Max Planck Institute for Astronomy

Heidelberg-Königstuhl

Annual Report 2015

Cover Picture:
High-resolution spectra like this of the star μ Leonis were taken with the NARVAL very high-resolution spectrograph installed at the Télescope Bernard Lyot, Observatoire Midi-Pyrénées as part of a large programme of ground-based observations to complement the measurements of the astrometry mission Gaia. The detailed analysis of such spectra, of which several hundred thousand are taken throughout the galaxy, are the key to understanding the origin of the chemical elements and the formation history of the Milky Way. See Chapter II.2, page 24.

Credits: Maria Bergemann / MPIA / NARVAL@TBL

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Annual Report 2015

Max Planck Institute for Astronomy

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Preface

Astronomy is a data-driven field. The quality and quantity of the data that enable astronomical discovery are linked to cutting-edge technology in an impressive feedback loop.

This year's developments at the Max Planck Institute for Astronomy (MPIA) provide some poignant examples. Our researchers discovered that there are moving features in the dust disc surrounding the nearby star AU Microscopii, the first observation of such structures changing over time. This discovery was made possible by the unprecedented imaging capabilities of the SPHERE instrument built with key MPIA contributions, which saw first light at ESO's Paranal Observatory in late 2014.

In turn, requirements of observational astronomy drive technological progress. The LINC-NIRVANA camera for the world's largest single telescope, the Large Binocular Telescope in Arizona, was completed at MPIA after a decade of construction and shipped to the telescope.

Also in 2015, the new planet finder CARMENES saw first light with spectra taken simultaneously by its optical and infrared arms. CARMENES is the largest joint German-Spanish instrumentation project, with major contributions by MPIA. The instrument will begin its hunt for planets at Calar Alto Observatory in spring 2016.

But we're looking even further into the future: Late in 2015, ESO officially began the construction phase for the two first-light instruments MICADO and METIS for the future 39 meter European Extremely Large Telescope (E-ELT). MPIA is a part of both instrument teams.

Observation must be complemented by understanding – and sometimes, careful planning by that extra bit of luck! The work of our PhD Student Athanasia Tsatsi on a "rocket drive" for merging galaxies is an example for the former, the discovery of a quadruple quasar by Joseph Hennawi and colleagues for the latter. Both are featured in the science highlights section of this report.

No institute is an island, and throughout this report you will find examples of scientific collaboration and cooperation. Notably, 2015 saw the establishment of the Heidelberg Initiative for the Origins of Life (HIFOL), which brings together researchers in astrophysics, geosciences, macromolecular chemistry, statistical physics and life science in order to further our understanding of the origins of life in the universe.

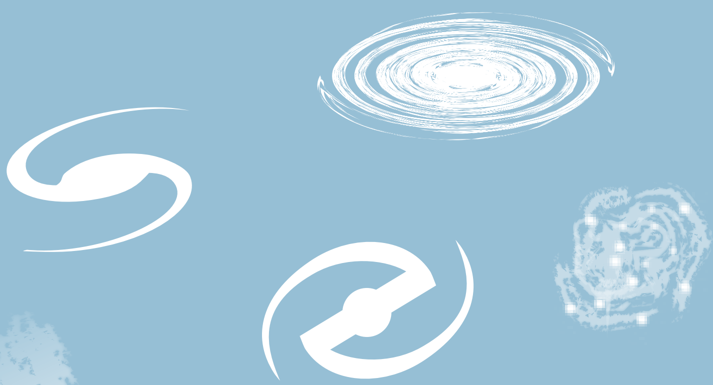
This annual report, intended both for our scientific colleagues and for the general public, is meant to provide in-depth information about the institute's activities. We present the year's scientific highlights as well as the current state of our instrumentation projects on the ground and in space, our activities in the area of outreach and academics as well as prizes and conferences.

Thomas Henning, Hans-Walter Rix

Heidelberg, June 2016

I. MPIA in a Nutshell

Our Fields of Research: Galaxies and Cosmology

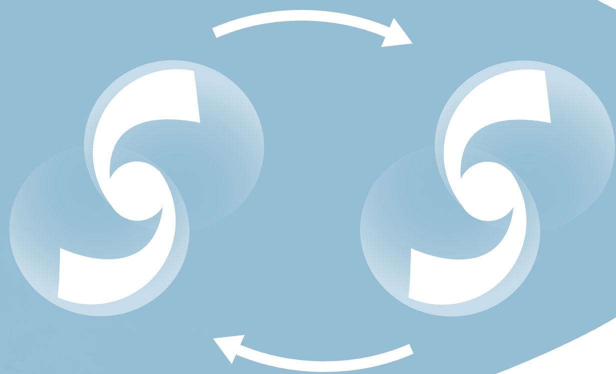


Galaxies come in many sizes and shapes. How do these differences arise? And what factors are responsible for how many stars a galaxy produces?

Our home galaxy, the ***Milky Way***, is a giant spiral galaxy with several hundred billion stars. In the Milky Way, we can study star and structure formation up close – and gather key data that can help us understand galaxy evolution.

Galaxies have ***supermassive black holes*** in their centers. How does the mass of such a black hole correlate with the total mass of a galaxy's stars – inspite of their totally different sizes? When and how do these black holes trigger some of the most luminous phenomena in the universe when matter falls into them, so-called quasars?

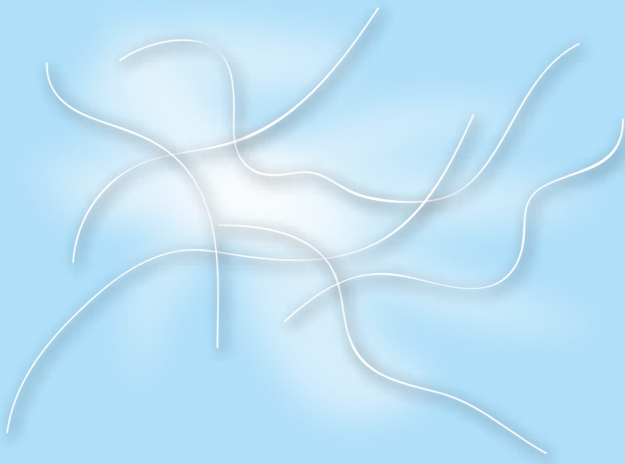
Galaxies grow as they merge with other galaxies, or swallow smaller galaxies. How do these growth processes work in detail? How do they influence the properties of different types of galaxies?



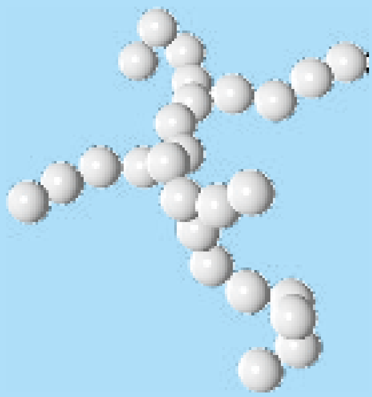
How are ***dark matter*** and hydrogen gas distributed on the largest ***cosmic scales***, across hundreds of millions of light-years? How is this distribution linked to the evolution of galaxies over the last billions of years? How did the complex structure of our universe arise from an almost perfectly smooth beginning?

Planet and Star Formation

Stars form when overdense regions in cold clouds of gas and dust collapse under their own gravity. Around a young star a swirling disk of matter condenses into ***planets***. How does this work in detail and how does this process produce the different kinds of planetary systems?



How do ***magnetic fields*** influence which clouds of the interstellar medium collapse to form stars? What is the role of turbulent motions within these clouds?

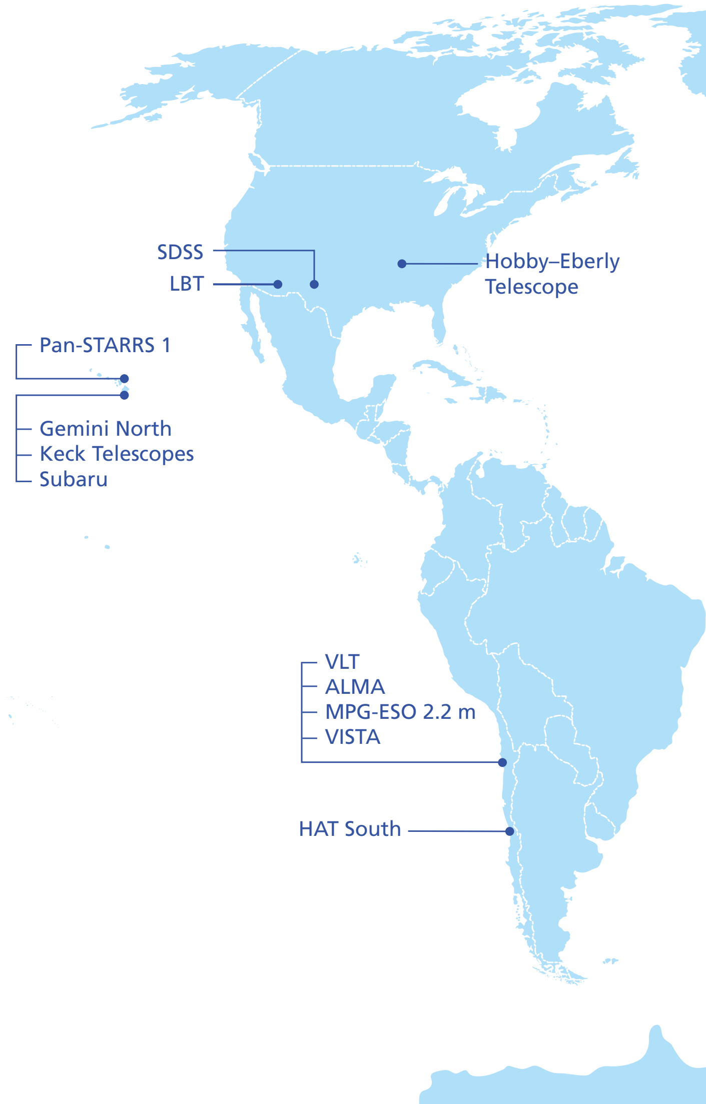


What are the ***stages of planet formation*** – from the first colliding ***grains of dust*** to objects thousands of kilometers across? What can laboratory experiments tell us about the properties of cosmic dust – and the ways to detect its properties?

Since 1995, astronomers have discovered more than 2000 ***exoplanets*** (planets orbiting stars other than the Sun). What can these widely different planetary systems tell us about planet formation?

MPIA Telescopes all over the World

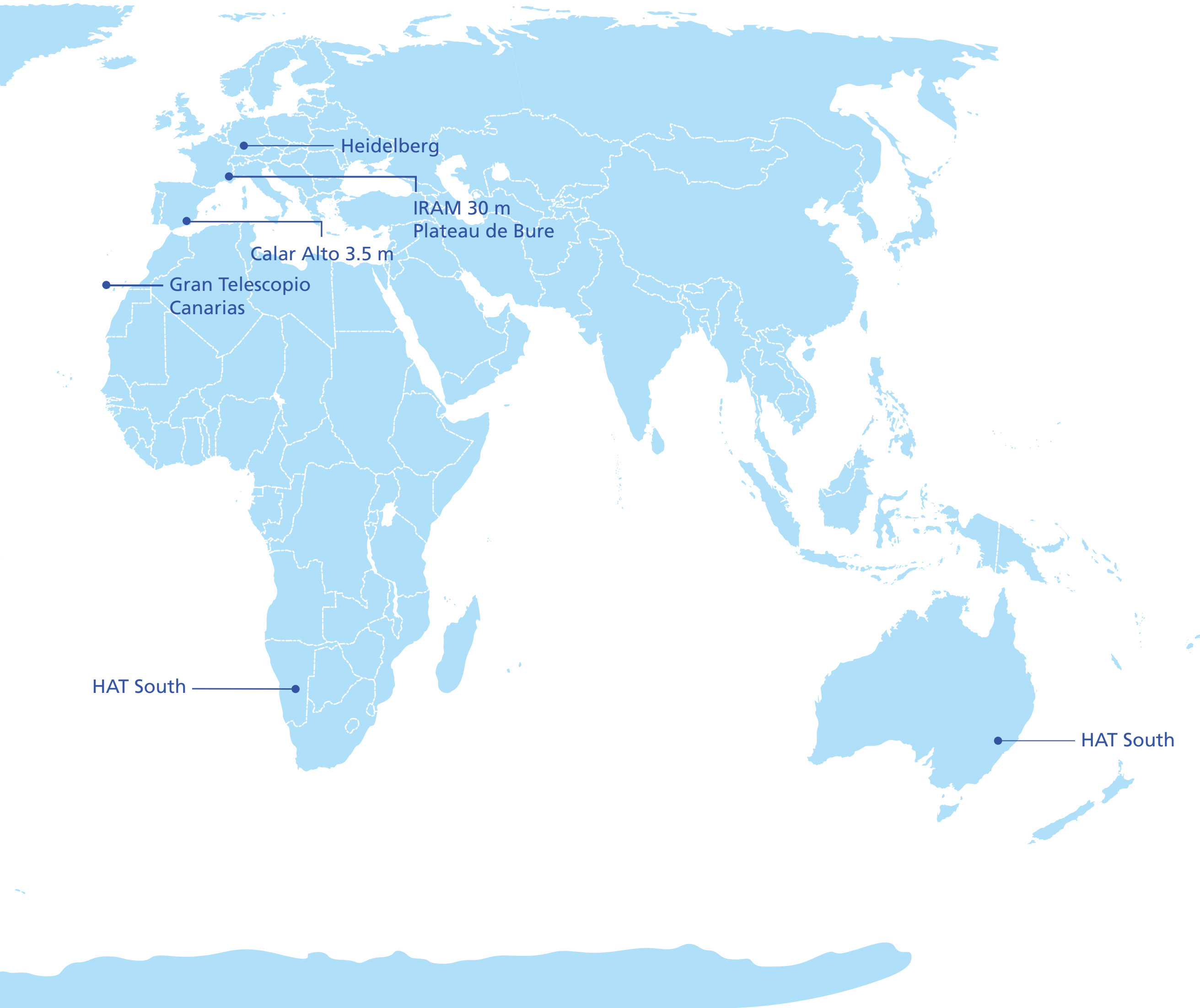
MPIA is part of the consortium operating the Large Binocular Telescope (LBT) on Mount Graham in Arizona. The LBT has two 8.4 meter mirrors on a single mount. This year, we shipped the double camera LINC-NIRVANA to the LBT site.



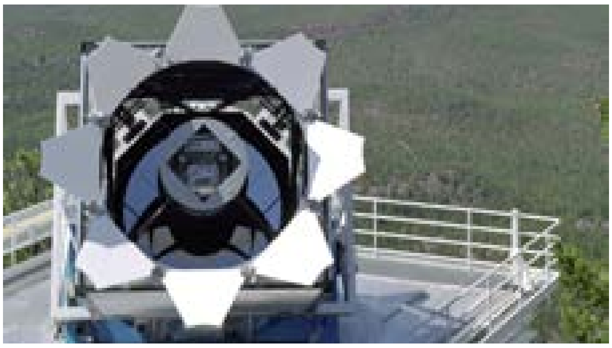
MPIA is involved in the construction of the instruments SPHERE, MATISSE, and GRAVITY for ESO's Very Large Telescope at Paranal observatory. Crucial components for GRAVITY were installed at Paranal in 2015.

MPIA researchers use the ALMA observatory at Chajnantor in the Atacama desert to study some of the coldest and some of the most distant objects in the universe. ALMA is an interferometer for observations in the millimeter and submillimeter wavelength range.

MPIA is part of the PS1 Science Consortium, which operated the Pan-STARRS1 telescope on Hawaii. By repeatedly taking wide-field images of numerous regions of the night sky, PS1 produced something akin to a movie of celestial goings-on.

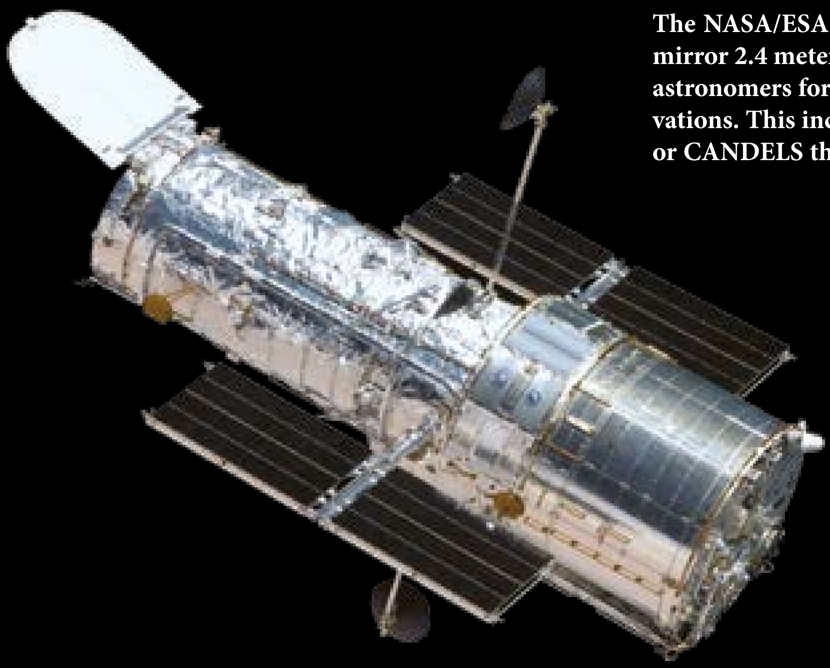


Calar Alto Observatory in Southern Spain was founded in the 1970s by MPIA, and is now operated as a joint German-Spanish research center. MPIA is involved in the construction of the instruments CARMENES and PANIC for Calar Alto telescopes.



MPIA is a member of the Sloan Digital Sky Survey (SDSS), a spectroscopic survey using a 2.5 meter telescope in New Mexico. The survey gathers high-quality spectra of a large number of astronomical objects.

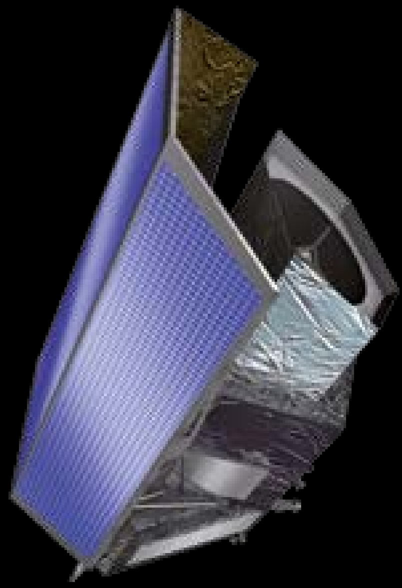
Space Telescopes



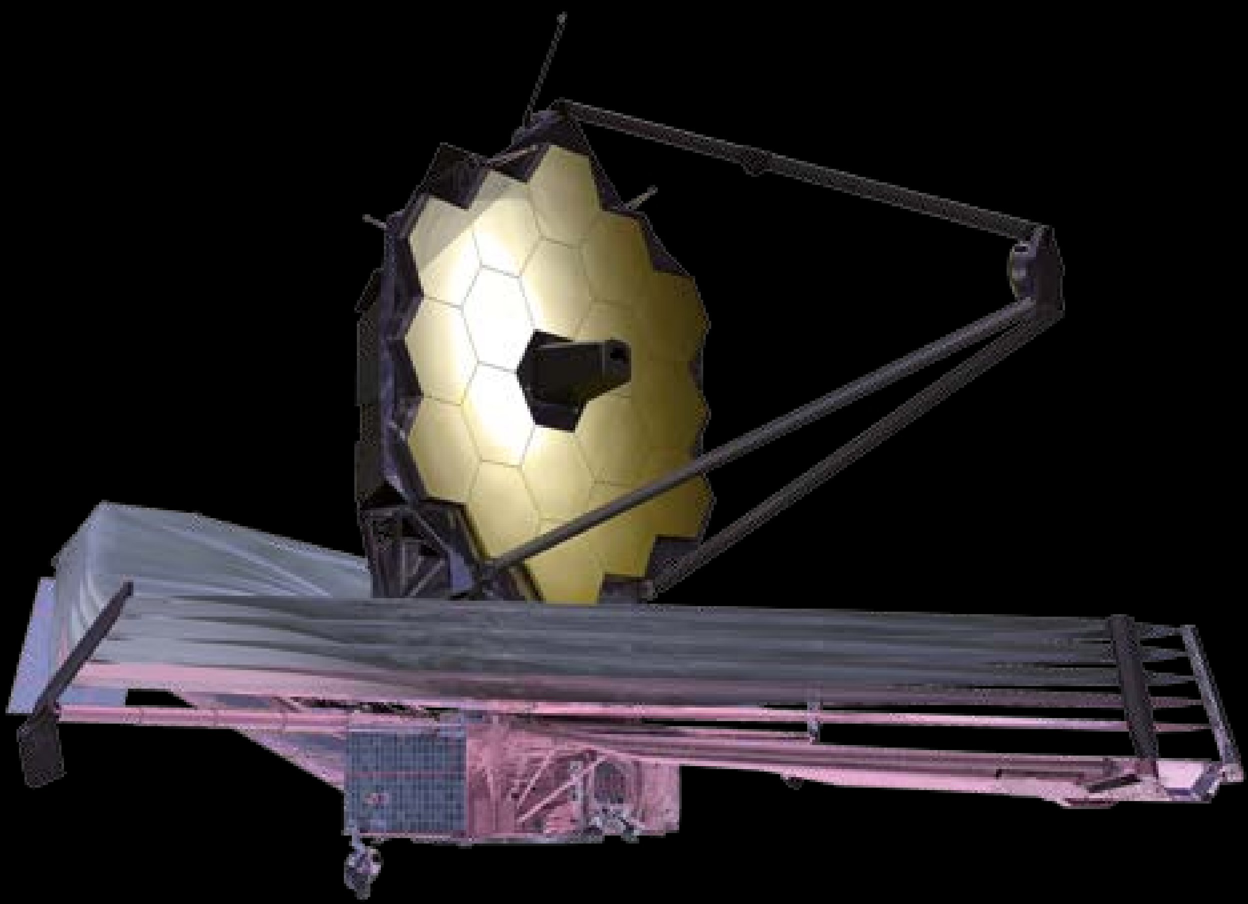
The NASA/ESA Hubble Space Telescope (with a main mirror 2.4 meters in diameter) has been used by MPIA astronomers for years for a variety of successful observations. This includes larger surveys such as COSMOS or CANDELS that involve MPIA researchers.

MPIA contributed to the construction of the ESA Infrared Observatory Herschel: We developed key components for the PACS instrument aboard the Herschel satellite, and were responsible for a number of observational programs undertaken with Herschel.

NASA's Spitzer Space Telescope is regularly in use for our researchers' observations. Using Spitzer, MPIA researchers have observed protostars inside clouds of dust, and detected active galactic nuclei from a time a mere billion years after the big bang.



For ESA's Euclid mission, which is slated for launch in 2020, MPIA scientist have developed calibration strategies and are contributing to the construction of the near-infrared spectrometer and photometer NISP. Euclid is set to answer fundamental questions about the nature of dark matter and dark energy.



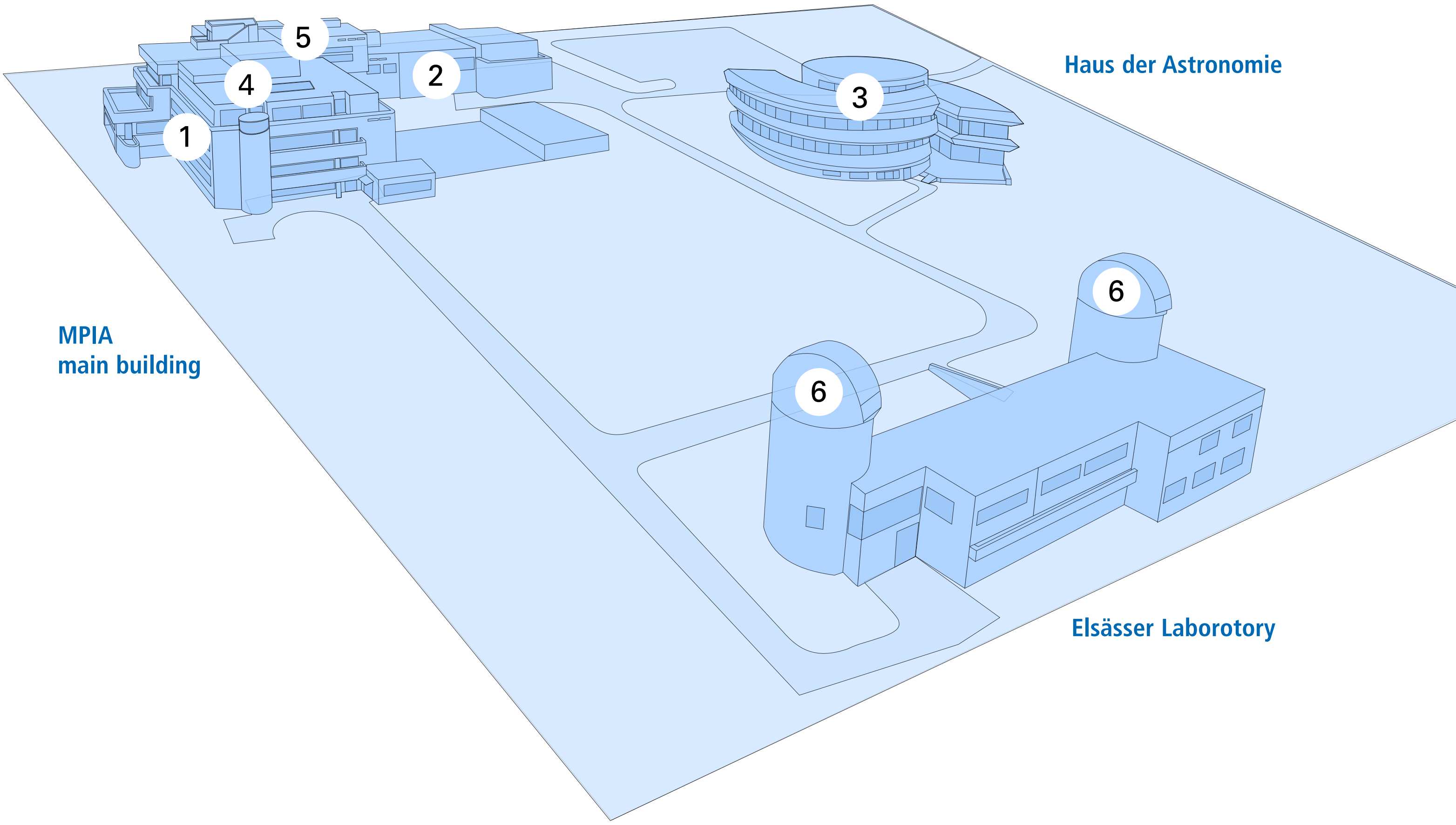
The James Webb Space Telescope (JWST, with a 6.5 meter mirror), the designated successor to the Hubble Space Telescope, is slated for launch in 2018. MPIA has contributed to two of the telescope's instruments: the mid-infrared instrument MIRI and the near-infrared spectrograph NIRSPEC.

Infrastructure

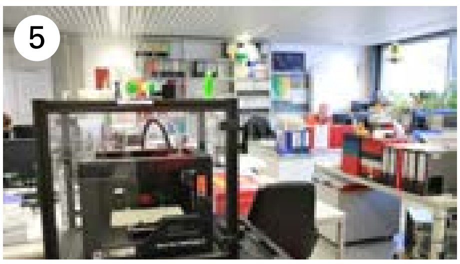
Specialized library offering nearly 9000 books and access to about 100 astronomical journals.

Experimental and assembly facilities including clean rooms for instrumentation.

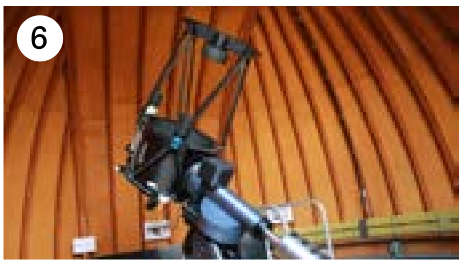
Two lecture halls and seven seminar/workshop rooms, here: HdA auditorium.



IT infrastructure capable of handling large amounts of data from observations and simulations.



Workshops and construction facilities, here: construction department.



50 and 70 cm telescopes for testing and training purposes (here: 50 cm MPIA/HdA telescope).

MPIA in numbers

310

employees
keep the institute running. 209 of those are scientists, including 67 junior scientists or long-term visitors, and 59 PhD students.

91.8

million CPU hours
on computer clusters at MPIA (THEO), in Jülich (JUQUEEN) and Garching (HYDRA) were used by MPIA researchers to simulate planet and star formation as well as galaxy evolution.

128

observing nights
were allocated to the LEGA-C galaxy survey, which is led by MPIA, making it the largest extragalactic survey at the Very Large Telescope to date.

79760

CPUs
are humming along busily inside the Hydra supercomputer, which is used by MPIA astronomers for sophisticated simulations of the formation of planets and galaxies.

