or can be achieved via a new funding program in combination with opening up those funding schemes for Max-Planck-Institutes. In order to maintain their long-term competitiveness within Europe, the universities depend totally on substantial and on sustainable funding structures, allowing them to contribute significant subsystems in the construction of the E-ELT instrument suite, enabled through the expertise developed and gained in the VLT era.

Within the next decade, the E-ELT development provides the world-wide pole position for European astronomy for gaining significantly deeper insights into fundamental physical questions ranging from the structure and evolution of our universe to life on other planets. Only a long-term and secured co-operation between Max-Planck institutes, the Universities and AIP secures and fosters the gained position of research institutions in Germany at the forefront of science and technology in astronomical research.

oOo