3454998

stars
have been monitored by the HATSouth collaboration, which includes MPIA, until the end of 2015 in a search for transiting exoplanets.

5

independent research groups
are part of our institute: two Emmy Noether groups (DFG), two Max Planck Research Groups and one group funded by the Alexander von Humboldt Foundation.

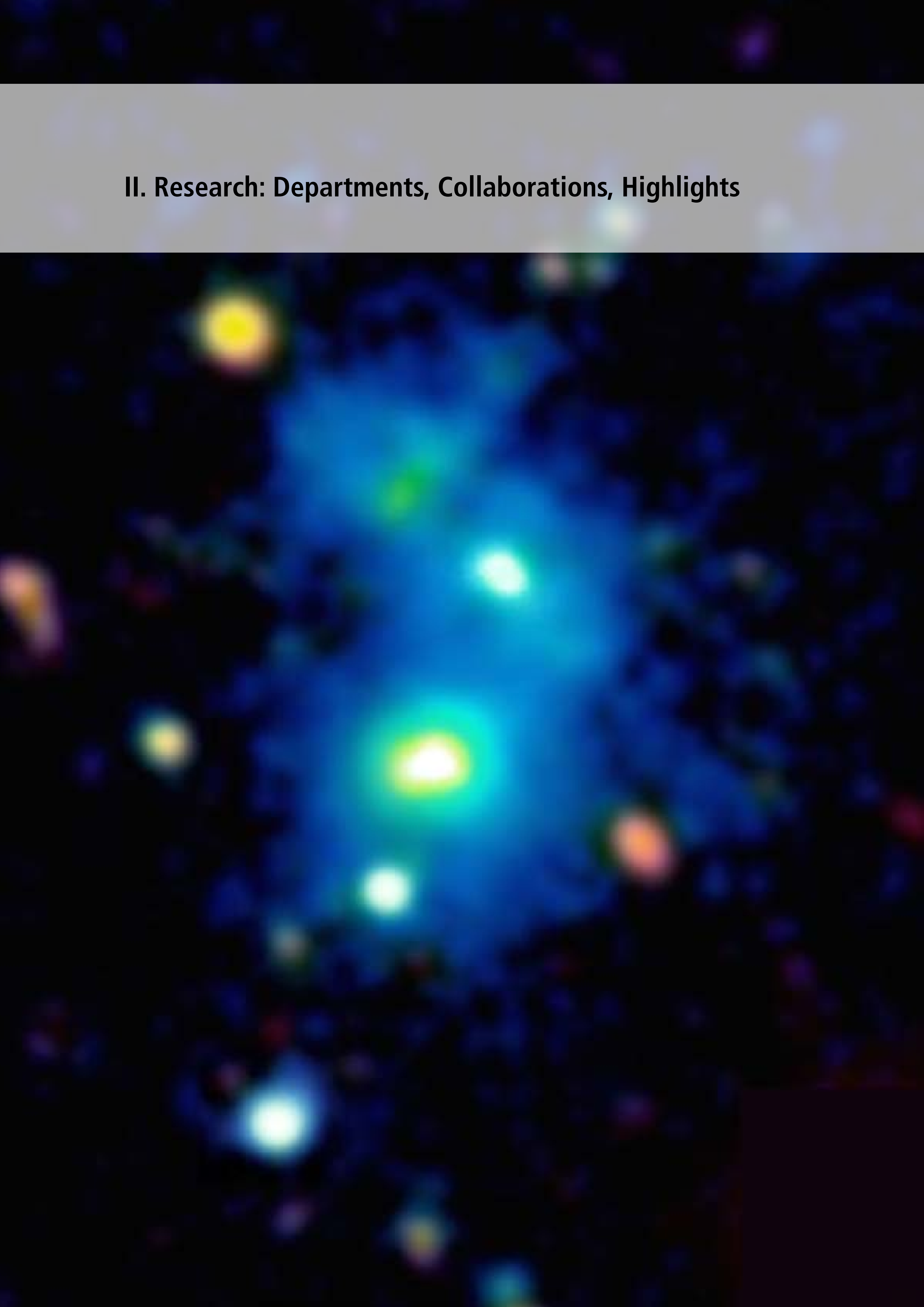
20

years ago
on November 17, 1995, ESA launched the Infrared Space Observatory (ISO), resulting in more than 1500 publications. MPIA led the development of one of ISO's instruments.

133

motors
and 40 control systems, linked by 966 cables, and more than 250 lenses and mirrors can be found in the camera LINC-NIRVANA built at MPIA.

II. Research: Departments, Collaborations, Highlights



II.1 Departments

Planet and Star Formation – The PSF Department

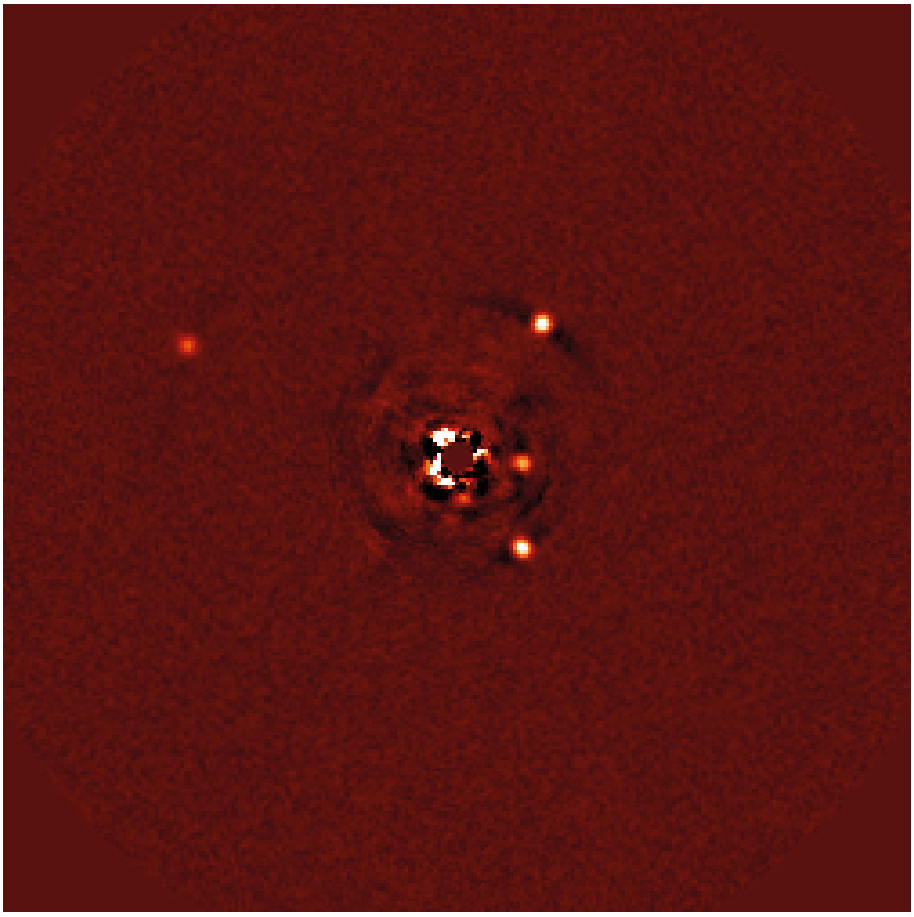
The origin of stars and their planets

Star formation is a fundamental process in the universe. Stars shape the structure of entire galaxies, create the chemical elements they contain, and provide the necessary conditions for the origins of life.

Stars are born in the dense parts of molecular clouds – giant clouds of cold gas, with masses thousands of times that of the sun. As parts of these clouds collapse under their own gravity, some compact regions become sufficiently hot and dense for nuclear fusion to set in: a star is born. The formation of planetary systems is a natural by-product of low-mass star formation. It takes place in protoplanetary discs of gas and dust which surround the nascent stars. Our own Solar System came into being in this manner, 4.5 billion years ago.

Scientists in the PSF Department attack a variety of open questions related to the process of star and planet formation, combining multi-wavelength observations with large-scale numerical simulations and dedicated laboratory experiments.

Fig. II.1.1: Direct image of the planetary system around the star HR 8799. On the left, the planet HR 8799b, on the right-handside, top to bottom, the planets c, e, and d. Most of the star's light has been suppressed with the help of a mask; some traces remain in the central region of the image. The overwhelming majority of exoplanets has only been detected indirectly; this rare image of a whole planetary system was taken using the Large Binocular Telescope on Mount Graham in Arizona, by an international team that included MPIA astronomers.



Credit: A.-L. Maire / LBT

Observing the formation of stars and planets first-hand

Observational techniques in astronomy have made considerable progress over the past decade. The observing programs of the PSF Department cover a wide range of wavelengths, from the optical to the infrared and radio domain, with a special emphasis on high spatial and spectral resolution.

PSF researchers use a wide range of telescopes and facilities for their work, including the Hubble Space Telescope and ground-based facilities such as ESO's Very Large Telescope, the Large Binocular Telescope in Arizona, the IRAM Plateau de Bure Interferometer (whose name was recently changed to NOEMA), the Atacama Large Millimeter/Submillimeter Array ALMA, and the Karl G. Jansky Very Large Array. Observations with these telescopes provide insight into the physics and chemistry of the interstellar medium and the earliest stages of star and planet formation.

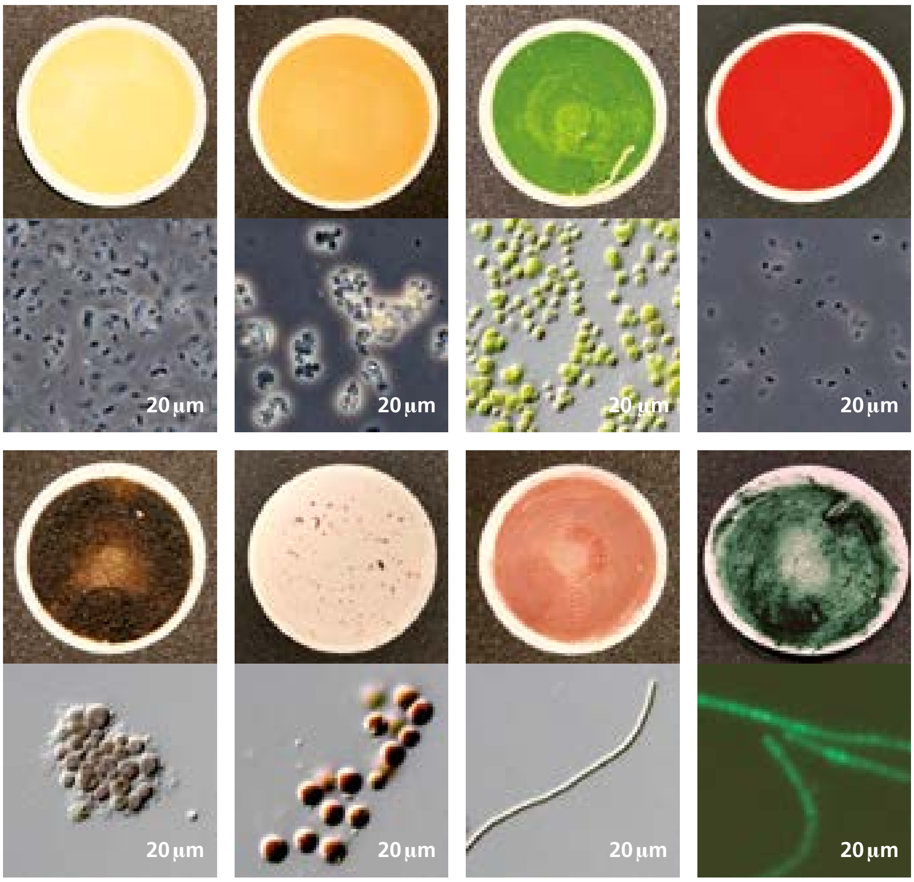
High spatial resolution – the ability to discern minute details – is the key to many observations that help advance our understanding of star and planet formation. The spatial scales relevant to molecular cloud fragmentation and planet formation in protoplanetary discs are comparatively small.

The PSF Department is involved in several programs that rise to this considerable challenge: Adaptive Optics is a technique to compensate for the distortions of astronomical images by earth's atmosphere, allowing large telescopes to reach particularly high resolution. Interferometry lets several telescopes act together, achieving the same resolution as a single, much larger telescope. Our observations include infrared interferometry with large telescopes and long baselines, and the use of (sub)millimeter and radio interferometers.

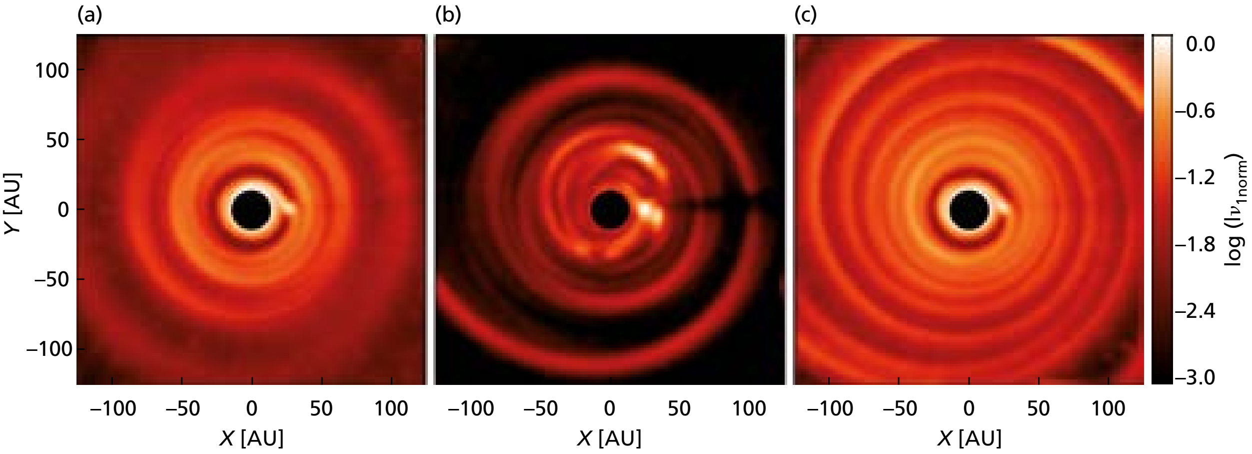
Understanding the origin of stars

One of the central questions of star formation concerns what astronomers call the initial mass function: How probable is it that a molecular cloud will form low-mass stars like the sun or high-mass stars like some of the objects in the Orion star-forming cloud? More specifically:

Fig. II.1.2: Astronomers and biologists led by MPIA graduate student Siddharth Hegde measured the "chemical fingerprints" of 137 different species of microorganisms. Eight of the samples are shown in this image. This could help future astronomers to recognize life on the surface of exoplanets (planets outside our solar system). Some of the microorganisms hail from the most extreme environments on earth; taken together, the samples should allow for a (cautious) estimate of the diversity of biological colors on planets other than earth.



Credit: S. Hegde et al. / MPIA



Credit: A. Pohl et al. / MPIA

Fig. II.1.3: The study of protoplanetary discs as the birthplaces of planets is an important goal of the PSF department. Simulations support the observers by showing them what to expect in high-resolution images. These images by MPIA PhD student Adriana Pohl and colleagues answer the question of how a protoplanetary disc would look in near-infrared light. In particular, the study asked how well spiral arm structures, produced by the interaction of newly formed planets and the remainders of the disc, would show up in high-contrast images. The study showed that the contrast of these spiral arms is well above the detection limit for today's telescopes, in other words: Astronomers have a good chance of detecting certain embedded planets by the spiral traces they leave. Shown in these three images is the simulated image of a disc in scattered (polarized) light (H band, λ = 1.65 µm). The disc material has 20% of the mass of the central star. Just as in real observations using a coronagraph, the central region containing the star has been blacked out.

How does the probability for the formation of a star of a given mass depend on its mass?

This leads to the more general question of which properties of the cloud determine the outcome of the star formation process. Open key questions concern the roles of magnetic fields and turbulent flows in controlling the onset of star formation – with direct consequences for the initial mass function and the duration of the star formation process.

In general, collapsing clouds will fragment to form binary stars or multiple systems in one go. On the high end of the mass scale, the formation of very massive stars takes place in clusters, which makes for exceedingly complex star formation environments. The rapid evolution of massive protostars and the associated energetic phenomena provide an enormous challenge in identifying the formation path of massive stars.

How do molecular clouds form from clouds of atomic hydrogen? What regulates the onset of star formation and the star formation efficiency? What triggers the fragmentation of molecular clouds? What is the role of filamentary structures in the star formation process? What is the mass limit for the highest mass stars and how long does it take to form a stellar cluster? These are just some of the questions under investigation by scientists of the PSF Department.

A peek behind the curtain

The earliest phases of star formation are obscured by enormous amounts of dust and gas and can only be detected by sensitive far-infrared and (sub)millimeter observations. At later evolutionary stages, the objects emit what amounts to a thermal glow, becoming visible at near- and mid-infrared wavelengths. Even later, the nascent stars disperse their cocoons of dust and gas, and become visible at optical wavelengths.

Due to the basic laws of fluid dynamics – namely the conservation of angular momentum – the accretion of matter onto the central protostar happens predominantly via a circumstellar disc. Discs around the low-mass T Tauri stars and the intermediate-mass Herbig Ae/Be stars are natural birthplaces for planetary systems.

While the protostar still accretes matter from the surrounding disc, some of the matter is ejected perpendicular to the disc in the form of molecular outflows, or as collimated ionized high-velocity jets, or both. Direct observations of such discs and the associated accretion and outflow phenomena can provide insight both in the formation of our own solar system and into the diversity of planetary systems in general.

Observing from the ground and from space

One of the goals of the PSF Department is to understand the earliest phases of stars both in the low-mass regime relevant to the formation of planetary systems and the high-mass regime important for galaxy evolution. Using space observatories such as the Hubble Space Telescope as well as ground-based infrared, (sub)millimeter, and radio telescopes, scientists of the PSF Department detect and characterize star formation and study the subsequent evolution of young stars – from the sub-stellar mass regime to the stars of highest known stellar masses. To this end, scientists of the department have established large observing programs at internationally competitive astronomical facilities.

Presently, the department is strongly involved in the preparation of projects in the field of star formation and protoplanetary discs for the James Webb Space Telescope, JWST, the designated successor of the Hubble Space Telescope scheduled for launch in 2018. As a member of the consortium for the JWST mid-infrared instrument MIRI, we have access to guaranteed time for this instrument.

With another, newly-begun instrumentation project, we are looking towards the largest ground-based telescope yet: The PSF Department will provide the camera system and part of the adaptive optics system for METIS, the mid-infrared instrument for the European Extremely Large Telescope, a 39 meter telescope under construction in Chile.

Planet formation and the search for exoplanets

With the detection of the first extrasolar planets around sun-like stars in 1995, the study of planet formation in protoplanetary discs entered a new phase. Suddenly, instead of a single example for a planetary system – our own solar system – astronomers were able to examine, compare and contrast hundreds, more recently even thousands of such systems.

PSF astronomers are heavily involved in observing programs to search for extrasolar planets through direct imaging, the transit technique, and radial velocity observations of objects discovered with the Kepler space telescope. The HATSouth transit network with its three stations in Australia, Chile, and Namibia is presently returning a flood of new discoveries, and the K2 mission extension of the Kepler observatory is allowing us to detect Super-Earths around relatively bright stars.

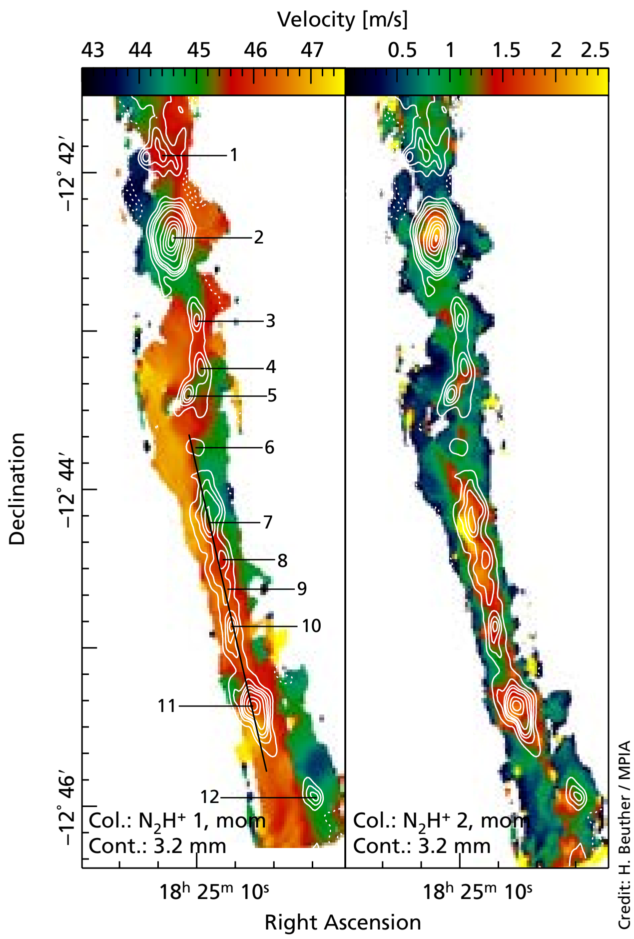
The consortium of the SPHERE planet finder instrument, where MPIA is the Co-PI institute, is presently embarking on the largest direct imaging survey for exoplanets at a 10 meter class telescope. In addition, this instrument is revealing unprecedented details of planet-forming discs, from gaps to rings and spiral arms, which point to complex dynamics and planet-disc interactions. The Department is a core member of the LBT LEECH planet search program and has initiated a large survey for young planets with the adaptive-optics instrument NACO.

In addition, two instruments for ESO's Very Large Telescope Interferometer, GRAVITY and MATISSE, with strong technical and scientific involvement of the PSF Department, are in their final stage of construction. These instruments will allow us to study the cradles of planets – the protoplanetary discs – with unprecedented spatial resolution, complementing our observations with the IRAM and ALMA (sub)millimeter interferometers.

Star and planet formation in a computer

Deep understanding of planet and star formation can only avise when astronomical observations make the connection with fundamental physical processes. The theory program of the PSF Department focuses on large-scale numerical simulations of protoplanetary discs, including the interplay between radiation, dynamics, chemistry, and the evolution of dust grains, in order to link observations with an in-depth understanding of the physical and chemical processes during planet formation. Additional topics of our theory group are the formation of massive stars and star formation on galactic scales.

Fig. II.1.4: The collapse of molecular clouds to form stars is a process of sequential fragmentation: Parts of the clouds contract into long filaments, and segments of these filaments collapse to form stars. Henrik Beuther and colleagues studied the filament IRDC 18223 in the constellation Scutum with the IRAM Plateau de Bure Interferometer, achieving sufficiently high resolution to show 12 distinct cores. Both images use data taken in a narrow band corresponding to the line $N_2H^+(1–0)$ of the ion Diazenylium (N_2H^+). The left-hand image is a first momentum map (a measure for the average velocity of matter at each location towards or away from the observer), the right-hand image is a second momentum map (a measure of how chaotically, at many different speeds, matter in that region is moving). The contours show infrared intensity at a wavelength of 24 µm, observed with NASA's Spitzer Space Telescope.



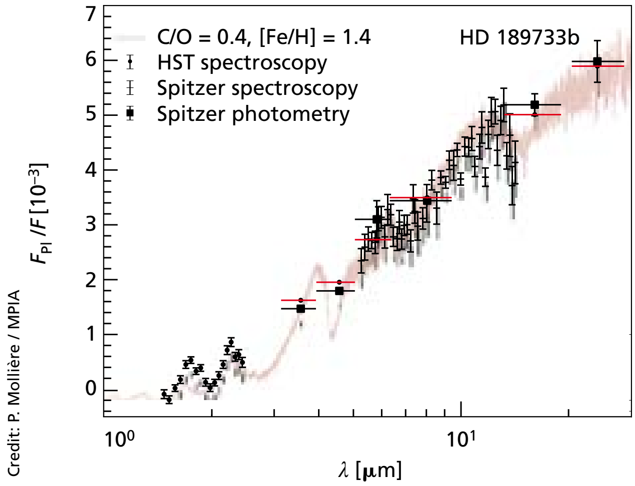


Fig. II.1.5: Information astronomers can glean about the atmosphere of an exoplanet – and one day even about the presence of living organisms on one! – is contained in the exoplanet's spectrum. In order to understand exoplanet spectra, astronomers from the PSF group create radiative transfer codes that allow for the simulation of spectra, given a hypothetical planet's properties. The image shows a simulated spectrum for the exoplanet HD189733b, based on work by MPIA PhD student Paul Mollière and colleagues, in comparison with actual data points taken for that planet with various telescopes during planetary eclipses.

Fig. II.1.6: How do clouds of atomic hydrogen (HI) transform into molecular clouds (H_2), creating a suitable environment for new stars that form? That was the main research question behind the HI/OH/Recombination line survey of the Milky Way (THOR) by Henrik Beuther, Simon Bihr and colleagues. THOR uses the NRAO's Very Large Array (VLA) in New Mexico, combined with data from the Herschel Space Telescope and the airborne telescope SOFIA to survey part of the Northern galactic plane. THOR enables the researchers to study the dynamics of the interstellar medium and cloud formation from the atomic to the molecular phase, and to directly compare the results to theoretical models.

The top left image shows emissions in the 21 cm line, indicating the presence of atomic hydrogen HI. The top right image is a reconstruction of the abundance of atomic hydrogen along the various lines of sight (column density), using the standard assumption that we can see all the hydrogen atoms (optically thin medium). However, the systematic study of sources that are behind the HI clouds shows this assumption to be wrong: Some of the hydrogen atoms are obscured by others; at least some parts of the cloud are optically thick. The background sources also determine corrections which can be used to account for the obscured portion of the hydrogen. The image in the center shows a reconstruction of line-of-sight abundances (column density) that is a key part of the THOR survey, based on these corrections. For comparison, the bottom image shows the abundance of molecular hydrogen, obtained with the HiGAL survey, using the Herschel Space Telescope.

The theory group of the PSF Department is developing multi-dimensional radiative transfer codes, which simulate the way radiation travels through molecular clouds and their cores, protoplanetary discs, and the atmospheres of planets. These codes can be used for interpreting cloud and disc images and spectra, and they also allow researchers to take magneto-hydrodynamical simulations and reconstruct how the object in question would look to observers. Another important application is to models of planetary atmospheres, where these codes allow for the calculation of transmission and emission spectra as they would be measured by telescopes on the ground or in space.

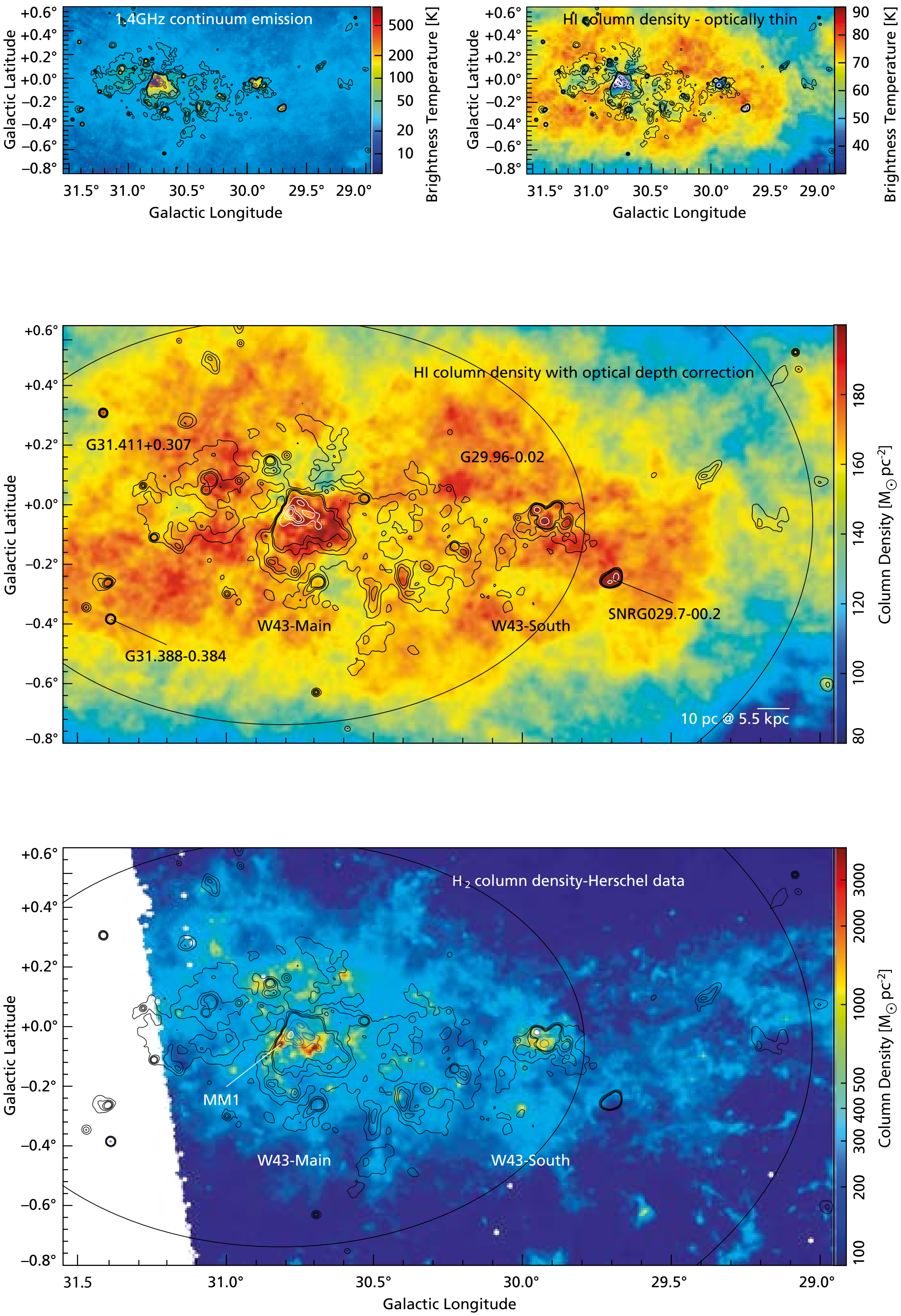
A versatile program has been launched to link planet formation with the properties of planets and their atmospheres in preparation for the analysis of the planetary spectra that will be obtained with JWST.

Linking the cosmos and the laboratory

Understanding the physics of the interstellar medium and protoplanetary discs requires in-depth knowledge of microphysical processes in the respective dust and gas populations, and the same goes for the interpretation of observational signatures in the spectra of these objects. This, in turn, can only be achieved by dedicated laboratory studies.

Such a laboratory astrophysics facility is part of the PSF Department, and is located at the Institute for Solid-State Physics at the University of Jena. The group investigates the spectroscopic properties of nano- and micron-sized solid particles as well as of complex molecules, especially polycylic aromatic hydrocarbons (PAHs) as an important class of organic molecules found in astronomical settings in the gas phase. The scientists of the laboratory astrophysics group also study the formation pathways of small particles and their interaction with molecular ice layers.

Linking the cosmos with laboratories of another kind altogether, namely those of our colleagues in macromolecular chemistry, biogeochemistry and the life sciences, is the aim of another initiative: the Heidelberg Origins of Life Initiative (HIFOL) recently established by the PSF Department in collaboration with other scientific institutes in Heidelberg. The goal of this initiative is to understand the basic physical, chemical, and biological processes involved in the origins of life, and to connect them with the astrophysical conditions important for the emergence of life.



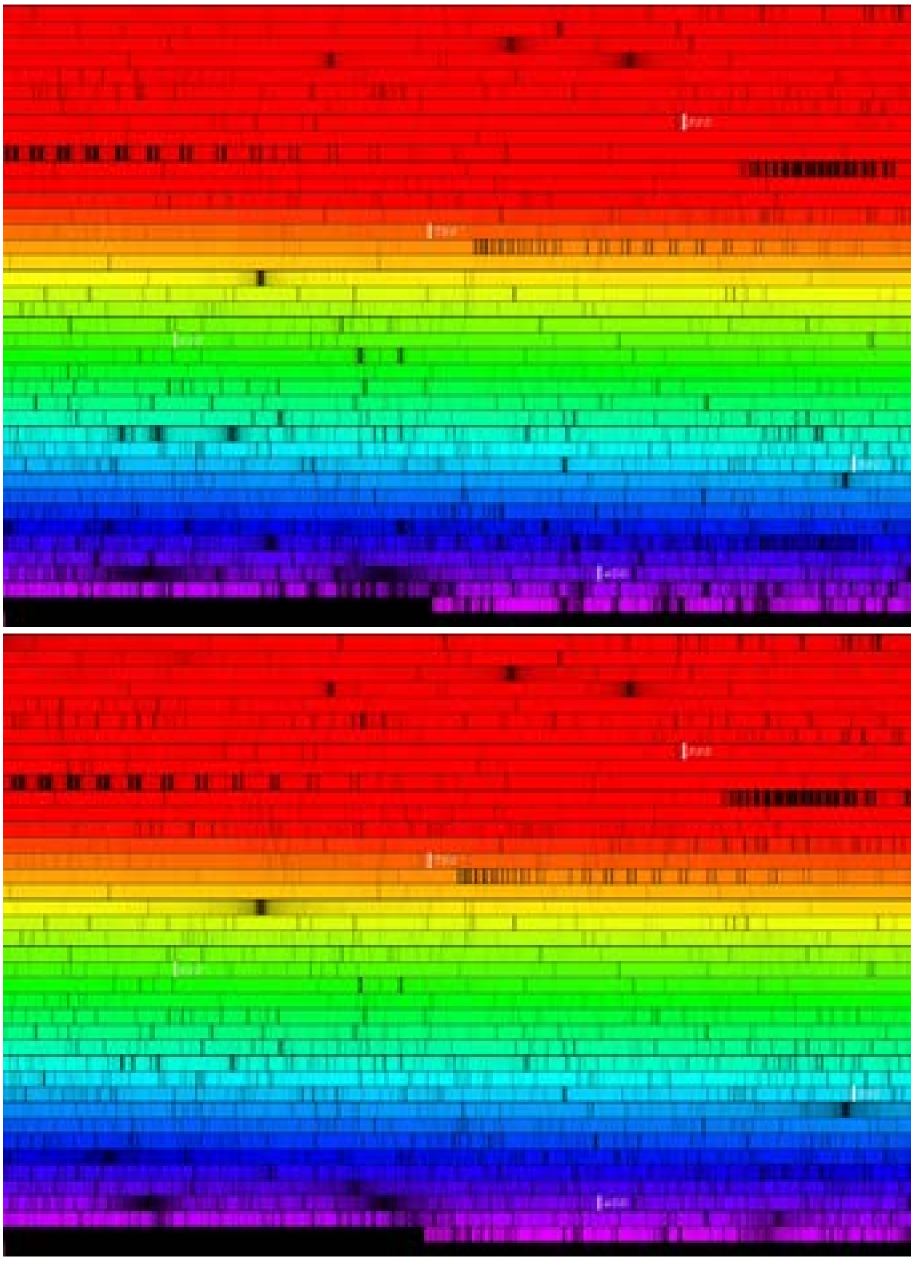
Credit: S. Bihr / MPIA

II.2 Departments

Galaxies in their Cosmological Context – The GC Department

How the universe became interesting

Shortly after the Big Bang, the universe was almost per-perfectly homogeneous and simple, that is: both elegant and boring. In stark contrast, the present cosmos exhibits a rich hierarchy of structures spanning a wide range of physical scales: from the filamentary distribution of galaxies known as the cosmic web down to galaxies, clusters of stars and individual stars with their planets. It is this structure that makes our universe interesting, yet also complex. The formation of all the large-scale structure appears to be driven by gravitational instabilities – by the ubiquitous influence of gravity, of matter pulling itself together, large structures collapsing and contracting. On the scales of galaxies, a plethora of other physical effects come into play.

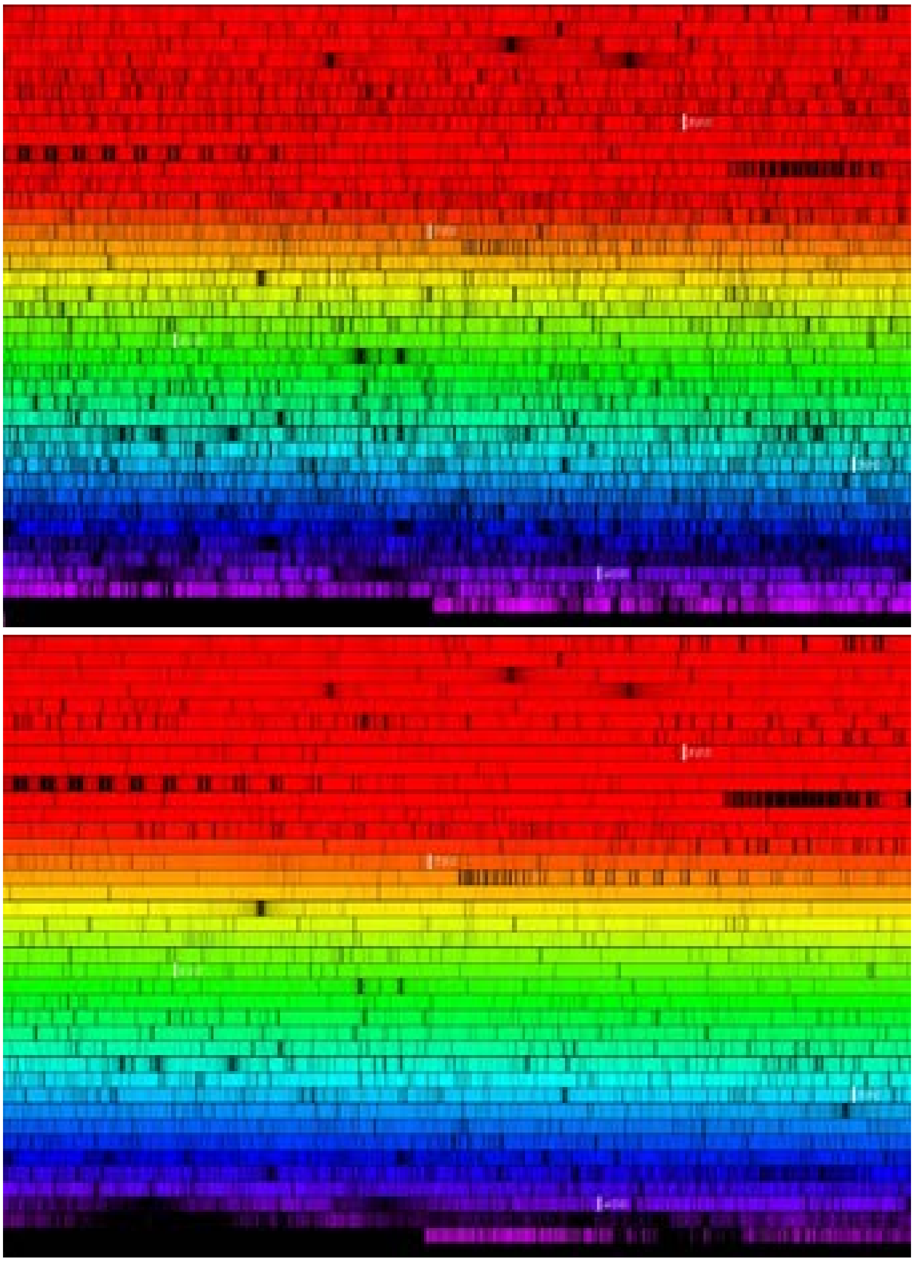


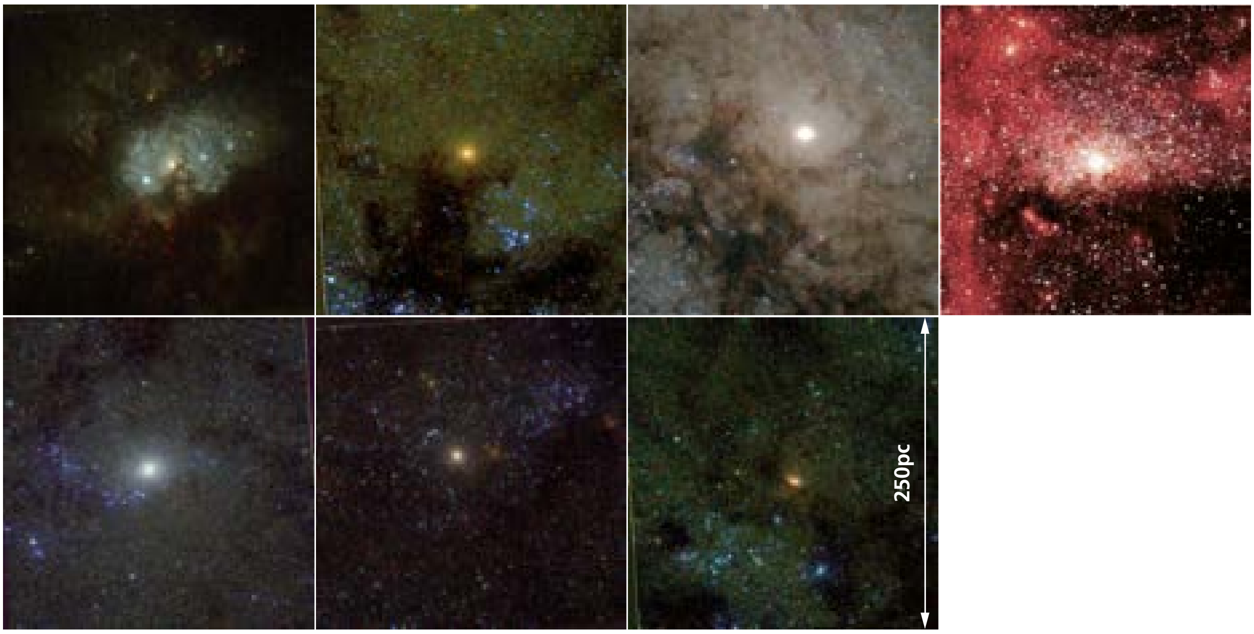
Credit: M. Bergemann / MPIA / NARVAL@TBL

To understand quantitatively how such structure arose in an expanding universe, however, current models need an unusual extra ingredient: Dark matter, which possesses mass, and hence gravitational attraction, but does not interact at all with electromagnetic radiation. The specific nature of this dark matter has yet to be understood. To make things worse, the expansion of the universe is observed to be accelerating, which forces astronomers to postulate an even more exotic ingredient: dark energy, which acts as a form of repulsive force.

There are places throughout the Universe where dense dark matter concentrations arise from gravitational instability and where consequently normal matter is distilled, so that stars form from dense gas clouds: these places we call galaxies, and they arguably form the centerpiece (at least in physical scale) of the overall hierarchical structure of the cosmos.

Fig. II.2.1: High-resolution spectra for several stars: μ Cassiopeiae (top left), Procyon (bottom left), μ Leonis (top right) and the sun (right bottom). These spectra were taken with the NARVAL very high-resolution spectrograph installed at the Télescope Bernard Lyot, Observatoire Midi-Pyrénées as part of a large programme of ground-based observations to complement the measurements of the astrometry mission Gaia. The detailed analysis of such spectra, of which several hundred thousand are taken throughout the galaxy, are the key to understanding the origin of the chemical elements and the formation history of the Milky Way.





Credit: Carson et al. 2015 (HST), Stolovy et al. 2006 (Spitzer)

Fig. II.2.2: Family portrait of nuclear star clusters: nuclear star clusters in six nearby galaxies from a recent WFC3/HST survey in comparison with the Milky Way nuclear star cluster observed with the Spitzer Space Telescope (top right). Nuclear clusters are star clusters in the central regions of a galaxy, surrounding the galaxy's central black hole. When material enters the innermost regions of the galaxy, part of it is accreted by the black hole, while some the rest forms a new generation of stars in the nuclear cluster. Researchers such as Nadine Neumayer and her group reconstruct the stellar generations of nuclear clusters in order to reconstruct the accretion history of central black holes.

Order in the realm of galaxies

Galaxies exist over a vast range of physical scales: they vary by many orders of magnitude in their stellar masses, in their rate of producing new stars, the mass of the black holes at their very centers, and their sheer physical size.

Yet, as Edwin Hubble realized already 80 years ago, these "island universes" are not as varied in their appearance and structure as the laws of physics would allow. Observations, particularly those made over the last 15 years, have confirmed this in ever greater detail: Only a small fraction of the possible combinations of galaxies' characteristic quantities (stellar masses and ages, size, central black hole and more) are actually realized in the universe. Virtually all physical properties strongly correlate with all other properties: Massive galaxies are large; massive galaxies contain virtually no young stars; the central black hole mass is proportional to the galaxy's spherical distribution of stars ("bulge") inspite of the vast difference in size between the two structures (a factor of roughly ten millions). While spiral galaxies are the most common kind of galaxy, none of the most massive galactic specimens are of this type.

All this means that the "realm of galaxies", to use Hubble's expression, exhibits a high degree of order. How did this order develop from the random mass fluctuations existing after the Big Bang? That is the fundamental question of galaxy formation and a central issue of cosmology.

There are three broad lines of explanation for the limited variety in the zoo of galaxies. Either, observed galaxies represent the only configurations that are dynamically stable over long times. If each galaxy spends a long time in a stable state, and a very brief time only in a transitional state, then with astronomical observations at an essentially random moment in cosmic time (namely now), we are unlikely to catch more than a few (if any) galaxies in transition.

Alternatively, it is possible that the initial conditions of our universe only permitted the formation of the galaxies we see. Finally, it is conceivable that galaxy formation is a highly self-regulating process that, regardless of initial conditions, can only result in a very limited set of outcomes – namely those combinations of properties that we actually observe.

Current research suggests that all three aspects may play a role.

Gas: the fuel for making galaxies

Stars, the most manifest, ubiquitous and defining constituents of galaxies, are made from interstellar gas, in particular from molecular gas – gas whose atoms are sufficiently cool to have bonded into molecules, notably hydrogen molecules H_2. But most of the gas in the universe is not part of any galaxy. Throughout the history of the universe, the lion's share of gas has always resided in between galaxies, forming the intergalactic medium.

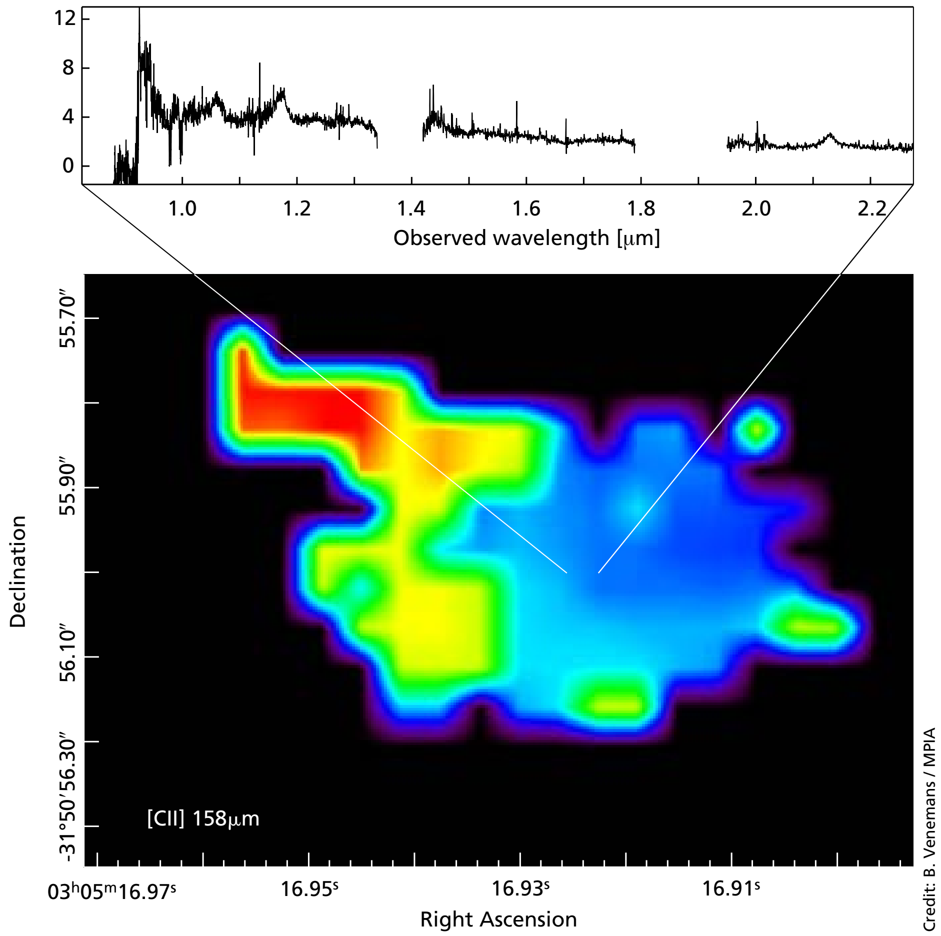


Fig. II.2.3: Velocity map derived from the spectral emission line [CII] at 158 micron in a quasar host galaxy at $z = 6.61$, when the Universe was ~850 Myr old. These ALMA data show that the line emission is coming from a ~3 kpc region that is possibly rotating and indicates the presence of an outflow of matter. With an estimated star formation rate of ~1000 solar masses per year, this galaxy is one of the fastest growing galaxies in the early Universe. Intriguingly, at optical and near-infrared wavelengths the galaxy is invisible as the emission of this system is dominated by the radiation coming from the immediate surrounding of the active black hole in the centre (inset). Thus, the observation is an impressive demonstration of the power of ALMA to characterize extreme galaxies of this kind.

In order to understand galaxy formation, it is crucial to understand the ways in which gas cools and condenses at the centers of gravitational potential wells that are due to the presence of dark matter, gets transformed into molecular gas and finally forms stars. Understanding the processes that suppress or at least hinder star formation is just as important: How does gas get re-heated and possibly ejected from galaxies, either by the intense radiation of luminous young stars, by supernova explosions, or by the presence of an active central black hole?

The galactic and circumgalactic gas cycle is far from understood. In order to further our understanding, we need to find ways of studying all the different varieties of gas: dense molecular gas, neutral (atomic), and ionized gas. This requires a wide range of techniques, from sub-millimeter observations of molecular lines to UV absorption lines caused by hot gas. Facilities such as ALMA, the IRAM Plateau-de-Bure Interferometer, and large optical telescopes to study quasar absorption lines are crucial tools for this research, which is a more recent focus of research at MPIA.

Asking the right questions

The fundamental questions raised here inform numerous projects currently undertaken by researchers in the GC department. As always, the key to success lies in transforming fundamental into specific questions, which can be addressed using current tools and methods.

A number of these questions concern the broader aspects of galaxy formation: What is the state of the intergalactic medium – the extremely rarefied gas in the space between galaxies, where most of the atoms in the universe reside? How did gas get from the cosmic web into galaxies, there to be processed into new stars? In turn, how does it get expelled from galaxies? And when and where does gas get converted from atomic to molecular, in order to be ready to form stars? Or, to bring up a more general question about the relationship between galaxies and dark matter's cosmic web: Which kinds of galaxies reside in dark matter halos of different size?

The process of star formation on the scale of galaxies must be the key to understanding why galaxies look the way they do. When, how and how efficiently did gas in galaxies get converted into stars? The questions of whom, can be addressed by looking at distant galaxies, which we see at an earlier epoch – because the speed of light is not infinite. The how can be addressed by mapping the gas (the fuel for star formation) and the star formation itself in great detail in closer galaxies.

Another area of particular interest to MPIA concerns the central black holes of galaxies: Why is it possible to predict the properties of the central black hole from a galaxy's overall properties? And how did the central black holes in galaxies form and grow in the first place?

Most galaxies are so far away that we cannot study their stars – their central and defining ingredients – individually. Yet, the chemical composition and the orbits of individual stars hold clues to when and where they were formed. Looking at stars individually, mostly in our own galaxy, can therefore test the understanding of galaxy formation processes in absolutely unique ways. But it remains a challenge ahead to make the Milky Way a Rosetta Stone of galaxy formation. In particular, this requires learning all we can about the individual and population properties of stars, from spectra and from the ongoing Gaia space mission.

From observations to simulations

In order to tackle these questions, the GC department follows a three-pronged approach. On the one hand, we study galaxies in the present day universe, including our own Milky Way, making the most of the level of details afforded by observations in our direct cosmic neighborhood.

On the other hand, we study galaxies at earlier cosmic epochs directly by observing very distant objects (corresponding to high cosmological redshifts z); after all, astronomy always means observing the past: When light from a distant galaxy takes, say, 9 billion years to reach us, our present observations show us that galaxy as it was 9 billion years ago, affording us a glimpse into the distant past.

Finally, we compare our observations with physical models. This strategy requires diverse observational capabilities: survey telescopes to obtain large samples of cosmic objects, the largest available telescopes for sheer photon collecting power to examine faint sources, and techniques such as Adaptive Optics and interferometry in order to achieve high spatial resolution. Comprehensive studies of galaxy evolution also require observations across the whole of the electromagnetic spectrum from X rays to radio wavelengths.

Collaborations and initiatives

MPIA is leading a number of major, global observing programs to tackle theses questions. These range from deep fields with ALMA to find dense gas at high redshifts to large programs at the VLT and Keck to study the intergalactic medium, and a VLT legacy survey to study the physics of high-redshift galaxies.

But we are also leading large programs using the ALMA, VLA of the National Radio Astronomy Observatory in New Mexico, US, as well as IRAM's Plateau de Bure Interferometer in the French Alps to map gas in nearby galaxies.

Extensive spectroscopic surveys of nearby galaxies map their stars' kinematics to reveal their dynamical structure and the nature of their central black holes.

MPIA is playing a leading role in making 3D maps of the Milky Way with the PS1 survey and Gaia, as well as in large spectroscopic surveys to understand our Galaxy's prehistory.

Finally, MPIA is leading the near-infrared photometry effort on ESA's Euclid mission, which will elucidate the most puzzling aspects of physics in the cosmos: the nature of dark energy.

II.3 International Networking

Scientific Initiatives

Science is a cooperative venture, and large-scale projects are usually tackled by more than one institute: in larger consortia or as a cooperative project between selected institutes. MPIA is an integral part of the international astronomy landscape and takes part in a number of key initiatives.

PanSTARRS 1 Sky Survey

The PS1 Science Consortium funds the operation of the Pan-STARRS1 telescope on Mount Haleakala in Hawaii. The telescope features the largest digital camera in the world. During the PS1 survey, the telescope made repeated scans of the sky in order to provide timeseries data of astronomical phenomena – a "movie" of the night sky, ideal for discovering transient phenomena. The consortium consists of astronomers from 10 institutions from four countries, including MPIA.

Sloan Digital Sky Survey IV

MPIA is a member of the Sloan Digital Sky Survey IV (SDSS), a spectroscopic survey using the Sloan Foundation 2.5 meter telescope at Apache Point Observatory. Previous SDSS have revolutionized astronomy, providing quality spectroscopic data in unprecedented amounts and enabling statistical analyses that previously would have been impossible.

Collaborative Research Center 881: The Milky Way System

MPIA is part of the Collaborative Research Center 881 at the University of Heidelberg, which is funded by the German Science Foundation (DFG). SFB 881 examines various properties of our home galaxy to obtain a better understanding of its structure and evolution, as well as of the evolution of galaxies in general.

Heidelberg Initiative for the Origins of Life

The Heidelberg Initiative for the Origins of Life brings together researchers from astrophysics, geosciences, macromolecular chemistry, statistical physics and life sciences from the Max Planck Institute for Astronomy, the Max Planck Institute for Nuclear Physics, the Heidelberg Institute for Theoretical Studies, and the University of Heidelberg in order to further our understanding of the origins of life in the universe.

DFG Priority Program SPP 1573: The interstellar medium

MPIA takes part in the German Science Foundation's SPP 1573, a priority programme that is dedicated to research on the interstellar medium: the dilute mixture of charged particles, atoms, molecules and dust grains filling interstellar space.

International Max Planck Research School "Astronomy and Cosmic Physics"

MPIA is one of the founders of the International Max Planck Research School "Astronomy and Cosmic Physics" at the University of Heidelberg, which provides an internationally competitive graduate program to German and international students.

HAT-South

This collaboration between MPIA, Princeton University, the Australian National University and the Pontificia Universidad Catolica de Chile utilizes a network of six identical, fully automated wide-field telescopes on the Southern hemisphere to search for transiting exoplanets. The telescopes are located in Namibia, Australia, and Chile.

Additional initiatives with active MPIA involvement are the technological collaboration Frontiers of Interferometry in Germany FrInGe, the Opticon network for institutes involved in planning and building optical and infrared instruments and telescopes, the international consortium Chemistry in Discs (CID) focusing on the chemistry and physics of protoplanetary discs, the strategic search campaign SEEDS looking for exoplanets and their discs with the Subaru Telescope, and the exoplanet search LEECH at the Large Binocular Telescope.

In October 2015, MPIA signed a collaboration agreement with the Institute for Physics and Astronomy (IFA) of the University of Valparaiso (UV), Chile, to set up the first Max Planck Tandem Group in the field of Astronomy in Chile: a new research group at IFA that will be closely associated with MPIA.

Fig. II.3.1: MPIA is a part of several consortia, each dedicated to building a specific high-tech instrument. The year 2015 saw kick-off events for two consortia that will play a key role for MPIA development in the years to come: The ceremonial exchange of signatures on the contract for the construction of the instrument METIS in Leiden in September and the kick-off meeting for the instrument MICADO in Vienna in October (image). METIS and MICADO are two of the three first-light instruments for ESO's European Extremely Large Telescope (E-ELT) in Chile.

Credit: MPE / MICADO Consortium

II.4 Scientific Highlight

Galactic "Rocket Engine" Explains Unusual Stellar Motion in Galaxies

A discovery by MPIA graduate student Athanasia Tsatsi has changed astronomers' understanding of how mergers of two galaxies can produce unusual stellar motion in the resulting elliptical galaxies, with the central region rotating in the direction opposite to that of the galaxy's other stars. Previously, such differences had been thought to be the result of an opposite ("retrograde") orientation of the galaxies prior to their merger. Looking at a simulation of a galaxy merger, Tsatsi discovered a different way of bringing about such "counter-rotating cores," which involve mass loss from the bodies of these galaxies acting as a primitive galactic "rocket engine".

Spiral galaxies such as our own Milky Way galaxy present a measured stellar dance, with all stars orbiting the center of the galaxy in the same direction, at a stately pace (it takes our sun about 250 million years to complete one orbit around the galactic center). But for a different species, so-called elliptical galaxies, the situation can be more complex.

As the name indicates, these galaxies are shaped like ellipsoids, and at least some of them exhibit a two-fold rotation pattern: While the stars in their outer regions have a common preferred direction of rotation, stars in the core region can jointly rotate in a completely different direction – a "counter-rotating core," or more generally a "kinematically decoupled core," which is apparently completely independent from the motion of the majority of the galaxy's stars.

Why are there counter-rotating cores?

The best available explanations link the existence of such counter-rotating cores to a galaxy's formation history. Elliptical galaxies can be formed by the merger of two galaxies of similar size ("major merger," see figure II.4.1). There is one immediately plausible scenario for how counter-rotating cores could form in such a merger. Imagine that at least one of the galaxies has a core region that is fairly tightly bound by the galaxy's gravity.

Furthermore, imagine that the direction in which the two galaxies orbit each other before merging is opposite to the direction of rotation of stars in that tightly bound core ("retrograde merger," cf. figure II.4.2). In that case, it is likely that, after the merger, the tightly bound core will end up as the core of the new, larger galaxy, while retaining its original sense of rotation. The surrounding stars, on the other hand, will rotate in a different way dictated by the orbital motion of the galaxies around each other, before the merger.

While this is a plausible scenario, it can only explain some of the counter-rotating cores. In total, more than half of the more massive elliptical galaxies contain

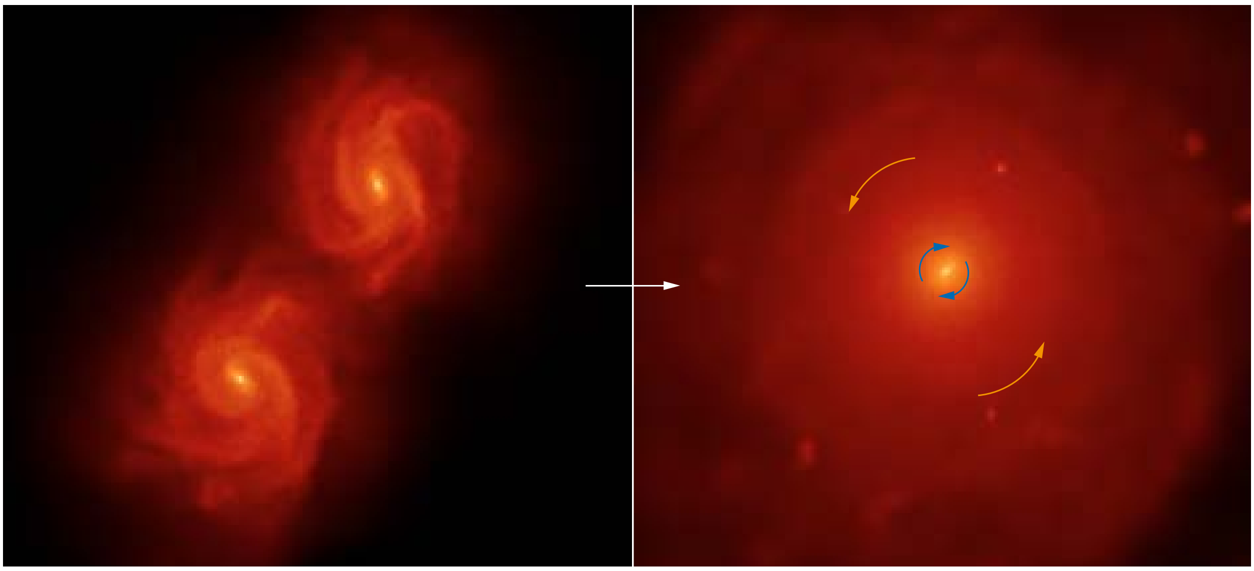


Fig. II.4.1: Snapshots from the simulation where Tsatsi made her discovery of the "galactic rocket engine". Left: the two galaxies before the merger; right: the resulting elliptical galaxy after the merger.

Credit: B. Moster / MPIA

kinematically decoupled central regions. This is significantly more than the retrograde merger scenario can explain. After all, by pure chance, one would expect a retrograde motion for the more tightly bound of the two galaxies in only about half of the cases – and only some of those mergers are thought to result in an elliptical galaxy with a counter-rotating core.

Surprising insight from a simulation

That was the situation when Athanasia Tsatsi began her research as a graduate student at the Max Planck Institute for Astronomy and at Heidelberg's International Max Planck Research School (in collaboration with the University of Heidelberg). Tsatsi, who is also a Marie Curie Fellow (within the DAGAL European Initial Training Network that studies the structure and evolution of galaxies), began to look at computer simulations of galaxy mergers.

Her aim was to analyze these simulations, which show the formation of an elliptical galaxy by the merger of two spiral galaxies, and to reconstruct how the resulting galaxy would look to astronomical observers: What would such observers find if they analyzed their astronomical images and spectroscopic measurements? Such a reconstruction is a key step if one wants to compare predictions from these simulations with observations of actual galaxies.

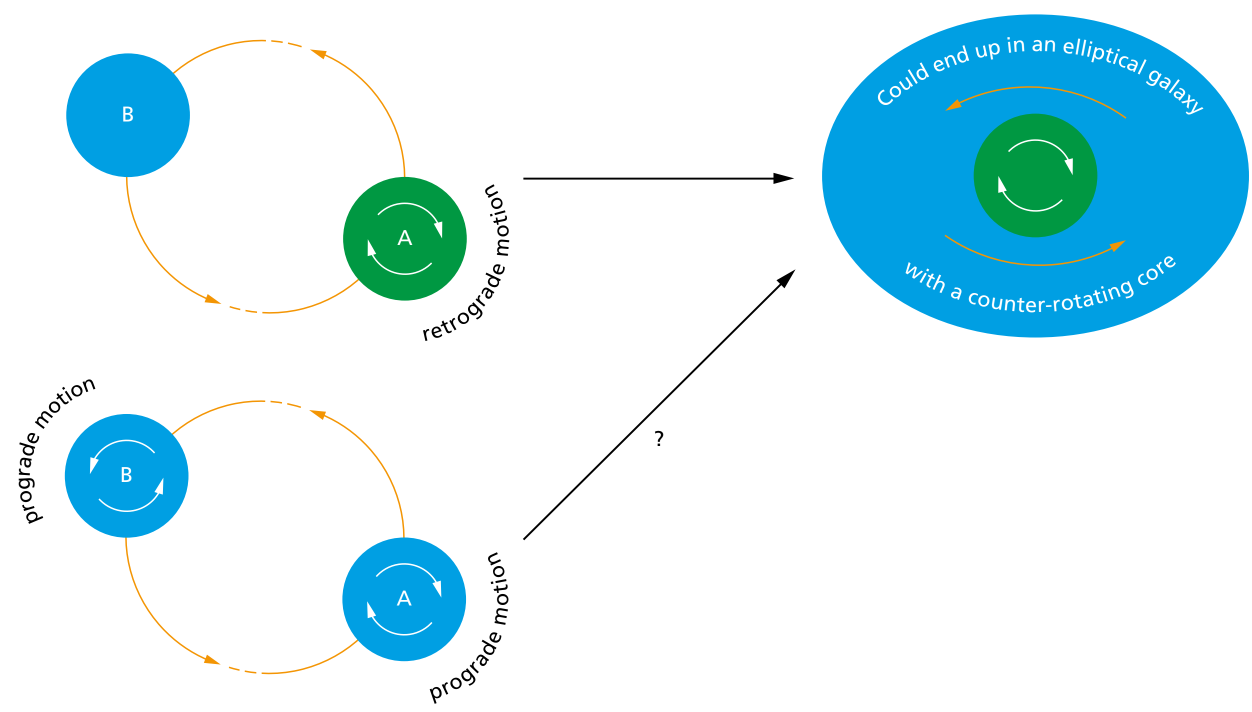
The simulations in question were created by Benjamin Moster, then also graduate student at MPIA and now at Cambridge University. They are based on the cosmological simulation code GADGET developed by Volker Springel and colleagues, which simulates a galaxy as a collection of a great many particles representing the galaxy's stars, gas and dark matter content. The code is particularly suitable for running in parallel, on a great number of processors at once, enabling detailed, yet large-scale simulations.

Simulating observations: Integral Field Spectroscopy

The main observational technique featured in Tsatsi's program is known as integral field spectroscopy. This type of observation allows astronomers to take spectra of many different regions of a galaxy, splitting light from each region into myriads of different colors. As stars move towards or away from the observer, the starlight is shifted towards shorter or longer wavelengths, respectively (a Doppler shift, more concretely a blueshift or redshift).

Such a wavelength shift can be identified in a star's spectrum. In this way, integral field spectroscopy allows astronomers to reconstruct which parts of the galaxy are, on average, moving towards us and which parts are moving away. Based on such observations, astronomers

Fig. II.4.2: Different orientations for galaxy mergers: retrograde motion (top left) means that stars in one of the progenitor galaxies (shown in green) rotate in one direction, while before the merger, the two progenitor galaxies orbit each other in the opposite direction. The existing model posited that elliptical galaxies with counter-rotating cores (right) can form only in situations like this, but not in the case of prograde motion (bottom left), where both galaxies rotate, and orbit each other, in the same direction.



Credit: Graphic Department / MPIA

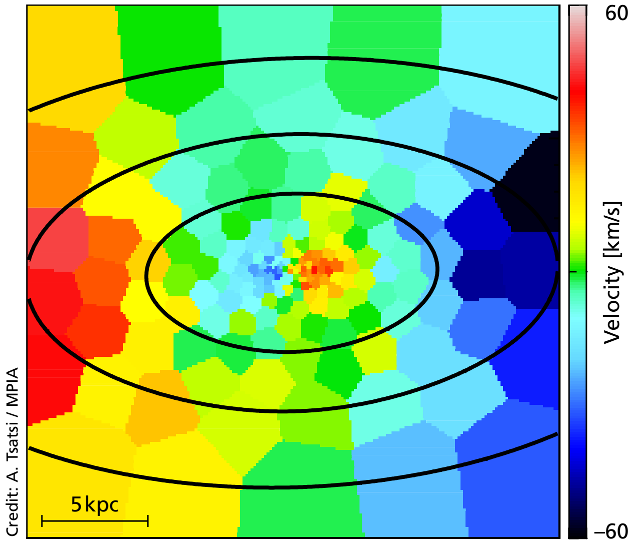


Fig. II.4.3: In this simulated integral field spectroscopic image, colors represent motion parallel to the line of sight: from blue (fastest motions toward us) to red (fastest motion away from us). The different types of motion in the inner and outer regions are clearly discernible. This is how Tsatsi first realized the simulation had produced a counter-rotating core.

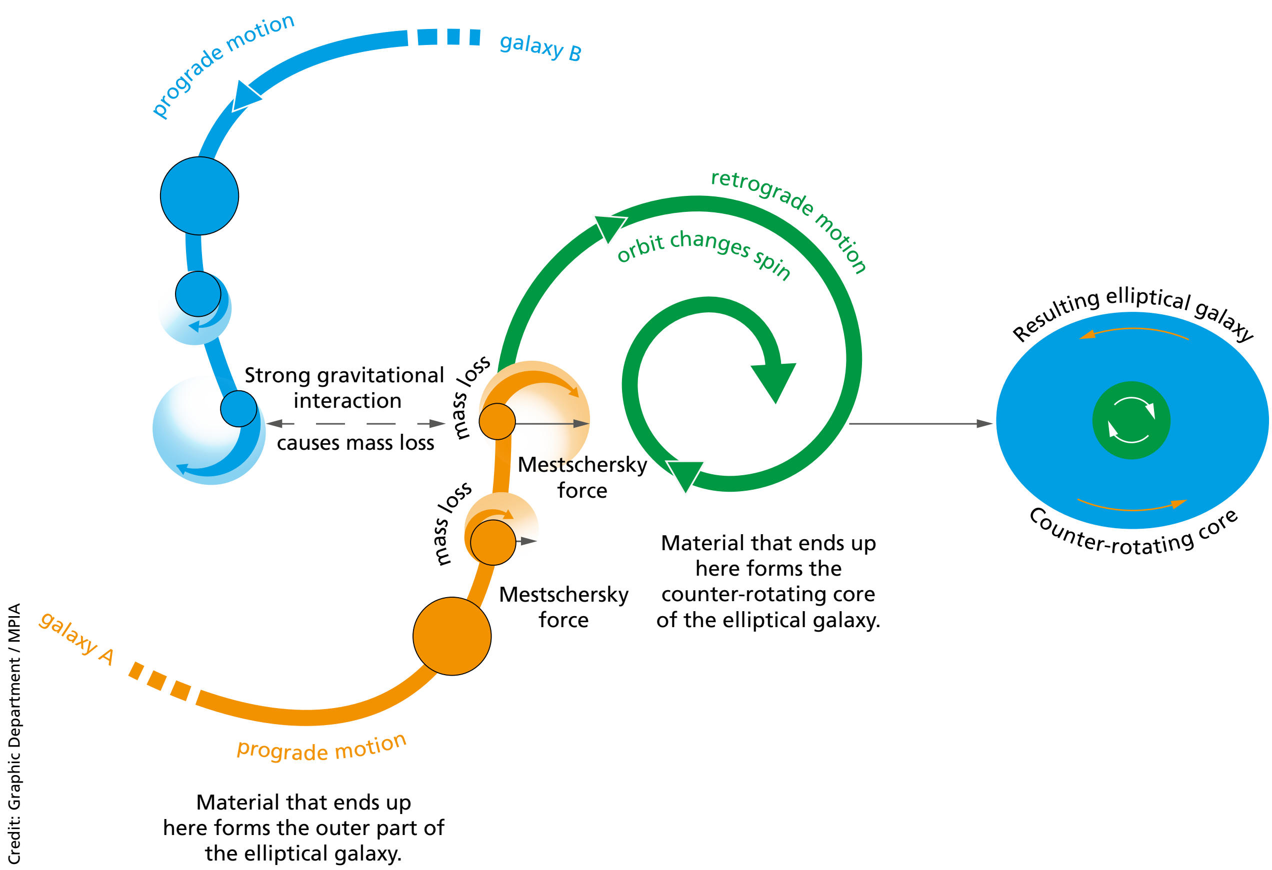
Fig. II.4.4: Schematic diagram of the Meshchersky mechanism: As the core regions lose mass during the merger, the reaction force ("rocket drive") changes their orbits; that way, the material that ends up in the center of the resulting elliptical galaxy rotates in the opposite way to the matter in the outer regions.

can reconstruct stellar motion within a galaxy, which in turn gives them valuable information about the distribution of the galaxy's mass.

When Tsatsi reconstructed integral field spectroscopic observations for one particular simulation, she noticed an unusual fact. The kinematic map showing stellar motion within the galaxy indicated that the central region was moving in a different way from the rest of the galaxy (cf. figure II.4.3). In other words: the galaxy evidently contained a counter-rotating core.

But this had been a merger in which the two colliding galaxies rotated in the same direction as that of their orbit around each other – a prograde merger, and thus a merger of a kind deemed incapable of producing a counter-rotating core (see figure II.4.2).

When Tsatsi had a closer look, she could see directly what had escaped the attention of all previous astronomers who had looked at the simulation: As the core regions of the two galaxies orbit each other, there is a particular time at which their orbital direction changes. This change in direction happens just as the galaxies are shedding mass in the form of stars while they interact via their mutual gravitational attraction (cf. figure II.4.4).



Exploring simulated counter-rotation

The result of the simulated merger was consistent with the observed examples for such counter-rotating cores: With 130 billion times the mass of the sun, this was one of the more massive elliptical galaxies, where such cores were known to be more common. In the simulation, the counter-rotating core remains distinct from its surroundings for 2 billion years after the coalescence of the two galaxies, making for a phenomenon sufficiently persistent as to be observable in real galaxies. Finally, the counter-rotating stars are mainly older stars that had been present before the collision, not the new generation of stars produced during the merger; this, too, was what observations of such systems had shown.

While searching the available scientific literature, Tsatsi realized that there was a precedent for this kind of effect. It is closely related to a special case of a problem studied intensively by the Russian mathematician Ivan Vsevolodovich Meshchersky (sometimes also spelled "Mestschersky"): point-like bodies, whose masses can change over time, moving under each other's gravitational influence. In such a situation, the influence of lost mass can change a body's direction of motion – resulting in the so-called Meshchersky force.

Galactic rocket engines to the rescue

The best-known example for the Meshchersky force is rocket propulsion, where the rocket's loss of mass as it expels hot gases in one direction is accompanied by a reactive force (and hence an acceleration) in the opposite direction. The analogy explains directly why, even in ordinary (prograde) collisions, counter-rotating cores could form: the mass loss experienced by the galactic bodies acted like a gigantic rocket engine, and could be sufficiently strong so as to change the direction of rotation for the stars in the new galaxy's core (the remnant of the two colliding galaxies' central region).

Tsatsi's discovery concerns a single case. But that is sufficient to serve as a proof of concept, showing that the Meshchersky mechanism of producing counter-rotating galactic cores is indeed feasible. Next, the astronomers will need to show the likelihood of this kind of interaction by varying the initial conditions of their galaxy collision simulations.

Should these systematic tests show that the Meshchersky mechanism for producing counter-rotating cores is common, they would resolve a long-standing discrepancy between the observed frequency of such counter-rotating cores and their assumed modes of production. But, even now, Tsatsi's discovery has had an impact on the way future astronomers will look at counter-rotating cores and galactic mergers – knowing that it doesn't necessarily take special, retrograde configurations of colliding galaxies, but that "galactic rocket engines" could do the job just as well.

Athanasia Tsatsi, Andrea Macciò
(now at New York University Abu Dhabi)
and Glenn van de Ven

in collaboration with

Benjamin Moster (Cambridge University)

A. Tsatsi et al. 2015: "A New Channel for the Formation of Kinematically Decoupled Cores in Early-type Galaxies" in Astrophysical Journal Letters 802, article id. L3. DOI: 10.1088/2041-8205/802/1/L3

II.5 Scientific Highlight

Against all Odds: Astronomers Baffled by Discovery of Rare Quasar Quartet

Using the W.M. Keck observatory in Hawaii, a group of astronomers led by Joseph Hennawi of the Max Planck Institute for Astronomy have discovered the first quadruple quasar: four rare active black holes situated in close proximity to one another. The quartet resides in one of the most massive structures ever discovered in the distant universe, and is surrounded by a giant nebula of cool dense gas. Either the discovery is a one-in-ten-million coincidence, or cosmologists need to rethink their models of quasar evolution and the formation of the most massive cosmic structures.

Hitting the jackpot is one thing, but if you hit the jackpot four times in a row you might wonder if the odds were somehow stacked in your favor. A team of astronomers led by Joseph Hennawi of the Max Planck Institute for Astronomy have found themselves in exactly this situation. They discovered the first known quasar quartet: four quasars, each one a rare object in its own right, in close physical proximity to each other – making #4 on the list of Astronomy Magazine's Top 10 Astronomy stories for the year 2015.

Black holes made bright: Quasars

Quasars constitute a brief phase of galaxy evolution powered by the infall of matter onto a supermassive black hole at the center of a massive galaxy. During this phase, they are the most luminous objects in the Universe, shining hundreds of times brighter than their host galaxies, which themselves contain a hundred billion stars. Astronomers believe that black holes a billion times more massive than the sun are embedded in the centers of galaxies.

As matter swirls around these supermassive black holes it travels at velocities near the speed of light, and is heated to temperatures of a million degrees, emitting copious amounts of light before being inevitably swallowed by the black hole. The peak of quasar activity in galaxies occurred when the Universe was about one fifth of its current age, whereas today all massive galaxies are observed to have dormant supermassive black holes at their center, thought to be relics which grew during a quasar episode in the distant past.

The physical processes that determine when and why supermassive black holes shine as quasars are poorly understood, but it probably has to do with the supply of fuel: in order to ignite a quasar episode, a large amount of gas must find its way deep into the core of a galaxy, sufficiently close to experience the gravitational pull of the black hole.

Why quasars are rare

While all supermassive black holes in massive galaxies underwent a quasar phase at some point in their evolution, this phase lasts only around ten million years, a thousand times shorter than the much longer ages of galaxies (ten billion years and counting). Thus when we observe a quasar, we are catching a galaxy during a very brief period in its life, which explains why quasars are so rare on the sky.

As a result, they are typically separated by hundreds of millions of light years from one another, and it is exceptional to find even two quasars inhabiting the same physical structure. Out of the over 500,000 quasars that astronomers have cataloged to date, only about a hundred such binary quasars are known. It came as a big surprise in 2007, when a team of American and Swiss astronomers announced the discovery of the first triple quasar.

But now the newly discovered quadruple quasar by Hennawi and his team dramatically ups the ante. Given our knowledge of the abundance of quasars on the sky, and our current understanding of the distribution of structure in the universe, the researchers estimated that the odds of discovering a quadruple quasar by chance is one in ten million! How on earth did the astronomers get so lucky?

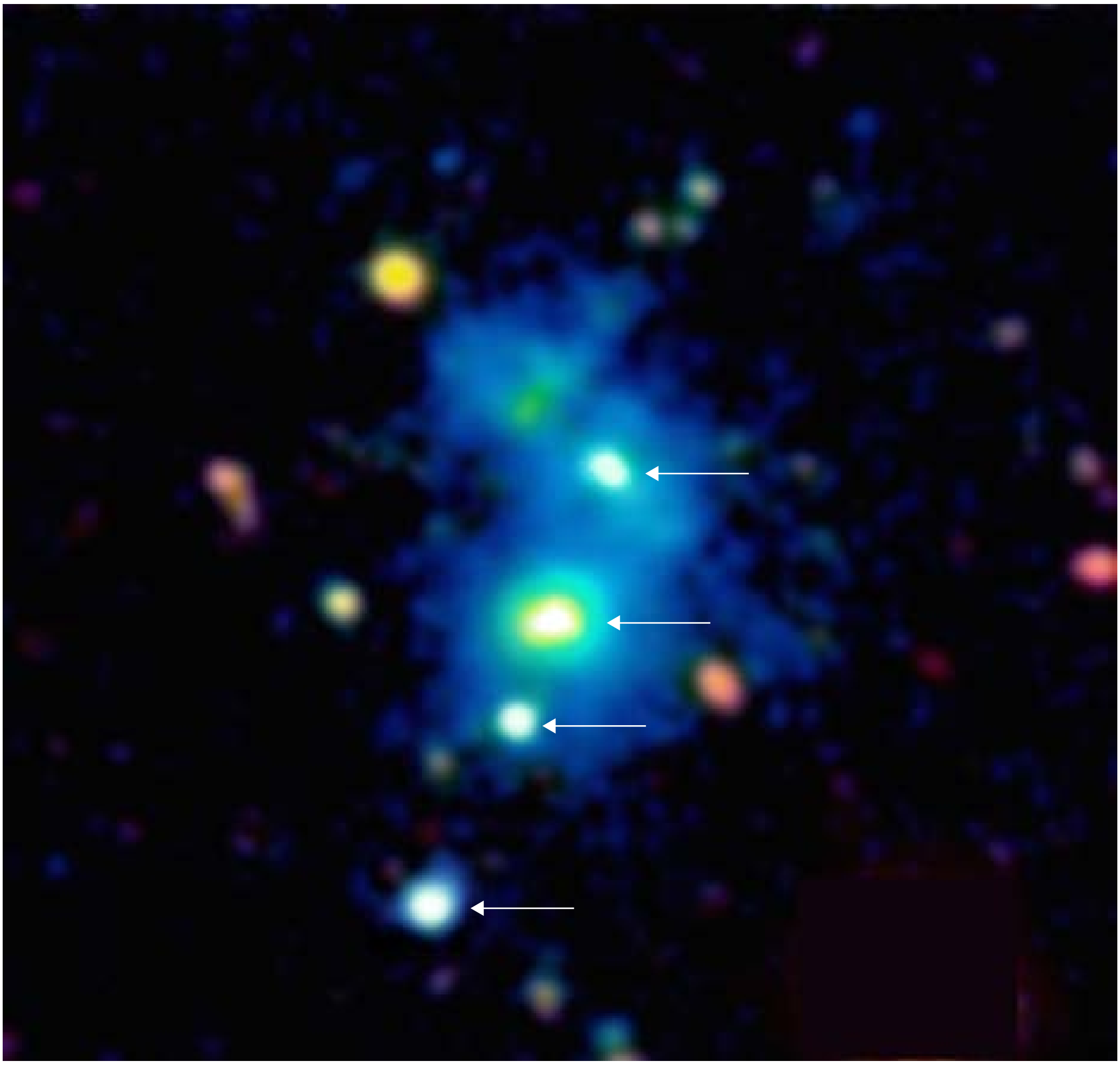
Clues come from the way in which the unusual quasar quartet was discovered in the first place. Hennawi and his colleagues were searching for quasars surrounded by so-called Lyman-α (pronounced "Lyman-alpha") nebulae. If a quasar is surrounded by a large reservoir of cool gas, the intense radiation emitted by the quasar can act like a "cosmic flashlight", illuminating gas in its environment and thereby revealing its structure. Under the quasar flashlight's intense glare, the gas emits light via the same mechanism at work in an ordinary fluorescent lamp, namely because it is being constantly bombarded with energy. In the case of ordinary lamps this energy is provided by an electrical current, whereas in Lyman-α nebulae the fluorescence is powered by energy from the quasar radiation (cf. MPIA's Annual Report 2014, section II.4).

In search of Lyman-α nebulae

To search for new Lyman-α nebulae, the researchers visually examined the spectra of 29 quasars to look for signatures of diffuse extended emission. One of their candidates, with the catalogue number SDSSJ0841+3921, appeared promising, and was then subjected to detailed examination using the LRIS imaging spectrometer at the 10 meter Keck Telescope on Mauna Kea, Hawaii. The object was observed with Keck/LRIS for 3 hours in late 2012, using a custom-built narrow-band filter that was tuned to capture only the light emitted by cool hydrogen gas (Lyman-α filter customized for the system's particular redshift).

These observations revealed one of the largest and brightest Lyman-α nebulae known to astronomy. The object is so distant that its light has taken nearly 10.5 billion years to reach us (cosmological redshift $z = 2.0412$). The nebula has an extent of one million light-years across (310 kpc, corresponding to an angular size of 37 arcseconds). In the process of examining these images, the astronomers realized that there was not just one quasar, but four of them embedded in the nebula in one large physical structure. Examination of the four quasar spectra confirmed that these were indeed four distinct quasars (rather than multiple images of a single quasar; a phenomenon that can occur through gravitational lensing, when light is bent by a massive object's gravity).

Fig. II.5.1: Image of the region of the space occupied by the rare quasar quartet. The four quasars are indicated by arrows. The quasars are embedded in a giant nebula of cool dense gas visible in the image as a blue haze. The nebula has an extent of one million light-years across, and these objects are so distant that their light has taken nearly 10 billion years to reach telescopes on earth. This false color image is based on observations with the Keck 10m telescope on the summit of Mauna Kea in Hawaii.



Credit: F. Arrigoni-Battaia & J. F. Hennawi / MPIA

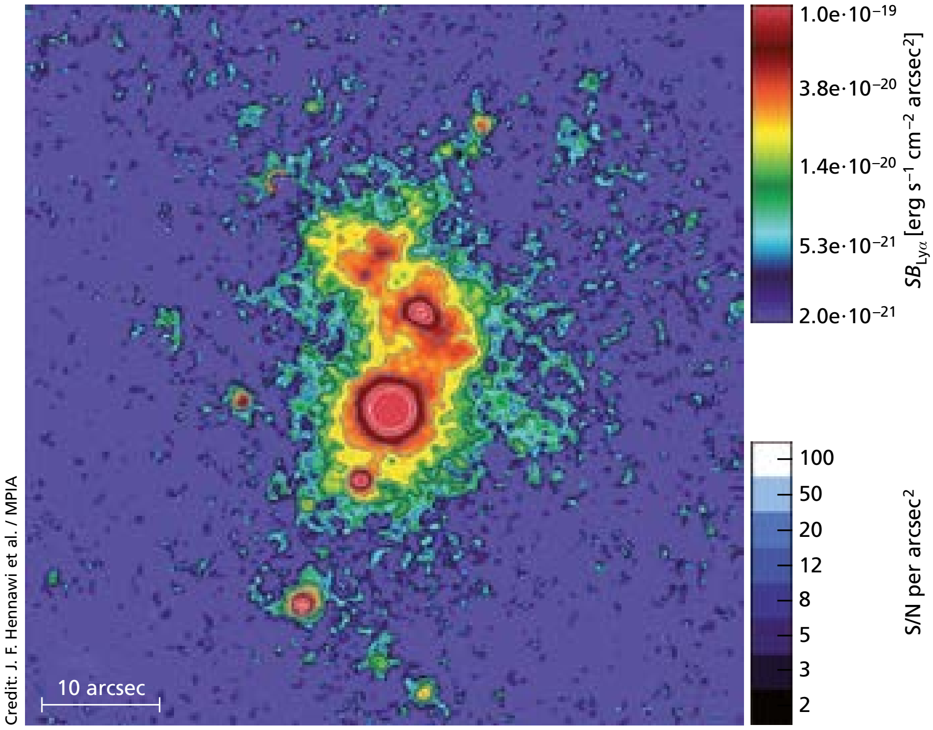
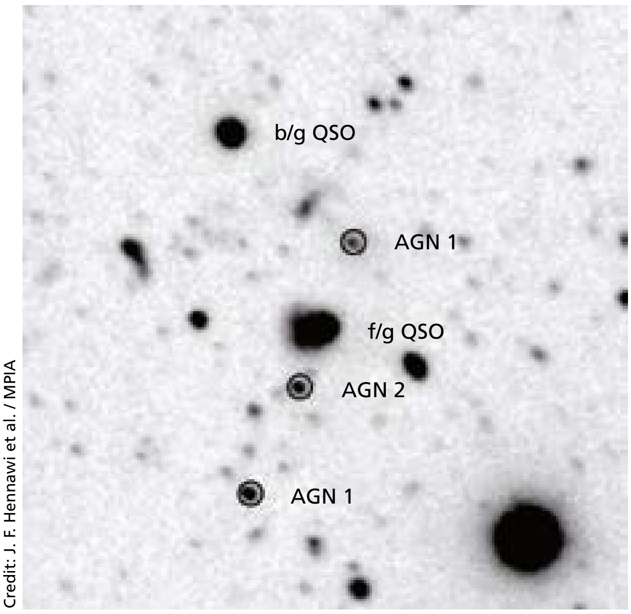


Fig. II.5.2: Narrowband image of the field surrounding SDSSJ0841+3921, taken through a custom-made filter specifically tailored for Lyman-α light at the system's redshift. The hue of each pixel indicates the surface brightness (upper color bar), while the brightness (lower color bar) indicates the signal-to-noise ratio (the confidence that this is indeed light other than the sky background) per square arcsecond.

Fig. II.5.3: Broad-band image of the region surrounding SDSSJ0841+3921 in visible light (V band) showing the foreground quasar (f/g QSO) and the three AGN completing the quasar quartet (AGN 1,2,3). These AGNs are roughly lined up following the orientation of the Lyman-α nebula. Also shown is the background quasar (b/g QSO), which is not physically associated with the quadruple quasar system.



Unusual object in unusual region

The strange coincidence of the first quadruple quasar with an extraordinary giant nebula gets even stranger. The object SDSSJ0841+3921 appears to be located in a rare corner of the distant universe with an exceptional amount of matter, as evidenced by the fact that there are several hundred times more galaxies there than in a typical location of the same size.

Since light from this cosmic metropolis has been traveling for more than 10 billion years before finally reaching our telescopes here on earth, our images show the region as it was more than 10 billion years ago, less than 4 billion years after the big bang. Given this tremendous enhancement in the number of galaxies, it seems certain that we are looking at the progenitor of a massive galaxy cluster in the present universe – a proto-cluster, to use the proper astronomical term.

Incredible luck or physical processes?

Piecing all of these anomalies together, the astronomers tried to understand what appears to be their incredible stroke of luck. They speculate that some physical process might make quasar episodes much more likely to occur in certain environments. Many theoretical models postulate that quasar activity can be triggered when galaxies collide or merge, because these violent interactions can efficiently funnel gas onto the central black hole. Such encounters are much more likely to occur in a dense protocluster filled with galaxies, just as one is much more likely to bump into someone in a crowded marketplace than in an open field.

It could also be that the sheer number of galaxies in the protocluster plays a role, since the large overdensity implies many more massive galaxies with supermassive black holes that can host a quasar. Very probably, the Lyman-α nebula is also an important piece of the same puzzle, since it requires a tremendous amount of dense cool gas. Supermassive black holes can only become active if there is infalling gas, and an environment that is gas rich, at least on large scales, could provide favorable conditions for fueling quasars.

On the other hand, given our current understanding of how massive structures in the universe form, the association of the proto-cluster with the Lyman-α nebula is totally unexpected. Current theories based on supercomputer simulations predict that protoclusters should be filled with rarefied gas that is about ten million degrees, whereas the Lyman-α nebula requires gas that is a thousand times denser and a thousand times colder. All in all, the discovery of the first quadruple quasar is likely to shake up our current picture of the formation of quasars and the most massive structures in the universe.

Joseph F. Hennawi and Fabrizio Arrigoni-Battaia

in collaboration with

J. Xavier Prochaska (University of California at Santa Cruz and Lick Observatories) and Sebastiano Cantalupo (University of California at Santa Cruz, Lick Observatories, and ETH Zurich)

Joseph F. Hennawi et al. 2015: “Quasar quartet embedded in giant nebula reveals rare massive structure in distant universe” in Science 348, pp. 779-783. DOI: 10.1126/science.aaa5397

II.6 Scientific Highlight

Unusual Moving Structures in Dust Disc around Star

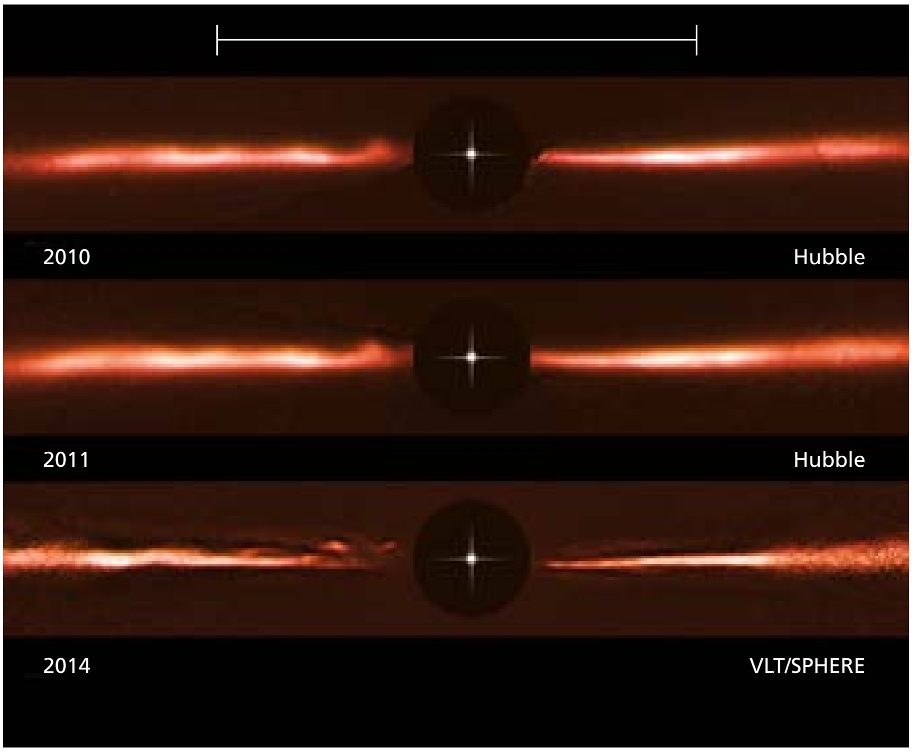
Using the instrument SPHERE and the Hubble Space Telescope, a team that includes MPIA astronomers have identified unusual moving features in the dust disc surrounding the nearby star AU Microscopii. This is the first observation of such structures changing over time, and at present, the nature and origin of the features is unclear. The features could be linked to eruptions of the star AU Mic, or to (as yet unseen) planets hidden within the dust disc.

The star AU Mic ("AU Microscopii") in the Southern constellation Microscope, which is less than 33 light-years from earth, is surrounded by a sizable disc made of dust, which observers on earth can see directly edge-on. This debris disc is left over from the phase of planet formation. Back then, AU Mic was surrounded by a protoplanetary disc of dust and gas, from which any of its planets (none of which have been detected so far) would have formed. In our own solar system, the Kuiper belt beyond the orbit of Neptune, which consists of thousands of smaller celestial objects (including Pluto), is a late-stage version of such a debris disc.

Details versus distance

When astronomers observe stars, their observations are limited by the sheer distances involved. Even with cameras installed at the largest current telescopes, straightforward images of distant stars never show these objects any different from the way they would show a point source. For a debris disc, typical radii are between 10 and 100 times the distance between the earth and the sun, that is, between 10 and 100 astronomical units (10–100 AU).

Fig. II.6.1: Images showing the debris disc around the star AU Mic in 2010 (top, Hubble Space Telescope), 2011 (center, ditto) and 2014 (bottom, SPHERE instrument), including newly discovered fast-moving wave-like features.
The black central circles show where the brilliant light of the central star has been blocked off to reveal the much fainter disc, and the position of the star is indicated schematically. The scale bar at the top of the picture indicates the diameter of the orbit of the planet Neptune in the Solar System (60 times the distance earth-sun, corresponding to 60 AU). Note that the brightness of the outer parts of the disc has been artificially brightened to reveal the faint structure.



Credit: ESO, NASA & ESA

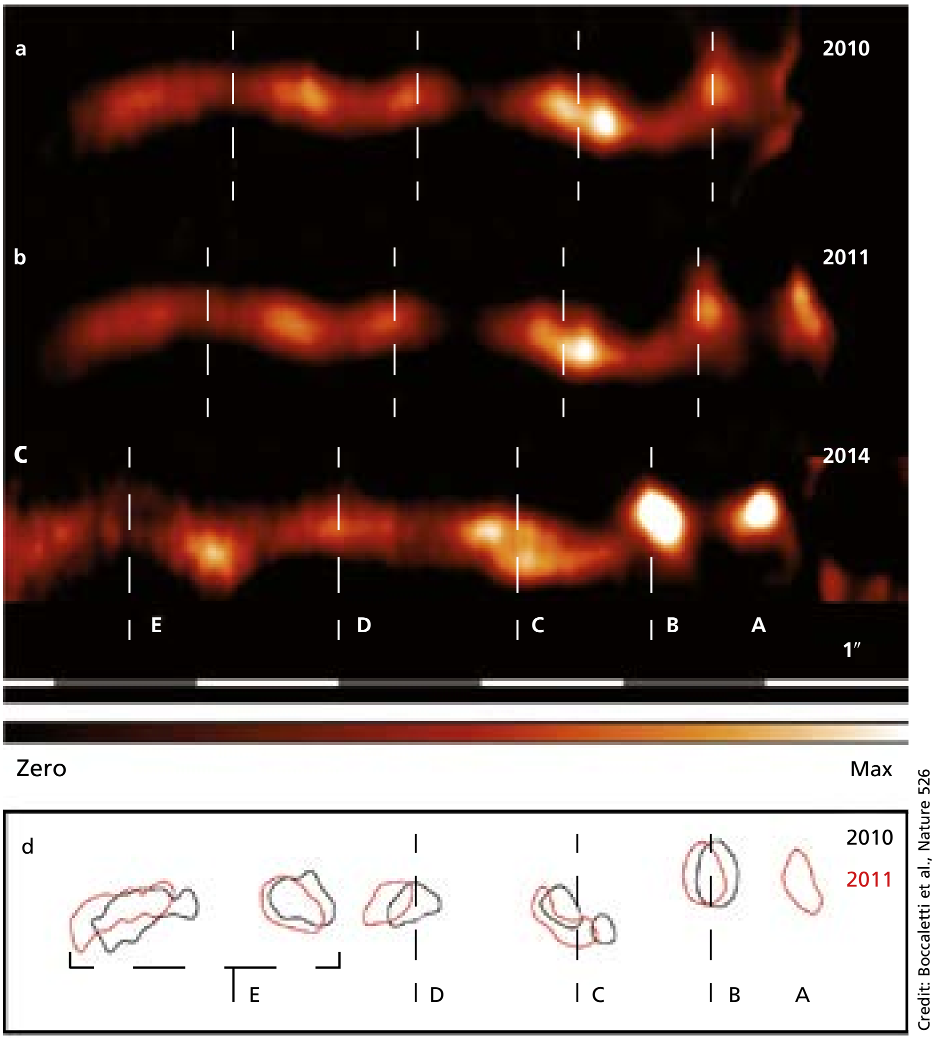


Fig. II.6.2: In order to identify disc features, the astronomers subtracted both the smooth main body of the disc, as well as a slightly blurred version of the image (unsharp masking). This technique, well known also in photographic image processing, makes sudden changes and small-scale features more prominent. For this image, the original image was also stretched by a factor 2 in the vertical direction. Five structures A-E that can be identified clearly in all the images are marked.

Most known debris discs have only been detected indirectly, by the infrared radiation that is produced as their dust scatters the star's light. Although a few discs are large enough to be seen on images, examinations of debris discs has mostly relied on studies of the rainbow-like spectra of their light.

Now, such a disc has been imaged in great detail using SPHERE, the newly installed exoplanet-and-discs imaging machine at ESO's Very Large Telescope, and previous data from the Hubble Space Telescope. And for the first time, astronomers could not only identify sub-structures, but also reliably track changes within the disc: fast-moving, wave-like features that move outwards within the disc.

Hunting discs with SPHERE

When the instrument team for SPHERE chose targets for their initial observations, AU Mic was a natural candidate. SPHERE combines major components that make it particular suitable for detailed imaging of such discs, which are usually hard to observe due to the bright glare of the central star: an "extreme adaptive optics system" to compensate for atmospheric turbulence (which limits telescopes' spatial resolution), a suite of components designed to physically block the light from the central star (coronagraphs), a polarimeter that can filter out reflected light (such as that scattered by dust in a disc), and a camera that is particularly suitable for high-contrast imaging and that also allows for "differential imaging," a technique to separate the image of an object like the dust disc from noise effects (for more information on SPHERE, see MPIA's annual report for 2014, section III.4).

On August 10th, 2014, the astronomers turned SPHERE's infrared camera IRDIS onto Au Mic. Highly favourable atmospheric conditions and high performance from the adaptive optics system combined to

Credit: Boccaletti et al., Nature 526

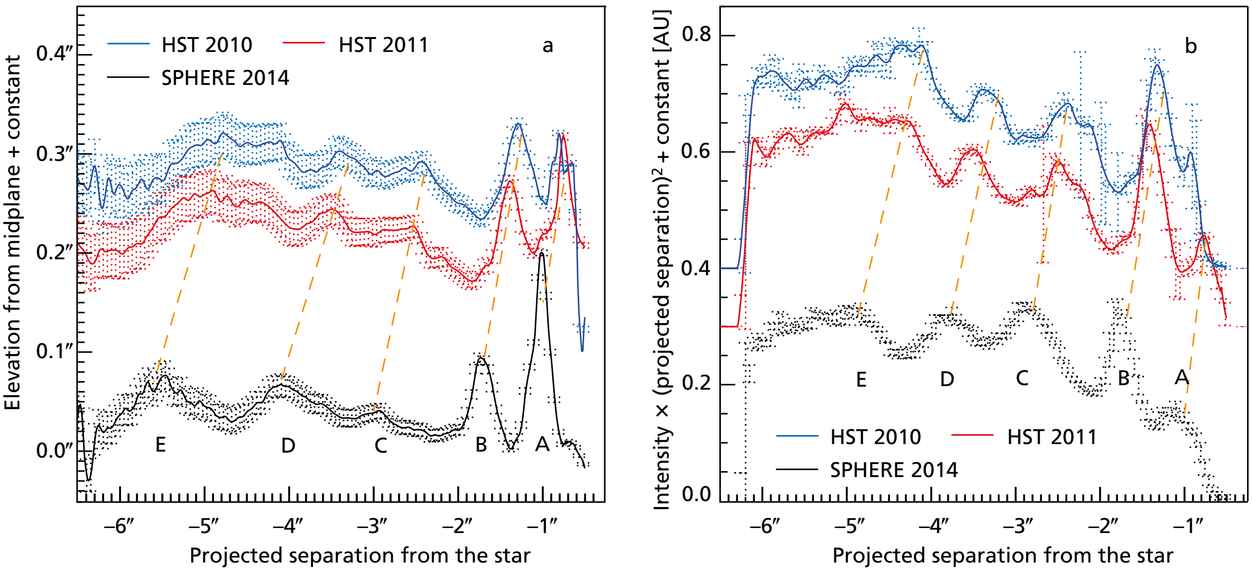


Fig. II.6.3: Plotting either the vertical excursions (left) or brightness variations (scaled with the square of the separation from the star, right), the various structures can be matched between the three imaging epochs (blue, red, gray). The blurry region around each curve indicates the 1σ dispersion (a measure for the measurement uncertainty of each curve). Clearly, the features have moved over time, as indicated by the dashed orange curves.

Fig. II.6.4: The SPHERE instrument shortly after it was installed on ESO's VLT Unit Telescope 3. The instrument itself is the black box, located on the platform to one side of the telescope.

yield a superb high-contrast image, allowing the astronomers to image brightness values differing by a factor of more than 10,000 over shortest distances (points separated by half an arc second).

This allowed the astronomers to image the disc between distances of 1.7 times the earth-sun distance (1.7 AU) to around 70 times the earth-sun distance (70 AU). Regions even closer to the star were blocked out mechanically to suppress stellar glare, while the outer limit was imposed by the instrument's limited field of view. In total, the disc extends out to distances of at least 200 AU.

Credit: ESO / J. Girard (djulik.com)

Surprising movement

Right away, the astronomers – including MPIA director Thomas Henning, who is part of the team that studied the disc – noticed detailed structures in the disc. Even a few years ago, the statement that such detailed images would be possible in 2015 would have been met with considerable skepticism by most astronomers. The researchers then compared their images with images taken by Henning and colleagues with the Hubble Space Telescope in 2010 and 2011, using the HST's imaging spectrograph STIS.

They were in for a surprise. Not only were they able to identify reliably a considerable number of structures in both the SPHERE and the Hubble images. But within those few years, the features had moved away from the star. For the first time, astronomers had observed not only the structure or the spectral features of a stellar debris discs, but actual changes in the disc over time. In retrospect, even a comparison of the Hubble images from 2010 with those from 2011 shows traces of these changes.

According to a preliminary analysis, which will need to be confirmed by future observations, some of the matter observed might even be on its way out of the disc altogether, with sufficient speed to leave the stellar system behind.

Understanding disc dynamics

There is, at this moment, no complete explanation for the disc dynamics observed by the combination of SPHERE and Hubble images. AU Mic, a red dwarf star (of type M1 Ve) a little over half the diameter of the sun, is a rather young star with an age of around 12 million years, compared to our sun's age of 5 billion years. As is not uncommon for such young stars, AU Mic is very active, and frequently produces sizable flares: Eruptions involving the star's magnetic field, which catapult stellar plasma at high speed into the star's surroundings. It is possible that the moving features in the dust disc are caused by such stellar activity.

Another, tantalizing possibility is that the changes could be tell-tale signs of the presence of one or more giant planets in the debris disc. In that case, the motion would be due to disturbances caused by one or more planets' gravitational pull as it moves through the disc. So far, no planets around AU Mic have been detected – but this could change as search and imaging techniques improve.

Future observations

In total, the surprising observations of disc changes around AU Mic provide for a whole program of additional observations: Follow-up observations both with the Hubble Space Telescope and with SPHERE could provide further data, and trace the further development. Measurements with the polarimeter ZIMPOL that is one of the subsystems of SPHERE could reveal the orientation of the features that are visible in the images. Observations with the millimeter/submillimeter observatory ALMA could show the amount of gas that is still contained in the debris disc; an important factor for understanding the dynamics of the disc. Monitoring of the stellar activity of AU Mic could help to prove – or disprove – the connection between the dynamics of the disc and eruptions on the star.

If the researchers are very lucky, they might even be able to detect proto-planets – smaller bodies busily gathering sufficient mass for planethood – within the disc. These planetary births could be observed using differential imaging techniques such as the ones for which SPHERE is optimized, using the characteristic light emitted by hydrogen atoms (Hα).

More generally, extending observations such as these should allow for detailed comparison with simulations of such objects, and could shed light on processes of planet formation, which might have left tell-tale traces on the disc.

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A. Boccaletti et al. 2015: "Fast-Moving Structures in the Debris Disc Around AU Microscopii"
in Nature 526, pp. 230-232. DOI: 10.1038/nature15705

II.7 Scientific Highlight

How Stars Grow into Heavyweights

How do stars reach masses more than 10 times the mass of the sun? It has long been suspected that gas and dust discs circling young stars could play a role, funneling matter onto what will become some of the most massive stars known. In 2015, a team involving MPIA astronomers detected the most massive newly-forming star to date with a stable disc.

The masses of stars range from close to 10% of the mass of our sun to more than a hundred solar masses. Do all these stars form in the same way, regardless of their strikingly different sizes? That has been a contentious question for the last few decades.

Stars form when the gas in cold interstellar clouds collapses under its own mass. Clouds are never perfectly still; their gas is bound to be in motion, resulting in an overall rotation around the center of mass. As the gas collapses, the rotation speeds up (think of a figure skater going into a pirouette by moving her arms close to her body).

Discs: the governors of star formation

The overall rotation can keep matter from falling onto the would-be star in the same way that planets do not fall straight into the sun, but instead circle the sun on regular orbits. But the rotation also creates a mechanism that helps the protostar gather additional mass: the combination of centrifugal forces due to the rotation and the inward collapse flattens part of the gas into a thin disc around the star, known as an accretion disc. This disc can then slowly funnel additional matter onto the would-be star.

Magnetic fields and gravity churn up the gas particles within the disc, causing them to interact and collide with each other. In doing so, particles transfer some of their energy and momentum to particles further out in the disc. As a consequence of these interactions, there will always be a significant fraction of particles that drift toward the inner rim of the disc and, finally fall onto the protostar in the center. Once the protostar has received (or "accreted") a sufficient amount of matter in this way, its gas is sufficiently dense and hot for nuclear fusion to set in: a star is born.

A need for stability

In order to play a significant role in the early evolution of the nascent star, the accretion disc needs to be around for a sufficient amount of time – it needs to be stable, not just a brief, transient phenomenon. Such stable discs settle down into a state that is reminiscent of how planets move in our own solar system: the motion of their gas is dominated by gravity.

Consequently, gas in the inner parts of the disc rotates faster than in the outer parts, similar to planetary motion in our own solar system, where the inner planets systematically move faster than the outer ones. Discs that follow this pattern of motion are called Keplerian, after Johannes Kepler, who first formulated the relation between distances and orbital periods for the planets.

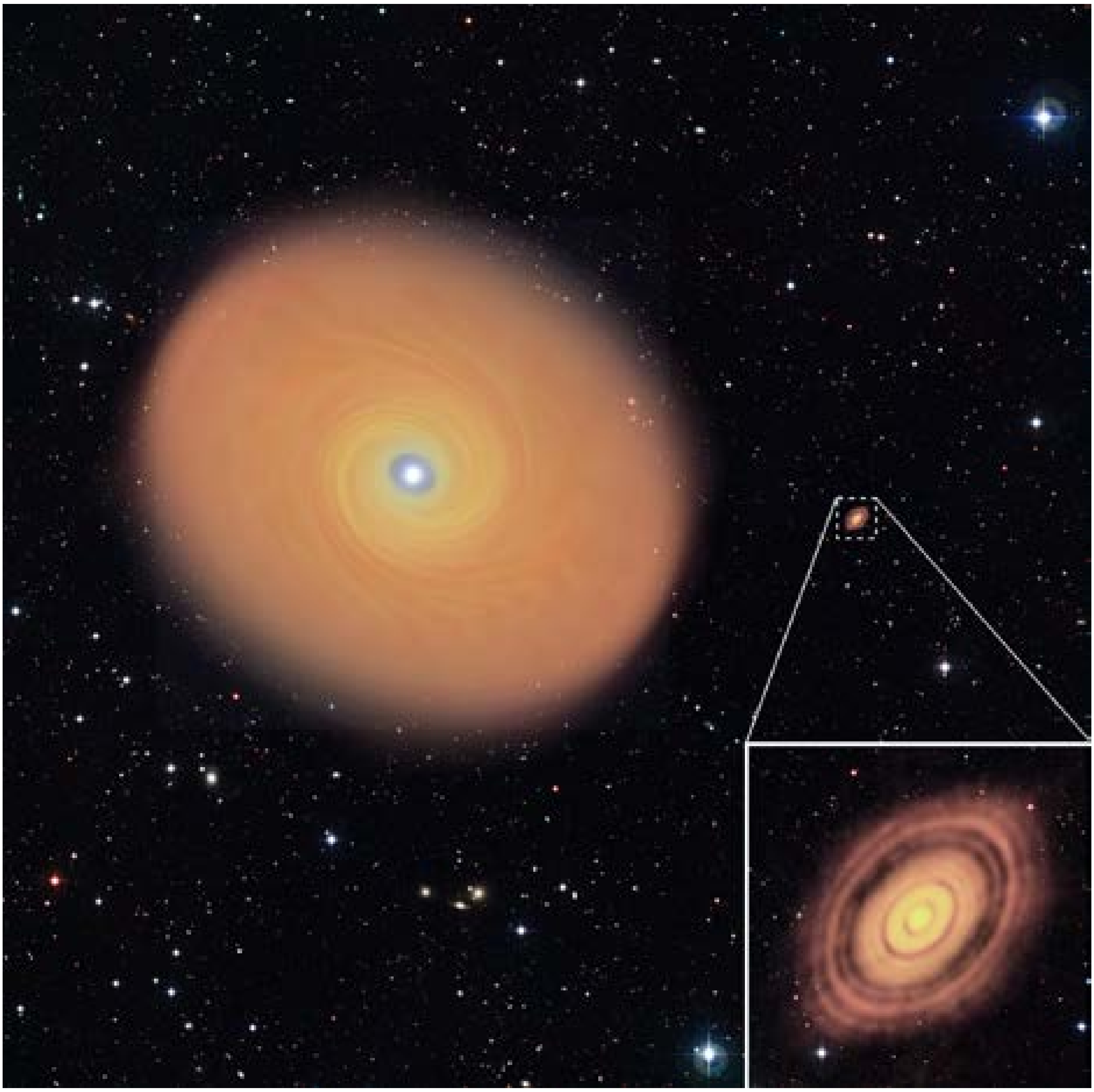
Do young high-mass stars have discs?

For low-mass stars, such accretion discs are well-known, and have been detected numerous times. The most prominent examples are the so-called T Tauri stars, lower-mass nascent stars which have blown away the surrounding gas, allowing for a clear view onto the star and disc.

Do high-mass stars form in the same way – do they form stable, Keplerian discs that help funnel matter onto the surface of the protostar? That is by no means a given. High-mass stars are much brighter than their lower-mass kin, and they form and evolve on much shorter timescales. In fact, in such stars, nuclear fusion sets in after a few hundred thousand years, while there is still plenty of infalling cloud matter – much faster than for their low-mass siblings, which start nuclear fusion (hydrogen burning) much later, only after a few million years.

This early onset of fusion is a potential problem. In order to form the stars with the highest observed masses, we need to keep adding matter to the newborn star even after nuclear fusion has begun. But nuclear fusion creates intense electromagnetic radiation, and radiation creates pressure (just like, say, a stream of matter particles would – think of turning your garden hose onto a bucket or other object to see this kind of pressure in action).

Radiation pressure makes it harder for additional matter to fall onto the star; sufficiently strong radiation will drive away any remaining matter altogether! Under these adverse conditions, how can stars with very high masses even form?



Credit: K. G. Johnston / University of Leeds and ALMA (ESO / NAOJ / NRAO)

This is where the presence (or not) of a stable (that is, Keplerian) accretion disc can make a crucial difference. Such discs can funnel additional matter onto the nascent star, after all, and as they are rather thin, they present a much lower profile to the star's radiation pressure than an envelope of gas surrounding the star altogether.

Where are the stable discs for massive stars?

Previously, astronomers had not observed Keplerian discs around young massive stars. What they did observe were toroidal – donut-shaped – structures resembling a thick ring centered on the protostar, providing high rates of flow, adding up to a hundredth of a solar mass per year.

Fig. II.7.1: Artist's impression of the large disc of dusts and gas around the massive young star AFGL 4176 (left), compared with the size of the disc recently observed directly with ALMA around the young lower-mass star HL Tauri (right and inset).

While these toroids rotate, they cannot be stable structures, as their matter falls inward in much less time than it would take for the donut to complete a single rotation. Do these transient structures play a key role for high-mass star formation? Or do massive stars accrete most of their material through stable, Keplerian discs that lie within these toroids?

The answer is anything but obvious. In particular, it has long been unknown whether or not the higher radiation pressure and higher rate of matter infall allow for the formation of a reasonably stable (Keplerian) disc in the first place. For some early B-type stars, with

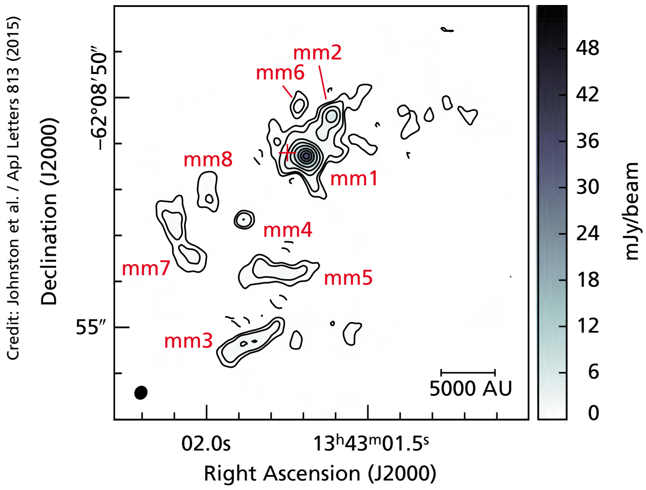


Fig. II.7.2: : ALMA millimeter wave image of the region around AFGL 4176 at a wavelength of 1.21 mm. Grayscale and contours indicate the brightness (σ = 78 μJy beam times -5, 5, 10, 25, 50, 100, 200, 300, 400; negative values are an artefact of the measurement principle of ALMA, which is not sensitive to flux on larger-size scales). The solid ellipse in the left bottom corner shows the minimum size of details that can be distinguished with this specific ALMA configuration. The millimeter sources are labeled; the source that includes the Keplerian disc is mm1.

masses less than 18 times that of the sun, discs had indeed been observed since 1997, and rotate in a Keplerian manner. For Herbig Be stars, young stars with up to 8 solar masses, such discs have been known for even longer. But for the most massive stars, O-type stars with 18 solar masses or more, the situation was much less clear.

Tell-tale jets

There have long been indications that discs may be present even in O-type stars. In lower-mass stars, there is a characteristic interplay between the disc and magnetic fields, which results in so-called jets: two highly energetic and focused particle streams that are shot from the innermost parts of the star-disc system in opposite directions perpendicular to the disc. Such jets have been found for O stars, as well. It is plausible that these jets are created in the same way as for low-mass stars, with the same magnetohydrodynamic effects in play. Sometimes, more extended outflows have been observed, up to a few light-years long.

Whenever transient rotating structures like the aforementioned toroids are present, the jets are perpendicular to the donut. This relation between the general sense of rotation of the system and jet/outflow orientation is another indication that the mechanism for jet production probably involves rotating discs hidden within the larger toroids.

Taken together, these facts would suggest that nascent O stars are likely to be surrounded by discs. But a suggestion is not the same as firm evidence.

A question of scales, details, and sensitivity

More direct observations are difficult because of the scales involved. For lower-mass stars, timing and radiation intensity are such that enveloping gas is driven away, for instance by radiation (photoevaporation), leaving only the young star with a surrounding disc (a configuration known as a T Tauri star). For higher-mass stars with their more intense radiation and stellar winds – streams of particles leaving the star's surface – there is only a short time (if any) when the envelope has already been blown away while the disc still remains. If one wants to observe a disc, it will need to be in a state where star and disc are still surrounded by an envelope of gas and dust.

This necessitates observations at longer wavelengths, such as for submillimeter or millimeter radiation, which can pass almost unhindered through such an envelope, exposing to view the structures that lie within. Such observations not only call for high spatial resolution – that is, access to small details – but also for high fidelity of the corresponding images and high sensitivity. At such comparatively long wavelengths, the high spatial resolution can only be achieved using interferometers: arrays of radio telescopes joined together to act as a single, much larger telescope.

Even so, the demands of the disc observations taxed existing interferometers to their limits. This changed with the opening of the ALMA observatory in 2011, producing high sensitivity and excellent quality images in combination with high spatial resolution. Hence, it was anything but a surprise that the past few years produced a number of ALMA-related publications featuring tentative identifications of such discs (Sanchez-Monge et al. 2014, Zapata 2015).

Success with ALMA

In 2015, a team of astronomers led by Katharine Johnston from the University of Leeds finally found clear evidence for a Keplerian disc around a nascent O-type star showing that, yes, apparently the physics of star formation is very similar across all mass scales.

The object under study, with the catalogue number AFGL 4176, is an O type star in the Southern constellation Centaurus (the Centaur), next to the Southern Cross. Distance estimates place the object at around 14,000 light-years from earth. AFGL 4176 is embedded in an extremely bright star formation region, whose total luminosity amounts to approximately 100,000 times that of our sun. When, in 2012 Katharine Johnston – then a post-doctoral researcher at MPIA – applied for ALMA observation time in order to study the material surrounding the stars in that region.

The star-forming region had previously been observed with the MIDI instrument for the VLT interferometer at ESO's Paranal observatory, and ALMA data would complement the existing MIDI data, allowing for comparisons that could reveal different parts of the circumstellar

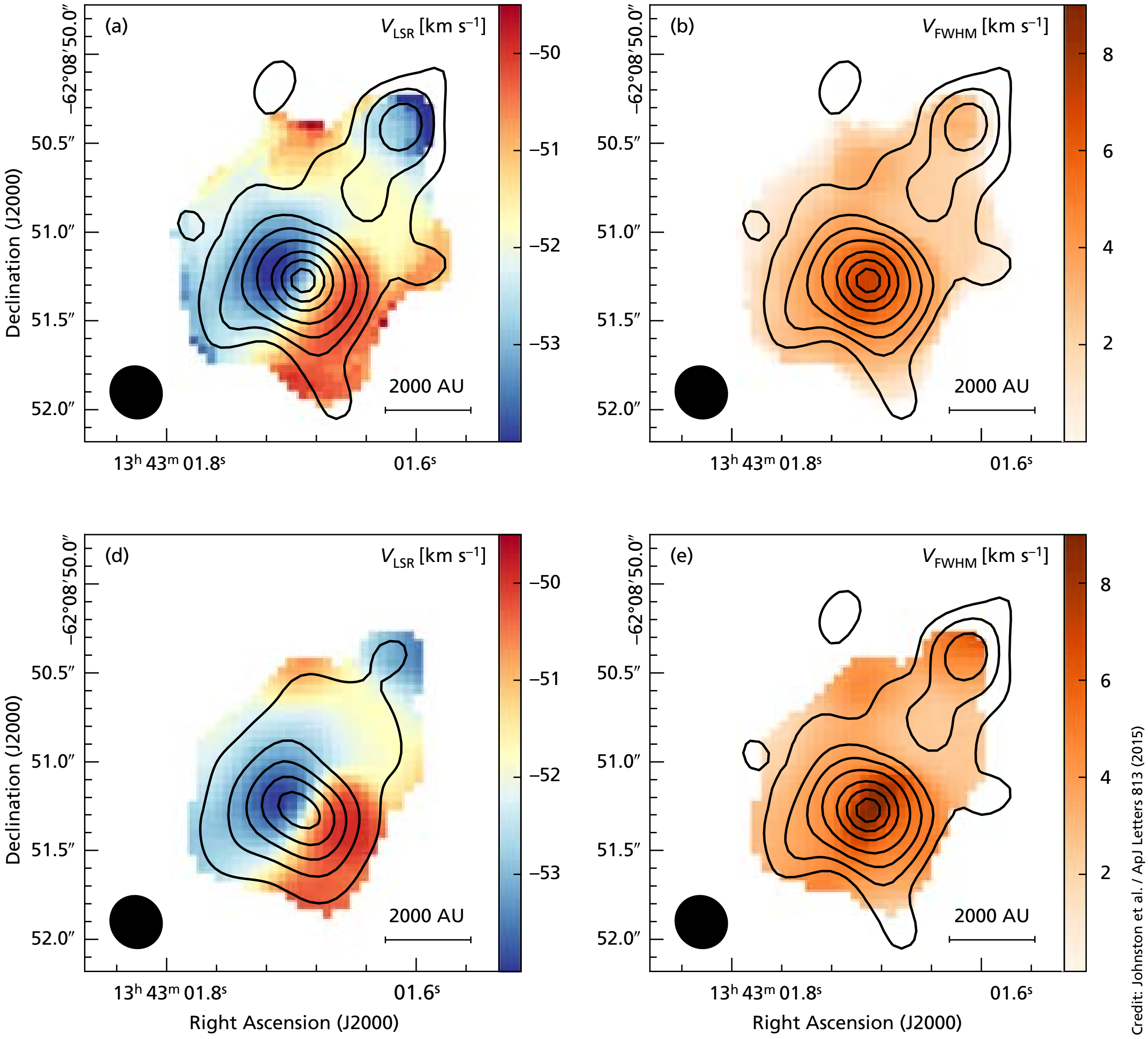


Fig. II.7.3: The top row shows ALMA data for the source AFGL 4176 mm1, specifically the velocity and linewidth of a characteristic spectral line of methyl cyanide that can be used to trace dense gas at temperatures between 10 and several 100 K (CH_3CN, J = 13 – 12, K = 3). The bottom row shows the same quantities determined by fitting a model to the spectrum observed at the position of each pixel in the image. The left-hand column plots gas velocity, as determined by Doppler shifts of the stellar line, with gas in the blue region moving towards us (on average), and gas in the red region away from us (first-moment map), representing a rotating disc seen almost sideways. The right-hand column traces whether gas in each region moves in unison, or with different portions of the gas travelling at different speeds (second-moment map tracing the width of the spectral line).

material: while MIDI traces the warm dust, the ALMA observations allow for the study of the colder dust and gas. In particular the latter are crucial to investigate the kinematics of the gas around the forming star.

Methyl Cyanide shows dense, cool regions

In addition to tracing interstellar material, the astronomers had also hoped that they might find a disc structure – and then find out whether that disc was affected by the presence of hot, ionized gas in the surrounding region. The observations targeted certain frequencies of light (spectral lines) characteristic for methyl cyanide: an organic solvent that is also known as acetonitrile, with the chemical formula CH_3CN.

Light at these frequencies is only emitted from regions that are dense and have temperatures between tens and hundreds of Kelvins; it can thus be used to trace denser structures within gas clouds. In the ALMA observations, most of the dense gas detected in this way was at the same location as a prominent infrared source. This was

Credit: A. Duro / ESO

Fig. II.7.4: Several of the 12 meter antennas that comprise a part of the Atacama Large Millimeter/submillimeter Array (ALMA). The ALMA observatory opened in 2011; its high resolution and sensitivity was crucial for the observations that allowed Johnston et al. to detect the Keplerian disc around a massive star.

a tantalizing hint that there might indeed be a disc of gas orbiting a protostar (which corresponds to the infrared source). But to find out whether this was indeed a rotating disc, additional analysis of a different kind was needed.

Velocity maps for a rotating disc

ALMA observations usually include spectral information, that is, information about the distribution of energy among the various frequencies of the observed radiation. But motion leads to systematic shifts in the frequency of the light: due to the Doppler effect, we see light from a source that is moving toward us at somewhat higher frequencies (blueshift), light from a source that is moving away at lower frequencies (redshift).

For the characteristic light emitted by methyl cyanide, the wavelength for a source at rest can be determined in the laboratory; therefore when astronomical observations show this spectral feature shifted to lower or higher wavelengths than that rest frequency, the gas emitting the light is moving either towards or away from the observer.

Using the ALMA observations, the astronomers were able to create velocity maps, in effect a kind of Doppler shift maps where for each image pixel, the average radial motion of the light-emitting gas in that region is tracked. For AFGL 4176, this kind of map showed the characteristic signature of a disc seen somewhat from the side (inclination angle 30 degrees), with one half of the disc rotating towards us, the other half away from us.

Keplerian or not?

But was this really a Keplerian disc, with a sharp increase of rotational velocity in the disc's inner regions? To answer this question, a more advanced analysis was needed. Johnston and her colleagues began to create models for the disc, with different disc masses, disc radii, distributions of mass within the disc, viewing angles and envelopes of gas around the disc.

Models of this kindincorporate the physics of what is happening in the disc: the spectral type of the star determines the amount of radiation emitted; the radiation in turn heats up the disc, determining disc temperature; the disc shape is a consequence of pressure (which follows from temperature) and the gravitational attraction of both the star and the different regions of the disc itself.

In this way, the researchers obtained more than 10,000 individual models (1512 models, each seen from

7 different angles), covering a variety of different possible situations: discs seen from angles of 10, 20, 30, 40, 50, 60 or 70 degrees; a range of more massive and less massive discs, with different kinds of additional envelopes of surrounding gas, and many more variations besides.

To simulate the appearance of each such disc, the astronomers used radiative transfer models, which simulate how radiation moves through a given configuration of gas and dust, being absorbed and re-emitted, and heating up the various parts of matter (thus creating additional thermal radiation) in proportion to the energy received in each region. As a last step, the astronomers needed to simulate the ALMA observations, arriving at a faithful simulation of how each of those 1512 hypothetical discs would look when observed with ALMA: a simulated ALMA image plus simulated measurements showing spectral lines of varying positions, widths, and brightnesses.

Matching models and observations

The final step was to match simulated with actual observations. The model which produces the best observational match, the reasoning goes, is likely to be the best match for the physical properties of the disc, e.g. mass, radius, viewing angle, and properties of the surrounding gas. The best fit corresponds to models that are close to the following values: a disc in a Keplerian orbit around the star (attracted not only by the mass of the star, but also by the inner part of the disc), with a radius of about 2000 AU (that is, 2000 times the average earth-sun distance) and a total mass of 12 solar masses, its surface density decreasing in a specific way with the radius (proportional to $1/r^{1.5}$).

From a wider perspective, the key message is that this is the best evidence yet that O stars, in other words: some of the most massive stars of all, can be formed in the same way as all other stars – while there are differences in scales and in timing, the basic mechanisms are the same, and matter is funneled onto the growing young star by a Keplerian disc.

Planning the next steps

The quality of the ALMA observation sets the scene for the next stage, which would involve a direct comparison between simulations of how stars form over time (based on equations linking gravity, hydrodynamics, and magnetic fields within the disc) and observations of young massive stars and their disc. Discrepancies would point towards areas where our current understanding of the formation of massive stars would be incomplete or flawed.

The superb resolution of ALMA, allowing for the mapping of the innermost regions of the nascent star system in great detail, is certainly needed for another key observation concerning massive stars: 96 % of all O stars are part of binary systems or even larger multiple star systems. Fragmentation leading to the formation of multiple stars is thought to occur while matter is still accreting onto the protostar.

Higher-resolution observations of the discs of massive protostars could show structures – such as spiral arms – that are conducive to fragmentation, or even the fragmentation into several cores itself that would indicate the formation of companion stars (or instead massive planetary companions of a massive star). Such direct observation of fragmentation would be the next big observational advance in understanding the formation of massive stars.

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K.G. Johnston et al. 2015: "A Keplerian-like Disc around the Forming O-type Star AFGL 4176"
in Astrophysical Journal Letters 813, article id. L19. DOI: 10.1088/2041-8205/813/1/L19

III. Instrumentation and Technology

III.1 Overview

Instrumentation for Ground-based Astronomy

In 2015, MPIA activities in the area of ground-based instrumentation concentrated on spectroscopy, high-fidelity imaging, and interferometric instruments for the ESO telescopes VLT/VLTI, VISTA and for the Large Binocular Telescope (LBT), as well as survey instruments for Calar Alto. MPIA is also involved in building two of the three first-light instruments for the European Extremely Large Telescope (E-ELT), a next generation telescope with a main mirror 39 meters in diameter.

Instrumentation for the Large Binocular Telescope

LUCI 1 and LUCI 2 are two near-infrared cryogenic imaging cameras and multi-object spectrographs for the Large Binocular Telescope (LBT) on Mount Graham in Arizona. The two instruments were built in collaboration with the Landessternwarte Heidelberg, the Max Planck Institute for Extraterrestrial Physics in Garching, the University of Bochum, and the Fachhochschule for Technology and Design in Mannheim.

The LUCI instruments provide a 4 × 4 field-of-view in seeing limited mode – a bit over 1/60 of the apparent area of the full moon in the sky, and extremely wide for an astronomical camera at a large telescope like the LBT.

At the beginning of 2010, the first excellent spectra and images taken with LUCI 1 were published. Particularly remarkable about these instruments is the use they make of adaptive optics – real-time deformable mirrors that can reverse most of the degradation experienced by astronomical images as a distant object's light passes through the earth's atmosphere.

With the adaptive secondary mirrors of the telescope, diffraction-limited performance (that is, observations virtually free of the atmosphere's disturbing influence) over a field of about 0.′5 × 0.′5 is possible. After LUCI 2 had been upgraded to full adaptive optics functionality in the previous year, it was successfully used in AO mode in January 2015. Later in the year LUCI 1 underwent the same upgrade and is now waiting to be tested on sky. Adaptive optics permits users to achieve spectral resolving powers of several tens of thousands. The various scientific applications for the multi-mode LUCI instruments include the study of star formation in nearby galaxies.

Adaptive optics makes use of reference stars to determine image distortion by the atmosphere and calculate the necessary corrections. Such reference stars, however, need to have a certain brightness – and there is no guarantee that astronomers will find a sufficiently bright star within the same limited field of view as their observation target. That is the rationale behind the ARGOS laser guide star system: ARGOS creates artificial reference stars on the night sky, which can be used with the two LUCI instruments. For one side of the telescope, ARGOS had first light in 2015 and was commissioned until mid-2015, with major MPIA involvement, while for the other side it had first light in December 2015 and will be commissioned in the months to come.

The largest current MPIA instrumentation project by far is the near-infrared beam combiner LINC-NIRVANA (L-N), which was disassembled and shipped to the LBT where it arrived in October. Subsequently, it experienced a successful test installation of its main structure at the telescope in November. It is now in the integration facility at the LBT in order to become fully reassembled and aligned during much of 2016 before it will finally be installed at the LBT in September. MPIA is the lead institute in the L-N consortium, which also includes the Italian Observatories (INAF), the Max Planck Institute for Radio Astronomy in Bonn, and the University of Cologne.

The initial aim of the instrument will be to deliver multi-conjugated adaptive optics imagery over a 10.″5 × 10.″5 field of view in the near-infrared regime at wavelengths between 1 and 2.4 µm. An optional future implementation step could provide diffraction-limited imaging with the spatial resolution of a 23 meter telescope. This would be achieved by coherent combination of light from the two LBT primary mirrors via Fizeau interferometry.

Scientific targets of LINC-NIRVANA range from supernova cosmology, galaxy formation, and extragalactic stellar populations and star formation, to extrasolar planets, stellar multiplicity, the structure of circumstellar discs, and the imaging of solar-system planets and their atmospheres.

In preparation for the test installation of LINC-NIRVANA at the LBT the test system Pathfinder that had successfully demonstrated the communication of one LINC-NIRVANA wavefront sensor with the adaptive optics secondary of the telescope was removed from the telescope.

Instrumentation for ESO's VLT/VLTI and for the VISTA telescope

MPIA is participating in the second-generation projects MATISSE and GRAVITY for ESO's Very Large Telescope Interferometer (VLTI) at Paranal Observatory. VLTI combines multiple telescopes of the Very Large Telescope (VLT), namely different combinations of the 8.2 meter unit telescopes and the 1.8 meter auxiliary telescopes.

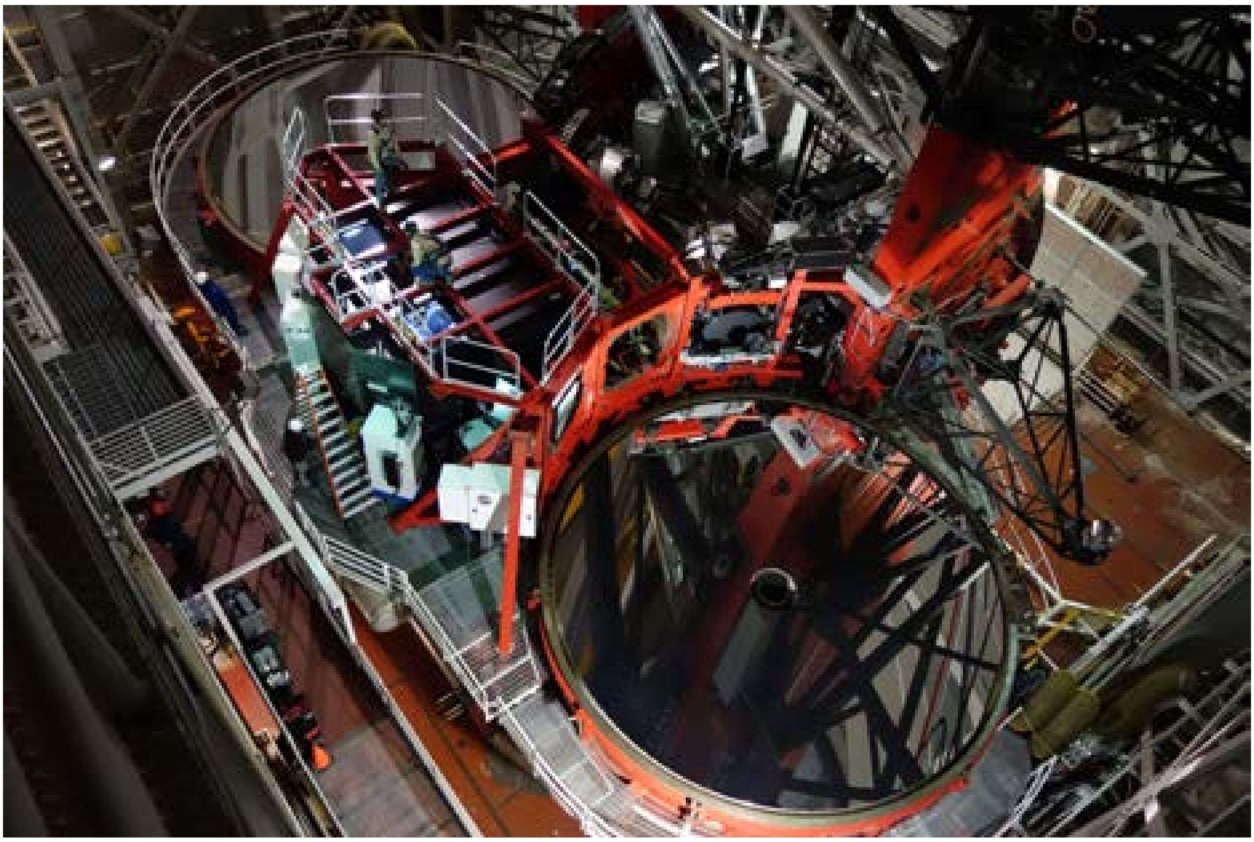
The MATISSE consortium consists of nine institutes led by the Observatoire de la Côte d'Azur. MATISSE will combine the light from all four VLT unit telescopes in the mid-infrared for high spatial resolution image reconstruction on angular scales of 10 – 20 milliarcseconds. Scientific applications range from studies of Active Galactic Nuclei (AGN) to the formation of planetary systems and of massive stars, as well as the study of circumstellar environments. After having delivered in 2014 its contributions to MATISSE, the two main instrument cryostats, to the point of final instrument integration in Nice (France), MPIA was involved in preparatory work for the acceptance of the instrument by ESO prior to shipment which is planned for mid-2016.

GRAVITY will also combine the light of the four VLT unit telescopes, but in the near-infrared. The GRAVITY consortium is led by the Max Planck Institute for Extraterrestrial Physics in Garching; the partners include MPIA, the observatories in Paris and Grenoble, and the Universities of Cologne and of Lisbon. Assisted by a high-performance adaptive optics system, GRAVITY will provide precision narrow-angle astrometry and phase referenced imaging of faint objects over a field of view of 2".

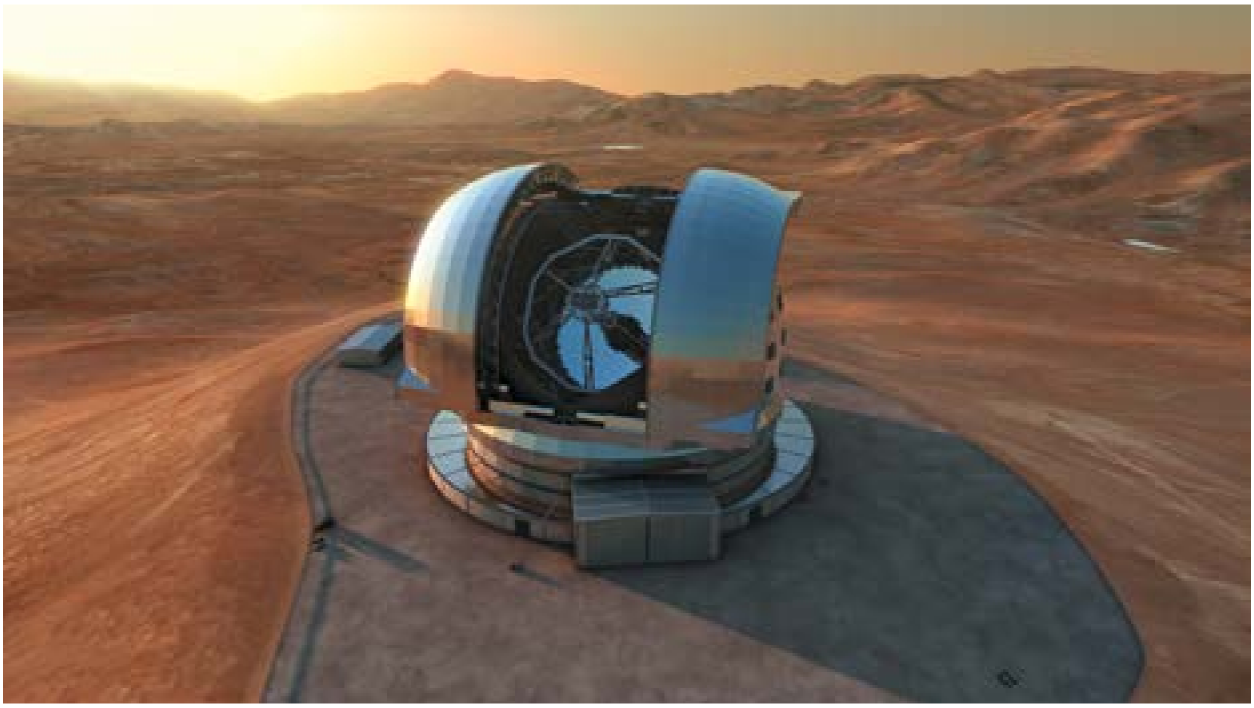
While the beam combiner part of the GRAVITY instrument has been installed on Paranal in 2015 (an in fact it has already seen first light at the time of writing this article), other components such as the metrology system as well as MPIA's main contribution, the four wavefront sensor systems, will be installed in 2016. After a very intense phase of redevelopment of the wavefront sensors the first of these systems is ready to be shipped in February.

Applications of GRAVITY include the study of motions close to the massive black hole in the galactic center, the direct detection of intermediate mass black holes in the Milky Way galaxy, dynamical mass determina-

Fig. III.1.1: The Large Binocular Telescope (LBT) on Mount Graham in Arizona (USA). With its two 8.4 meter mirrors on a single mount, the LBT is currently the largest single telescope in the world with a total light gathering power of a 12 meter telescope. The image was taken during the test installation of the main LINC-NIRVANA structure, which consists of the instrument cover (black surface between the two primary mirrors) with the optical bench under it and the electronics cabinets (e.g. next to the ladder on the left). Above the LINC-NIRVANA cover the observatory installed the basic structure of a platform for human access.



Credit: T. Bertram / MPIA



Credit: ESO / L. Calçada

Fig. III.1.2: Artist's impression of the European Extremely Large Telescope (E-ELT) on Cerro Armazones in Chile close to ESO's VLT on Paranal. The kick-off for the preliminary design phases of the first light instruments took place in early fall 2015.

tions of extrasolar planets, the origin of protostellar jets, and the imaging of stars and gas in obscured regions of active galactic nuclei (AGN), star forming regions, or protoplanetary discs.

For the instrument SPHERE, a VLT instrument specialized for the imaging of Jupiter-like extrasolar planets, MPIA is a Co-PI institute in a consortium that includes the Laboratoire d'Astrophysique de l'Observatoire in Grenoble, the Laboratoire d'Astrophysique in Marseille, ETH Zürich, and the University of Amsterdam.

The main challenge for SPHERE is to overcome the huge disparity in brightness between extrasolar planets and their host stars. To this end, the instrument uses eXtreme Adaptive Optics (XAO), and coronagraphy (that is, a physical obstruction blocking the star's light in the telescope's optical path). It features three sub-instruments in the focal plane that are capable of differential imaging, that is, of comparing different images of a planet and its host star, with a view towards distinguishing between the image of the planet and various image artefacts. The three sub-instruments employ polarimetry in the visual, dual imagery in the near-infrared, and integral field J-band spectroscopy, respectively. After science verification phases in December 2014 and February 2015, SPHERE has begun regular operations and is highly demanded by the community.

The project 4MOST, which MPIA joined in 2014, is a multi-object spectrograph for the 4.1m VISTA telescope at ESO's Paranal observatory. It is currently in its preliminary design phase which is expected to end in May 2016 with the pertinent review after which the final design phase will commence. The project is led by the Astrophysical Institute Potsdam. MPIA is responsible for the instrument control electronics. The instrument is supposed to study the origin of the Milky Way and its chemical and kinematic substructure, as well as the evolution of galaxies. To this end it will employ 2400 fibres over a field of view of 4 square degrees, enabling simultaneous spectrography of up to 2400 different objects within the field of view.

Survey instrumentation for Calar Alto (CAHA) and other Observatories

The Panoramic near-infrared Camera (PANIC) is a wide-field general purpose instrument for the CAHA 2.2 meter telescope and a joint development of the MPIA and the Instituto de Astrofísica de Andalucía. With four Hawaii2-RG detectors, it provides a field of view of 30' × 30' (corresponding to the apparent size of the full moon in the sky), allowing for surveys of extragalactic, galactic, and solar system objects. Having had First Light in November 2014, PANIC has become operational in April 2015.

CARMENES is a high-resolution near-infrared and optical Échelle Spectrograph currently being built for the CAHA 3.5 meter telescope by a consortium of German and Spanish institutions. After successful commissioning of both spectrographs in the second half of 2015 the instrument has commenced a survey in January 2016 of 300 M-type main-sequence stars in order to find exoplanets in their habitable zones.

The search for transiting extrasolar planets by surveying a large number of nearby stars is the goal of the HATSouth project, a collaboration of MPIA with Princeton University, the Australian National University, and the Pontificia Universidad Católica de Chile. HATSouth is a network of 24 small-sized automated telescopes located at Las Campanas in Chile, Siding Springs in Australia, and at the H.E.S.S. site in Namibia. MPIA is responsible for the site preparation and operations of the Namibian node.

MPIA scientists also continue to use the ESO/MPG 2.2 meter telescope at La Silla, namely for special survey work.

The European Extremely Large Telescope (E-ELT)

In 2010, an ESO commission led by MPIA, finished the search for the site of the planned 39 meter E-ELT. The telescope will be located on the Cerro Armazones mountain in Chile's Atacama Desert, in close proximity to ESO's existing Paranal observatory.

In late 2014 the ESO council took the decision to go forward with the construction of the telescope and its first-light instruments. MPIA participates in two of the (three) first-light instrumentation projects: METIS and MICADO. Both projects had their kick-off for the phase of trade-off studies and preliminary design in early fall 2015.

METIS is a thermal/mid-infrared imager and spectrograph covering a wavelength range between 3 and 19 microns. Adaptive optics will permit the instrument to perform diffraction-limited observations. The instrument's science case includes the conditions in the early solar system, the formation and evolution of protoplanetary discs, studies of the galactic center and of the luminous centers of nearby galaxies, high-redshift active galactic nuclei and high-redshift gamma ray bursts.

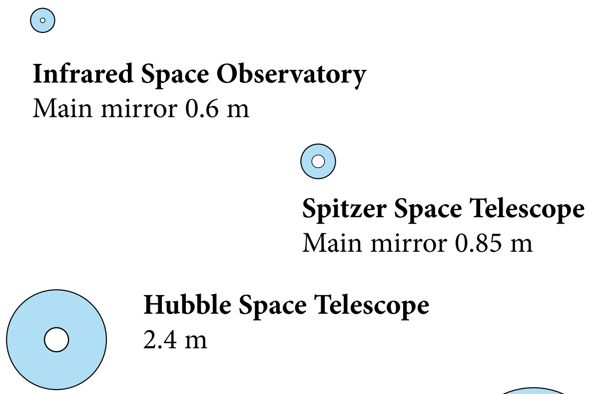
MICADO is a near-infrared imaging camera with multi-conjugated adaptive optics that will provide a spatial resolution exceeding that of the James Webb Space Telescope (JWST; the successor to the Hubble Space Telescope) by a factor of 6 to 7. It will have a sensitivity down to 29 mag – in visible light, this would include stars more than a billion times fainter than those which are visible with the naked eye – in the near-infrared bandpasses from I to K.

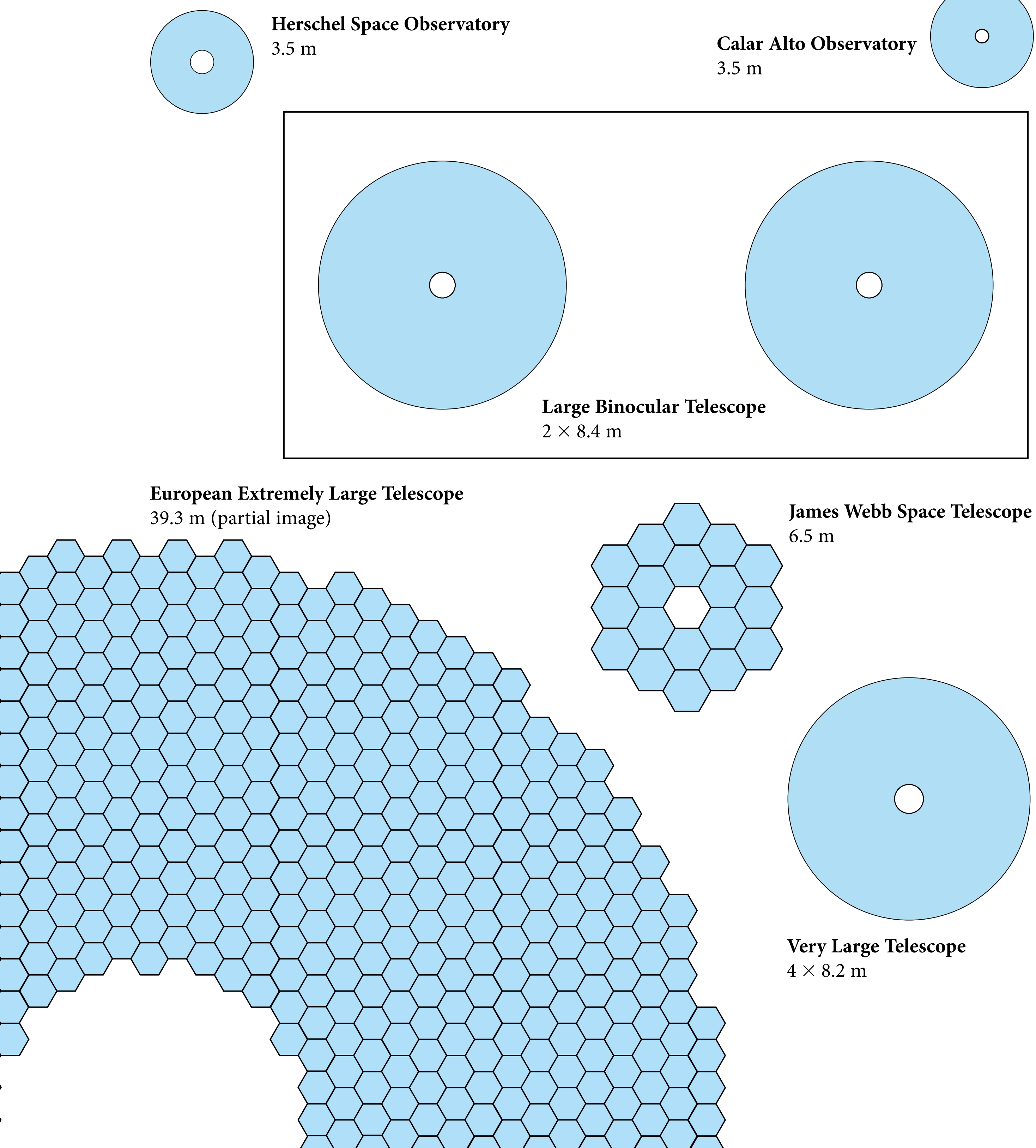
Scientific targets for MICADO include young stellar objects in our galaxy, but also star formation in high-redshift galaxies. High astrometric precision will further advance studies of stellar orbits around the black hole in the galactic center, of the proper motions of globular clusters, the structure, the stellar populations, and the interstellar dust distribution in galaxies with redshifts $z < 1$.

Martin Kürster
for the MPIA Technical Departments

Telescope Mirror Sizes

Shown here are shape, structure and size of the main mirrors of selected telescopes that are used by MPIA scientists. For a number of these telescopes, MPIA has contributed or is contributing to instrumentation.





III.2 Overview

Instrumentation for Space-based Astronomy

James Webb Space Telescope (JWST)

The James Webb Space Telescope (JWST), a space telescope for wavelengths from visible light to the mid-infrared, is on track for launch in autumn 2018 as successor to the Hubble Space Telescope. With its cold 6.5 meter primary mirror and four science instruments, JWST will be the premier infrared observatory in space for a decade to come.

MPIA is the leading institute in Germany for the development of instrumentation for the JWST. As a member of a European consortium, MPIA is responsible for the development of the cryogenic wheel mechanisms required for precise and reliable positioning of the optical components in JWST's mid-infrared instrument MIRI and is also leading the electrical system engineering of this instrument.

MIRI consists of a high-resolution imager and a medium resolution spectrometer and will work in the wavelength range from 5 to 28 micrometers. MPIA has also delivered vital components such as cryogenic motors and high-precision position sensors for the near-infrared multi-object spectrograph NIRSPEC, the second of two JWST science instruments that have mainly been developed in Europe.

Since the delivery of the MIRI instrument to the NASA Goddard Space Flight Center (USA) for integration into the JWST integrated science instrument module, the instrument has been undergoing a series of rigorous testing campaigns. In 2015, the third full cold test campaign CV3 with all four JWST science instruments was successfully completed. For this campaign, MIRI, together with other instruments on the telescope's Integrated Science Instrument Module (Figure III.2.1), were subjected to temperatures of less than -230° C and to vacuum conditions, simulating the environmental conditions under which they will need to operate once deployed into space.

Fig. III.2.1: Group photo of JWST project members with the complete Integrated Science Instrument Module. The near-infrared Spectrograph NIRSpec was just added, completing the package of four instruments. The other instruments are the mid-infrared instrument MIRI, in which MPIA is also involved, a near-infrared camera and the camera-spectrograph combination NIRISS. The fine guidance sensor has also already been installed on the module.

Credit: NASA

Credit: NASA

Fig. III.2.2: A close-up view of the eighteenth and final James Webb Space Telescope primary mirror segment being installed on the telescope. The black covers are protecting the gold-coated mirror segments.

The NIRSPEC instrument was equipped with the flight detectors and the flight micro-shutter array to provide NIRPSPEC's multi-object capabilities. All MPIA wheel mechanisms showed an excellent and reliable performance. The MPIA JWST team significantly contributed to the preparation, conduction and analyses of these tests on site. The team is also deeply involved in the development for the future data processing pipeline for the MIRI instrument.

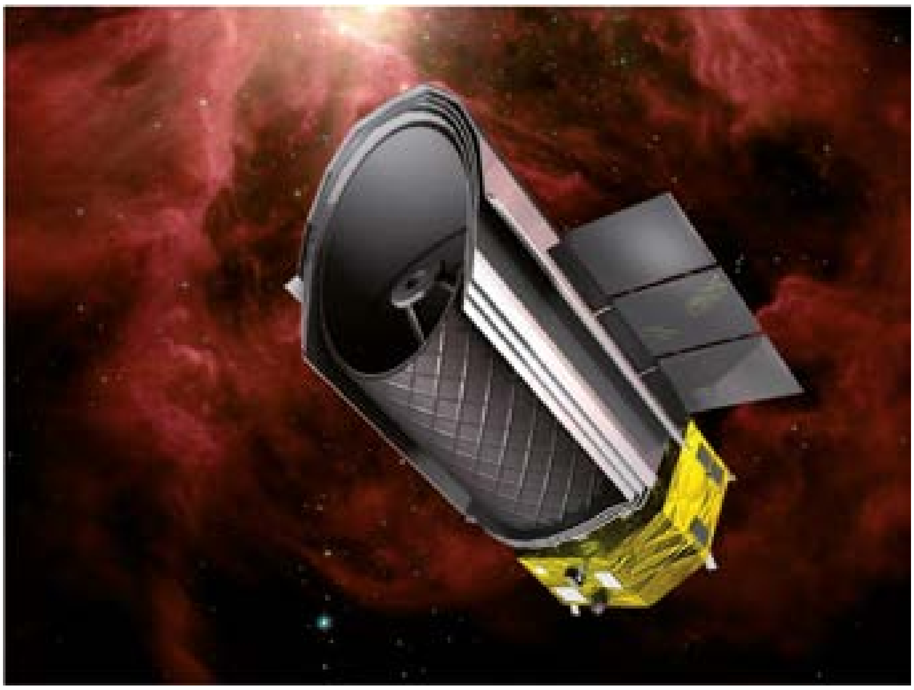
Other main components of JWST advanced significantly during the year 2015 as well. The installation of the flight telescope structure consisting of the 18 primary mirror segments was completed by February 2016 (see figure III.2.2). The mirrors were mounted in adjustable optics segments onto the primary mirror backplane support structure, made of lightweight carbon fiber composite material. The ability to adjust the mirrors in space is required in order that the primary segments can be "phased" and act as one monolithic mirror. The secondary mirror must also be adjustable in this manner. In addition, the first flight membranes for JWST's tennis court sized sunshield were delivered. The manufacture of the remaining sunshield layers and the manufacture of the sunshield structure will continue into the year 2016.

During the week of the 12th to 16th of October 2015, an international conference took place that was dedicated to the presentation and discussion of future scientific research that will be enabled by JWST "Exploring the Universe with JWST", it took place at the European Space Agency ESTEC center in the Netherlands. A total of 200 researchers including MPIA scientists attended the conference, giving talks, presenting posters or simply listening to and participating in the discussion sessions. Reflecting the richness and variety of JWST scientific goals, the presentations covered scientific topics ranging from studies of planets and planetary systems (including our solar system) to deep imaging and spectroscopic surveys targeting the reionization epoch and the birth of the first galaxies.

Herschel and SPICA

Europe's far-infrared and submillimeter space observatory Herschel was launched in 2009 and provided observational data until April 2013. The space observatory continued throughout the year 2015 its final formal phase, the post-operations phase. During this phase, the aims are to consolidate and archive the exquisite data sets that Herschel delivered during its active four-year mission. Recent focus has been to prepare the data analysis and calibration for the final inclusion of all Herschel observations in the Herschel Legacy archive, which will be compliant to Virtual Observatory standards and allow for efficient archive research. The unprecedented observations from the Herschel mission will remain reference data for far-infrared observations for years to come.

MPIA has been one of the four major partners in the development of the PACS instrument, which enables imaging and spectroscopy in the wavelength range from 60 to 210 micrometer with unprecedented sensitiv-



Credit: ESA

Fig. III.2.3: Conceptual design of the SPICA far-infrared observatory.

ity and spatial resolution (the PI institute was the Max Planck Institute for Extraterrestrial Physics in Garching). MPIA was responsible for delivering the PACS focal plane chopper (a device allowing frequent comparisons between the object under study and the celestial background) and for characterizing the spectrometer cameras and their -270° C readout electronics (which is a necessary step to understand the data they provide).

The institute also coordinated a large number of tasks for the calibration of the instrument and was responsible for establishing the PACS performance verification phase plan and the central PACS calibration document. In particular, the MPIA team has exclusively carried out the detailed mission planning of all PACS performance verification phase operational days, with the help of dedicated software tools, and has delivered the observational data bases to the Herschel Science Center at ESAC in Villafranca (Spain) and the Mission Operations Center at ESOC in Darmstadt (Germany). The MPIA team also designed a corresponding calibration plan for Herschel's routine phase and ensured the optimum inflight setup of the Ge:Ga spectrometer detector arrays, following a procedure developed in MPIAs space laboratory.

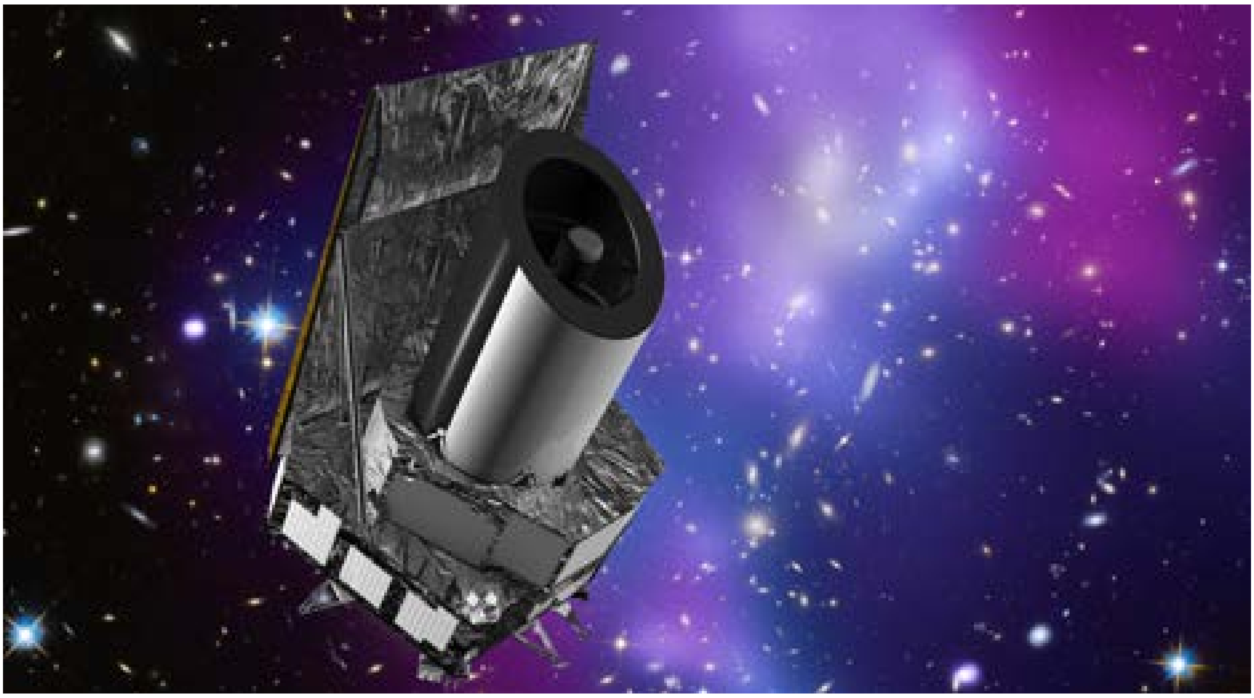
As a possible successor to Herschel, the Space Infrared Telescope for Cosmology and Astrophysics SPICA (figure III.2.3) is currently under study as one of the candidate astronomy missions of ESA's Cosmic Vision space science program. The mission is foreseen to feature a ~ 2.5 meter cryogenic IR telescope, providing a sensitivity advantage of up to two orders of magnitude over Herschel, mostly for spectroscopic observations. SPICA is planned to be proposed as mid-size mission M5 with European leadership and strong participation by the Japanese Space Agency Jaxa with a potential launch date in the year 2029. In the European consortium for SPICA's far-infrared SAFARI instrument (PI: P. Roelfsema, SRON) MPIA's role is responsible for cryogenic detector testing and the definition and design of the filter wheel mechanism.

Euclid

The nature of dark matter and that of dark energy are two of the key open questions in contemporary cosmology: Dark matter does not interact with light or other radiation, yet makes its gravitational influence felt in galaxies, galaxy clusters, and in the expansion of the universe as a whole. Dark energy was introduced to explain the unexpected discovery, published in 1999 and earning its discoverers the 2011 Nobel prize in physics, that cosmic expansion is not slowing down, but accelerating.

ESA's dark energy mission Euclid (figure III.2.4) is set to tackle these open questions by mapping the geometry of the "dark universe". The mission, which is on track for a 2020 launch, will utilize high-fidelity imaging and spectroscopy in the visual and near-infrared wavelength ranges to map extragalactic objects within 15,000 square degrees of the sky. Its goal is to measure the evolution of cosmic expansion and the distribution of dark matter across cosmic time from a time 10 billion years in the past (redshift $z = 2$) to today.

Euclid will carry two instruments. The first is VIS, a visible wavelength range imager for high spatial resolu-



Credit: ESA

Fig. III.2.4: Current Euclid satellite design. The diameter of the primary mirror is 110 cm.

tion mapping of galaxy structures. It will be used to create a three-dimensional map of weak gravitational lensing across the universe – tiny, statistical effects caused by the deflection of light by mass in the universe, giving information about large-scale mass distribution.

The second instrument is the NISP near-infrared spectrometer and photometer whose development is led by the Laboratoire d'Astrophysique de Marseille (LAM). NISP will provide spectroscopic distance measurements of three-dimensional clustering properties of 50 million galaxies. It will also provide the infrared photometry component for so called photometric redshift distances for one billion galaxies.

MPIA contributes to programmatic work in Euclid, specifically by overseeing all calibration strategies, and also to the planning and construction of the NISP instrument. The Euclid group at MPIA is responsible for overseeing hardware performance which includes to simulate the instrumental abilities and detailed detector properties during the construction of the instrument. In addition, a major MPIA contribution will be hardware components for NISP, namely the near-infrared filters and the calibration light source, funded by the German national aerospace agency DLR.

In 2015, the Euclid group at MPIA worked on addressing all remaining issues from the Preliminary Design Review in 2014 as a preparation for the next step, the Critical Design Review, which is scheduled for early 2016. This included securing funding for the remainder of the development and production. Once all components and the overall instrument have passed this re-

Fig. III.2.5: Structural and thermal model of the Euclid calibration source as delivered in December 2015 to the Laboratoire d'Astrophysique de Marseille (LAM) for installation as part of an instrument model.

Credit: von Hoerner & Sulger GmbH / Schwetzingen; F. Hormuth / MPIA view, production will start for those components that will actually be used during the flight. The delivery of both the filters and the calibration source to the other project partners is slated for 2017.

In the past year, a detailed flight model design for the filters was made by an industry partner, and test coatings showed very good performance inside the specifications, using a complex stack of 200 interference filter layers. Also, glass was ordered as a preparation for producing the filter substrates in France. In 2016 and 2017, the final versions of the filters will be manufactured and tested.

The NISP calibration source weighs in at a mere 600 g, but forms the core of calibrating NISP detectors in flight. Our design based on light-emitting diodes (LEDs) instead of the usually used tungsten filaments allows for better time-stability of light emission and a choice of five wavelengths from 900 to 2000 nm. Hence, it can be used not only to calibrate the relative pixel-to-pixel response of the detectors, but also to re-measure the instrument's response as a function of light intensity and wavelength. This is crucial, since infrared-detectors show bandpass-dependent sensitivity and a substantial non-linear transfer of input to output, and this would, otherwise, fundamentally limit the accuracy of the photometric data calibration.

The novel MPIA approach requires the qualification of LEDs for use in space, which includes exposing them to cryogenic temperatures, vacuum and a high-radiation environment. This is complex work which started in 2014 and will stretch into 2017. The design of the calibration source was completed in 2015 and a model containing all the mechanical parts, ready for testing the unit's structural and thermal properties, has already been completed and delivered to LAM (figure III.2.5).

Overall, Euclid at MPIA is well on track towards the final design of the NISP instrument by end of 2016, and a completion of the whole instrument in 2018. MPIA's involvement in Euclid will not stop there, but will shift towards contributions to the computing ground segment and, later, to exploitation of the vast and unprecedented dataset.

This will include highly interesting analyses outside the mission's nominal main science goals: With a substantial high spatial-resolution visible imaging dataset (0.1 arcseconds) and deep infrared data ($S/N = 5$ for point sources at 24 magnitude) for over a third of the sky, the possible science applications are vast, ranging from observational studies of galaxy evolution to the discovery and characterization of exoplanets.

Oliver Krause for the IR Space Group

and

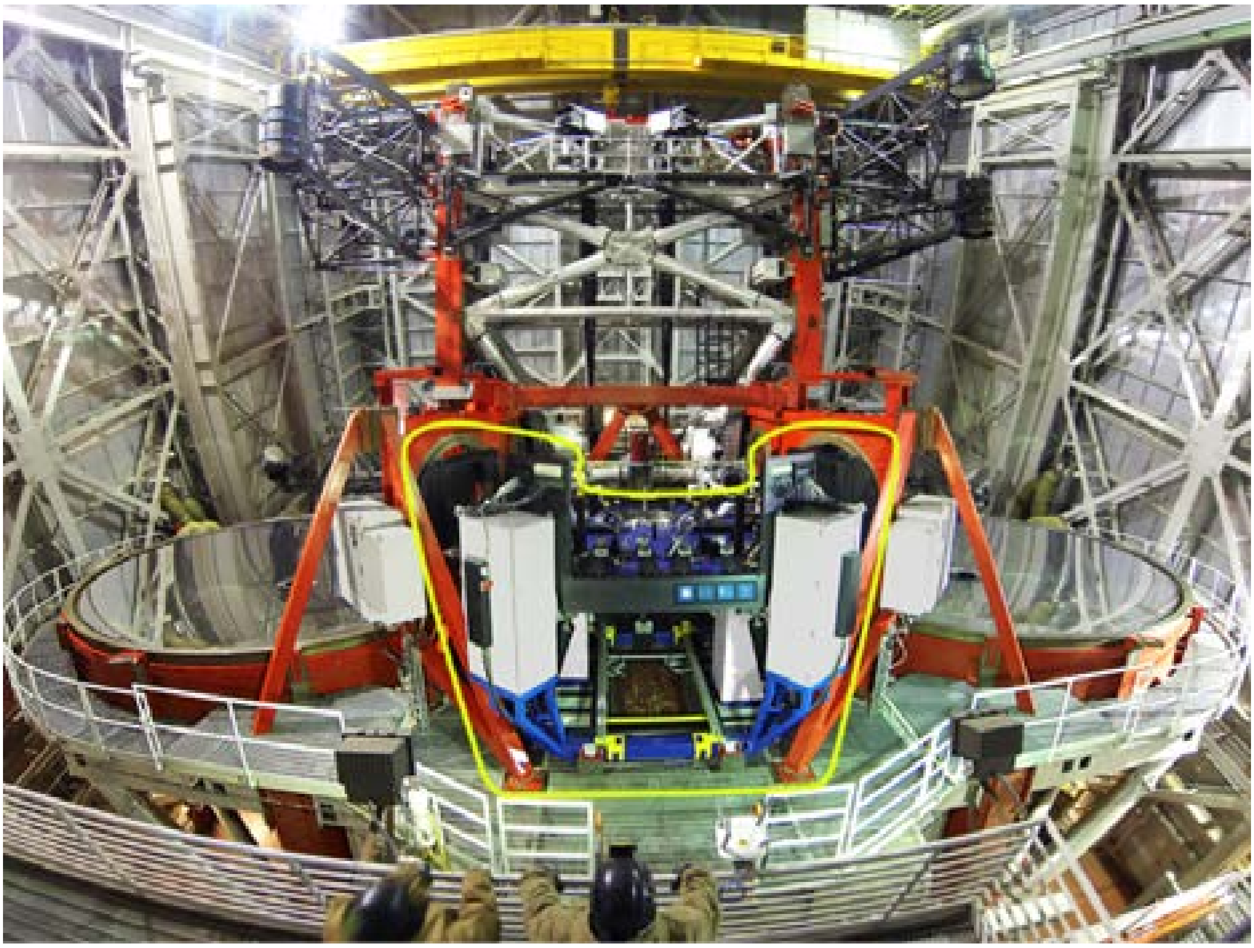
Knud Jahnke for the Euclid Group

III.3 Instrumentation and Technology

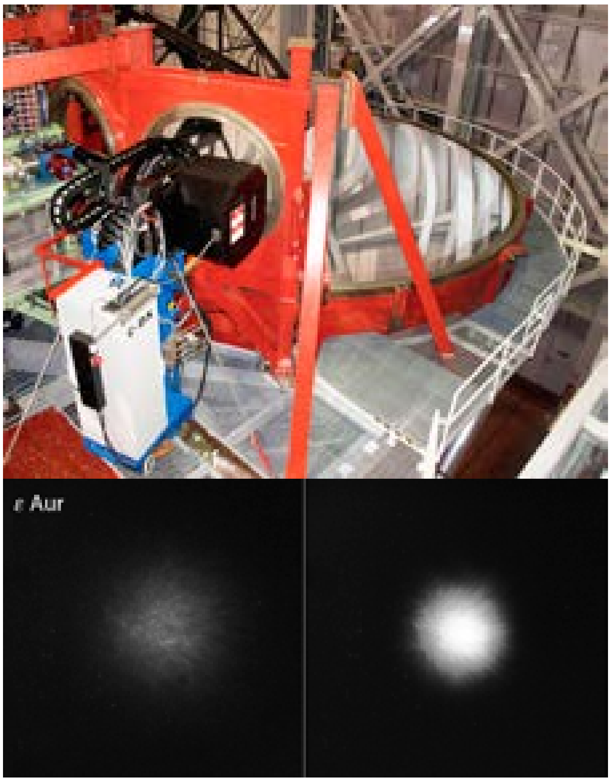
LINC-NIRVANA: On its Way to First Light!

LINC-NIRVANA (LN) is an innovative high-resolution near-infrared imager for the Large Binocular Telescope (LBT). LN employs Multi-Conjugate Adaptive Optics (MCAO) to deliver a diffraction-limited field of view two arcminutes across. There are actually two MCAO systems in LINC-NIRVANA, one for each of the 8.4 meter diameter mirrors of the LBT. The instrument accepts light from both telescopes and is designed for both conventional, single-eye imaging and eventually, interferometric beam combination: in the interferometric mode, which is not implemented at this stage, the instrument would combine light from both of the LBT's mirrors so as to produce an instrument with a resolution equivalent to a single 23 meter telescope. During 2015, the LINC-NIRVANA team completed final laboratory tests at MPIA, passing the Preliminary Acceptance Europe review in May. Packing and shipment took place over the summer, and the team installed LINC-NIRVANA for the first time on the telescope at Mount Graham Observatory for preliminary tests in November (figure III.3.1).

Fig. III.3.1: LINC-NIRVANA (inside yellow line) mounted at the rear bent focus of the Large Binocular Telescope in Arizona in November 2015. For safety, the sensitive optical components were not in place for this initial installation. Note for scale that the primary mirrors are 8.4 meters in diameter.



Credit: T. Herbst / MPIA



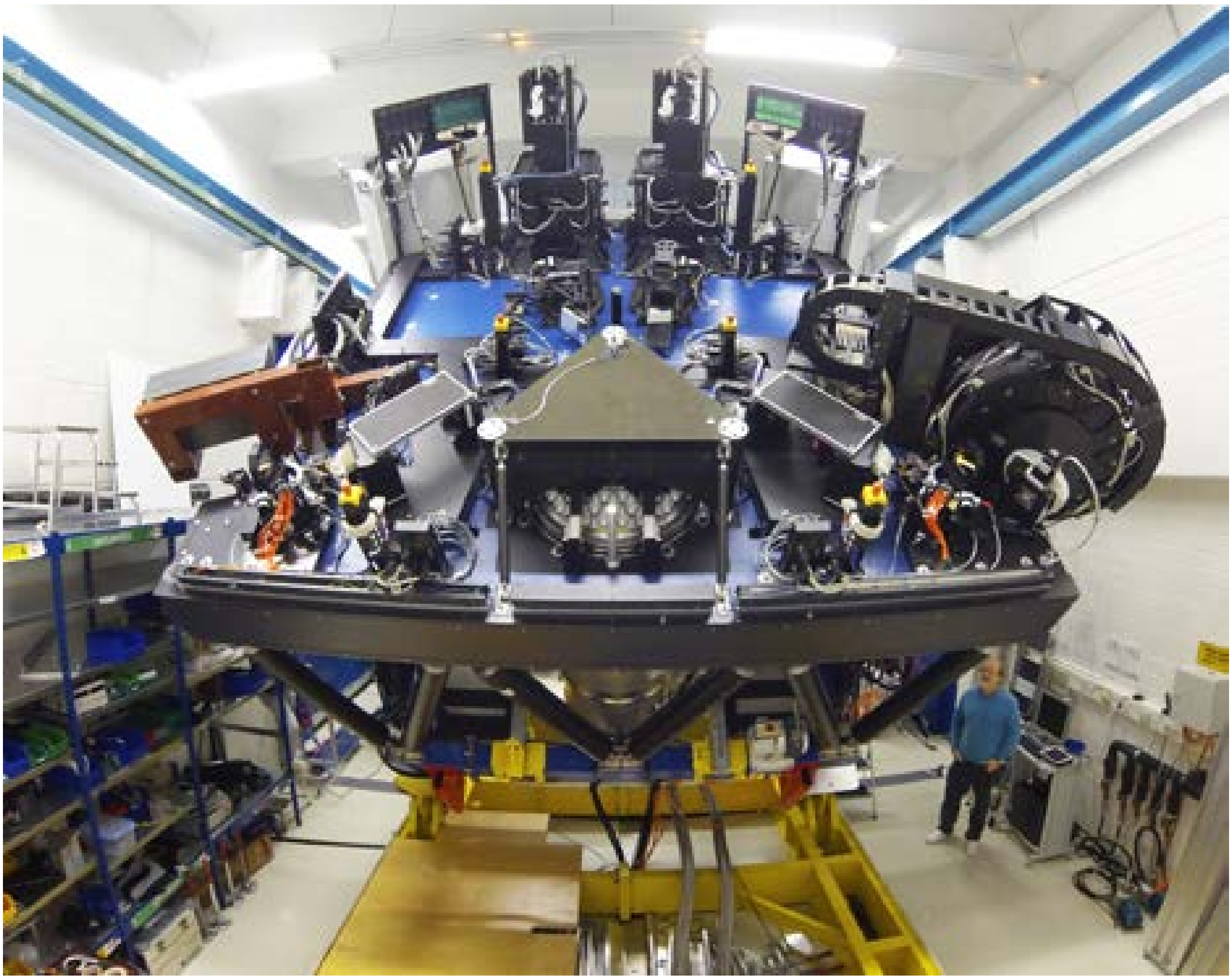
Credit: T. Herbst / MPIA

Sharper eyes for sharper insight

LINC-NIRVANA represents a major step forward in our ability to image the Universe with the maximum possible spatial resolution that our telescopes can deliver. Conventional observations are limited by atmospheric turbulence, which can blur the intrinsic optical quality of a telescope by a factor of twenty or more. Indeed, without atmospheric correction, even the largest astronomical facilities in the world cannot deliver images sharper than those from a hobbyist's 20 cm backyard telescope.

The development of adaptive optics (AO) at the end of the 20th century has enabled astronomers to overcome this obstacle. A typical AO system uses measurements of a single bright star or, alternatively, a laser spot projected high into the atmosphere, to provide infor-

Fig. III.3.2: Left: The Pathfinder experiment demonstrated AO loop performance at the LBT in November 2013. The inset shows the Pathfinder "first light" correction of a star. Below: Flexure testing the fully-populated LINC-NIRVANA bench in the integration hall at MPIA. Note the person at lower right for scale.

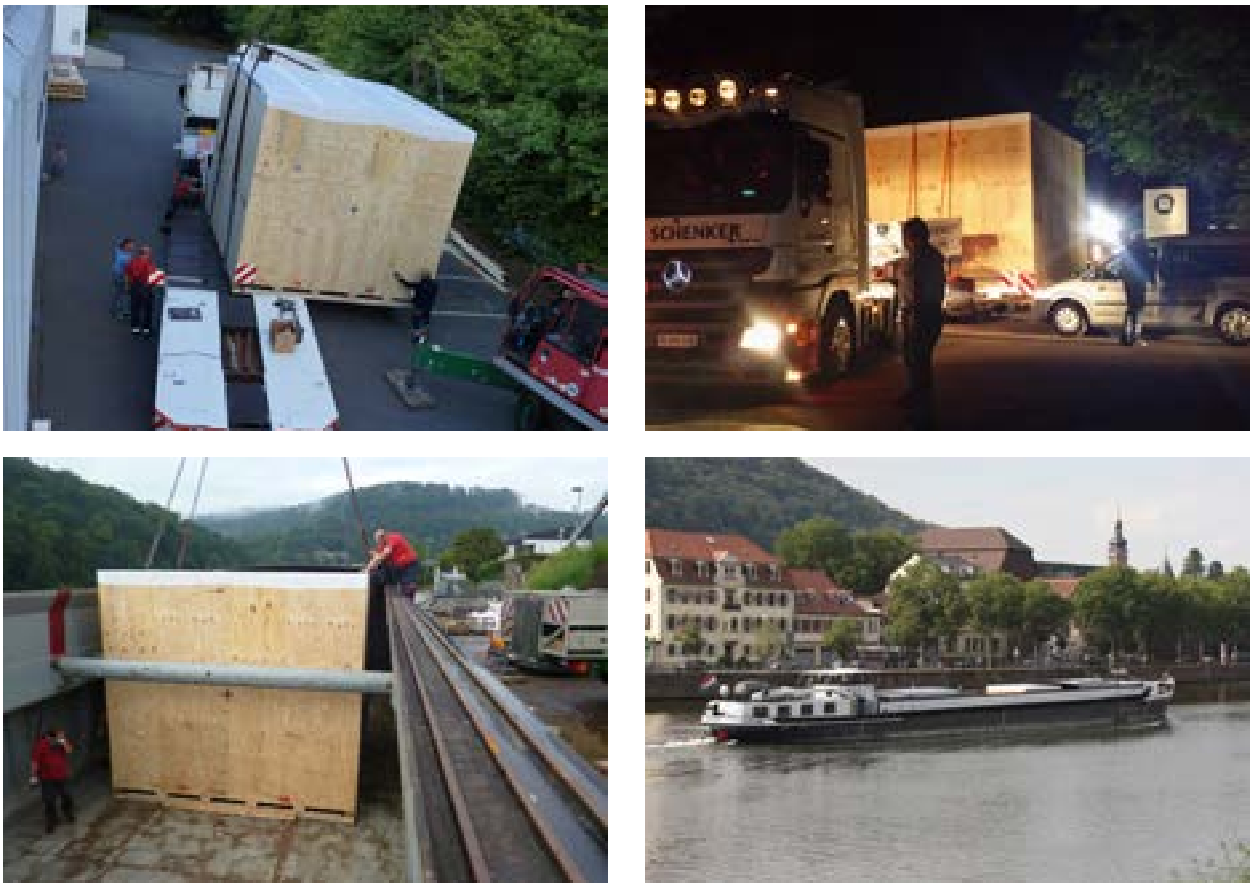


Credit: T. Herbst / MPIA

mation on the atmospheric distortion. Given this information, a flexible mirror will apply suitable corrections in real time. When done properly, AO can deliver incredible imagery, limited only by the optical phenomenon of diffraction, an unavoidable, fundamental limit set by the diameter of the telescope.

Unfortunately, conventional adaptive optics only allows for high-resolution observations of tiny patches of sky. Typical corrected fields of view are only a few arc seconds across under the best conditions. Multi-Conjugate Adaptive Optics, on the other hand, exploits the presence of multiple reference stars to expand the corrected field of view enormously. For example, the LINC-NIRVANA MCAO system can deliver a fully corrected field two arc minutes across! This is more than a hundred-fold increase over prior systems. As an added bonus, MCAO images are very uniform across the full focal plane, and do not suffer from field-dependent degradation typical of single-reference-star AO.

Fig. III.3.3: The LINC-NIRVANA optical bench begins its journey to LBT. Top left: Loading the large custom crate onto a "low-boy" transporter to enable safe passage under bridges and other obstructions. Top right: The late night trip from the Königstuhl to the Neckar river. Bottom left: Transfering the optical bench to the barge. Bottom right: The *Venture* with its single, large cargo item passes the old town of Heidelberg, heading for the North Sea.



Credit: D. Anders, T. Bertram, T. Herbst / MPIA

These advancements make a number of exciting science projects possible for the first time, and in preparation for early observations, the LN team has developed a diverse early science program. Highlights include a project to exploit the wide-field, uniform image quality to search for intermediate-mass black holes in globular clusters, and to perform an accurate stellar membership census of nearby massive star-forming regions down to previously unattainable levels. Such observations should reveal whether the star (and ultimately planet) formation process is uniform throughout the Galaxy.

Final laboratory tests

LINC-NIRVANA is a large, complex instrument consisting of multiple subsystems, hundreds of optical components, eight science-grade detectors (six visible, two infrared), and almost a thousand individual electrical cables. Getting all of this hardware to work together is a challenging task, and the team attacked it hierarchically, verifying individual components and subsystems in the laboratory before integrating them into the instrument. The final step in this hierarchical process was overall system verification, which took place in the MPIA integration hall in early 2015. Important tests included verification of the second of LN's two adaptive

Fig. III.3.4: LINC-NIRVANA arriving at LBT. Left: The 42 km journey from base camp to the summit was accomplished in a single day. Right: The large crate joined four of the nine shipping containers in the high bay of LBT. Due to space constraints, the other five remained at base camp until needed.

optics control loops using laboratory turbulence (the first loop had already been tested on-sky with the Pathfinder experiment in late 2013).

What makes an instrument like this more of a challenge than a stationary setup in a laboratory is that the instrument will be installed on the telescope itself – and just as the telescope will need to be tilted to varying degrees as it is aimed at specific celestial targets, so will the instrument be tilted. All optical pathways and other components will need to work just as well with the instrument horizontal as they will with the instrument tilted by nearly 90 degrees. These tilts can be simulated using a special platform on which the LINC-NIRVANA test installation is based in the MPIA integration hall, and indeed the team was able to demonstrate consistent performance as the telescope and instrument tipped over to the horizon (figure III.3.5 right). These efforts culminated in successful passage of the Preliminary Acceptance Europe review in May 2015.

The journey to Arizona

Transportation of such a large, delicate instrument to a remote mountaintop observatory presented its own challenges. Disassembly and packing alone occupied the team for a full two months. During this period, several final operations and tests – most notably the mating of the main LN structure with a custom-built traverse – took place with a mobile crane in the parking lot of the MPIA, since no hall at the Institute could accommodate them.

The shipment to Arizona filled nine standard shipping containers plus one large custom box for the optical bench, a total of more than 35 tonnes. The containers travelled by truck to the port of Bremerhaven for transhipment to a standard ocean-going cargo vessel, but the optical bench required special measures. Final packing of the bench took place in the MPIA parking lot, again with the assistance of a large mobile crane. A late-night journey down the Königstuhl with police escort brought the shipping crate to a nearby barge port, where the Dutch-registered *Venture* awaited its single item of cargo (figure III.3.3).

Several days later, the optical bench arrived in Bremerhaven and was transferred to an enclosed automobile carrier for the journey to Port Huaneme, California, via the Panama Canal. Thereafter, several large trucks brought both the containers and the bench to Mount Graham Basecamp, where the observatory staff took charge for the final leg of the journey to LBT. After more than a year of planning and preparation – and almost eight weeks of actual transport – all of the components of LINC-NIRVANA arrived at the summit by early November 2015 (figure III.3.4).

Re-integration and on-telescope testing

As the shipment arrived, members of the LN team were in place to receive and inspect the containers and to begin the process of re-integration and testing. (LINC-NIRVANA's size demanded a sea transport, and this in turn required disassembly and removal of the delicate optical components from the bench.)

One of the immediate re-integration tasks undertaken in November 2015 was the initial fit test of the instrument on the telescope. Even without the sensitive optics in place, LN and its handling rig weigh in excess of ten tonnes, and the clearance between the instrument and the entry hatch to the observing enclosure is only 10 mm. Passage through this bottleneck takes place with LN hanging from the crane 25 meter above the floor, requiring steady hands (and steady nerves) from all involved.

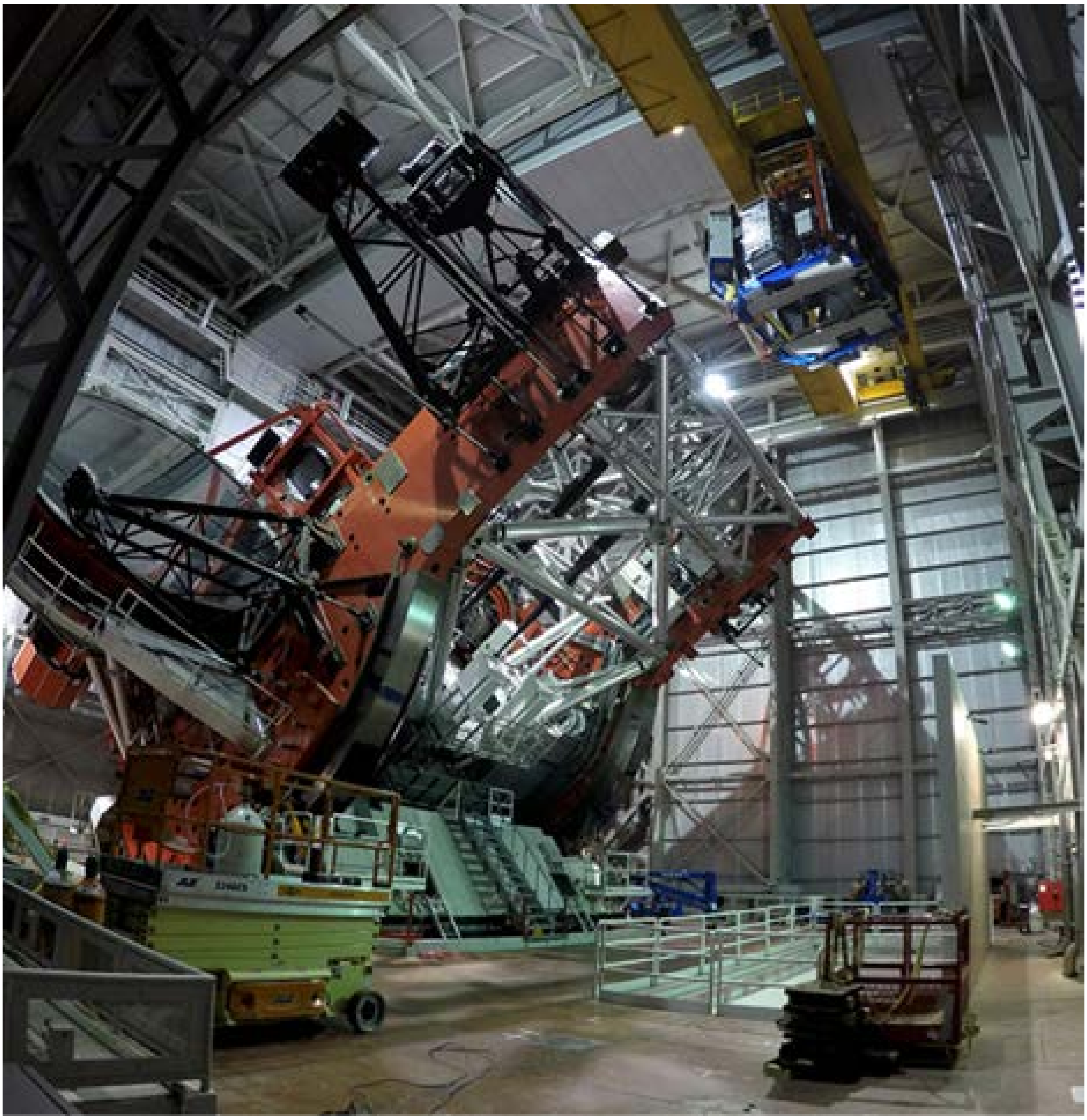
Once inside the enclosure, LN and the telescope itself must execute a carefully choreographed “dance” in which LN is raised and lowered, and the telescope is tilted in various ways, to avoid collisions between the instrument and the telescope structure. All of this effort was carefully planned and story-boarded in advance, and the day-long craning and installation effort succeeded without a hitch (figure III.3.5).

As of the time of this writing (February 2016), the LN team has executed two subsequent re-integration campaigns to re-align and begin installation of the optical subsystems on the large bench. This is taking place in the LBT mountain laboratory to avoid conflicts with ongoing telescope operations.

LINC-NIRVANA on-sky and the future

The coming months will see seven additional re-integration and testing campaigns, culminating with installation readiness at the end of the summer. In September, the team will repeat the delicate and dramatic craning procedure to mount the instrument on the telescope, this time with all components in place. First Light for the full LINC-NIRVANA will happen soon

Fig. III.3.5: LINC-NIRVANA (upper right) flying high above the telescope after its narrow passage through the dome hatch (enclosed by handrails at bottom right). The telescope must tip over and move in coordination with the crane to avoid collisions.



Credit: T. Herbst / MPIA

thereafter, followed by the beginning of commissioning and early science. And, despite the intense ongoing effort dedicated to getting LINC-NIRVANA on sky, the team – and indeed, the wider LBT community – is already looking at ways of enhancing its scientific return.

The LINC-NIRVANA project is also looking forward a decade or more to the era of Extremely Large Telescopes (ELTs). While experience dictates that the current “large” telescopes, including LBT, will continue to be vital to expanding our scientific understanding, LINC-NIRVANA has a further contribution. All of the currently planned ELT’s depend to a greater or lesser extent on Multi-Conjugate Adaptive Optics, yet until that time, there will only be two MCAO systems in the world with which to gain experience, and only one that is directly accessible to MPIA (and indeed German and European) astronomers: LINC-NIRVANA.

Tom Herbst
for the LINC-NIRVANA Team

III.4 Instrumentation at MPIA

Overview of Current Projects

Astronomical instruments have different strengths and specializations. Here, we list **current MPIA instrumentation projects**. Almost all of the instruments are cameras for producing astronomical images, spectrographs for analyzing the component colors of light, or combinations thereof. The only exception is Argos, which supports other instruments to take sharp images by projecting an artificial laser star into the sky.

LUCI 1 + 2

LBT NIR spectroscopic Utility with Camera and Integral-Field Unit

Telescope	Large Binocular Telescope, Mt. Graham
Wavelength range	Near-infrared, 0.85 – 2.5 µm
Targets	Galaxy clusters and star clusters
Resolution	30 – 90 mas (wavelength-dependent with AO)
Special features	can examine multiple objects at once
MPIA contribution	Electronics, software, detectors, cryogenics, integration facility
Status	Operational, upgrades done; tests to be completed in 2016

ARGOS

Advanced Rayleigh guided Ground layer adaptive Optics System

Telescope	Large Binocular Telescope, Mt. Graham
Wavelength range	-
Targets	-
Resolution	-
Special features	Can examine multiple objects at once
MPIA contribution	Testing, control software/motor control, calibration, alignment
Status	Commissioning: one side completed in 2015, other side 2016

LINC-NIRVANA

LBT INterferometric Camera – Near-InfraRed Visual Adaptive interferometer for Astronomy

Telescope	Large Binocular Telescope, Mt. Graham
Wavelength range	Near-infrared, 1.1 – 2.4 µm
Targets	Star clusters, black holes, protoplanetary discs
Resolution	30 – 90 mas (wavelength-dependent); interferometric: 10 – 30 mas
Special features	Particularly wide-fileld adaptive optics
MPIA contribution	PI institute, project lead; optics, electronics, software
Status	Shipped in fall 2015, installation to be completed

SPHERE

Spectroscopic and Polarimetric High-contrast Exoplanet REsearch

Telescope	Very Large Telescope, Paranal, Chile
Wavelength range	Near-infrared, 0.5 – 2.32 µm depending on instrument mode
Targets	Imaging extrasolar planets and their birthplaces
Resolution	14 – 58 mas depending on wavelength and instrument mode
Special features	Coronagraph (masking the host star), eXtreme Adaptive Optics
MPIA contribution	Co-PI institute, data reduction software
Status	Routine operations since 2015

MATISSE

Multi AperTure mid-infrared SpectroScopic Experiment

Telescope	Very Large Telescope, Paranal, Chile
Wavelength range	Mid-infrared (3 – 25 µm = L, M, N bands)
Targets	Active galactic nuclei, protoplanetary discs, hot/evolved stars
Resolution	3 – 26 mas depending on wavelength and telescope baselines
Special features	Image reconstruction from interferometric data
MPIA contribution	Integration cryostats with cold optics/detectors, electronics/tests
Status	start of integration at VLT May 2017

GRAVITY

Telescope	Very Large Telescope, Paranal, Chile
Wavelength range	Near-infrared, 2.2 µm
Targets	Milky Way black hole, planets, brown dwarfs, discs/jets, AGN
Resolution	4 mas for imaging
Special features	High-precision narrow-angle astrometry down to 10 mas
MPIA contribution	Four wavefront sensors for the AO system
Status	Four AO units being built at MPIA

Each camera or spectrograph has a characteristic **wavelength range**, describing the kind of electromagnetic radiation it can receive. Most MPIA instruments work in visible light, with radiation we can see with our own eyes, or in the infrared regions of the spectrum: in the near-infrared (adjacent to the region of visible light, able to see through clouds of dust), the mid-infrared (where dust heated by stars radiates, as in protoplanetary discs) or the far-infrared (radiated by the coldest known objects in the cosmos, or the most distant).

Astronomical objects are extremely distant, making it difficult to discern any details. The **resolution** is a measure of the level of detail that can be discerned using a particular instrument. Resolution is given as an angle on the sky: a resolution of 0.1 arc seconds means that, say, an astronomical camera can distinguish two small objects that are 0.1 arc seconds (less than 0.00003 of a degree) apart on the sky. Resolution is typically given in arc seconds (1 arc second = 1/3600 of a degree) or even milli-arc seconds, mas (1 mas = 1/1000 arc second).

4MOST

4 meter Multi-Object Spectroscopic Telescope

Telescope	VISTA Telescope, Paranal, Chile
Wavelength range	420 – 900 nm
Targets	Milky Way and galaxies, structure of the cosmos
Resolution	Spectral resolving power of 5000 – 20000 (spatial resolution n/a)
Special features	2400 fibres over a field-of-view of 4 square degrees
MPIA contribution	Instrument control electronics
Status	Preliminary design phase

PANIC

PAnoramic near-infrared Camera

Telescope	2.2 meter telescope, Calar Alto
Wavelength range	Near-infrared, 0.9 – 2.15 µm
Targets	GRBs, distances, star formation, ejected brown dwarfs, mapping
Resolution	Seeing-limited
Special features	Large field of view – size of the full moon
MPIA contribution	PI institute, cryo-mechanics, detector array, optical components
Status	Routine operations since April 2015

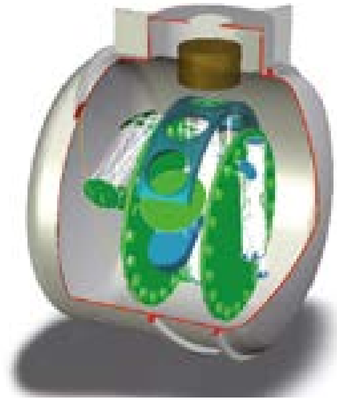
CARMENES

Calar Alto High-Resolution Search for M Dwarfs with Exoearths with near-infrared and Optical

Telescope	3.5 meter Telescope, Calar Alto
Wavelength range	Near-infrared and visible light, 0.5 – 1.7 µm
Targets	Planets around 300 M dwarf stars including Earth-like planets
Resolution	High spectral resolving power of 82,000 (spatial resolution n/a)
Special features	Two high-precision spectrographs for radial velocity measurements
MPIA contribution	NIR detector/cryostat, electronics, software, integration facility
Status	Commissioning complete, first survey starts 1/2016

Specific instruments have characteristic **special** features or properties. A particularly wide field of view, for instance, allowing for survey images of larger regions of the sky. Adaptive optics to counter-act atmospheric disturbances. The ability to determine the orientation in which an electromagnetic wave is oscillating (polarimetry), or to block out light from part of the field of view (coronagraphy). Or the use of interferometry to combine the light from several telescopes, allowing them a level of detail otherwise accessible only to a much larger telescope.

Each instrument is designed with specific astronomical **targets** in mind. For MPIA researchers, these targets center around our central research themes of planet and star formation on the one hand, galaxies and cosmology on the other. That is why typical targets are star formation regions, which are hidden behind clouds of dust that can be pierced using infrared radiation, or very distant galaxies whose light has been shifted by cosmic expansion, again necessitating infrared observations.



MICADO

Multi-AO Imaging Camera for Deep Observations

Telescope	European Extremely Large Telescope
Wavelength range	Near-infrared, 1.1 – 2.5 µm
Targets	Stellar motions in galaxies, dwarf galaxies, first supernovae
Resolution	6 – 13 milliarcseconds depending on wavelength
Special features	High sensitivity, precise astronometry
MPIA contribution	Cold filter wheel, astrometric calibration
Status	Kick-off for technical and trade-off studies 9/2015

METIS

Mid-infrared E-ELT Imager and Spectrograph

Telescope	European Extremely Large Telescope
Wavelength range	Mid-infrared (3 – 9 µm = L/M, N, Q bands)
Targets	Discs, exoplanets, supermassive black holes, high-z galaxies
Resolution	16 – 74 mas depending on wavelength
Special features	Can do coronagraphy and polarimetry
MPIA contribution	Imager and single-conjugate adaptive optics
Status	Kick-off preliminary design phase 10/2015

EUCLID

Telescope	Euclid denotes the whole space telescope
Wavelength range	Visible light, 0.5 – 0.9 µm, and infrared light, 0.965 – 2.0µm
Targets	Tracing cosmic large-scale structure and cosmic acceleration
Resolution	86 – 344 milliarcseconds depending on wavelength
Special features	Galaxy morphology, IR photometric redshifts and spectroscopy
MPIA contribution	Part of infrared detector calibration unit, large
Status	Preliminary Design completed 2015

For each instrument, we also list its **current status**. Design and construction of an instrument encompass several phases. In the beginning, there is a phase of intensive planning, which often includes tests of the necessary technology. The construction phase is followed by integration, in which the separate components are combined to form the instrument as a whole, the commissioning phase in which the instrument is installed at the telescope, first light as the first images/spectra are taken, science verification as the new instrument is tested on various astronomical targets, and finally an operations phase for scientific operations.

III.5 Highlight

Technical Departments

Observational astronomy places high demands on its tools: telescopes and instruments. New astronomical instruments are almost invariably custom developments, the result of cooperations between the researchers themselves and partners in industry. Designing and constructing such instruments – from highly sensitive detectors to spectrographs – has a long tradition at MPIA, which boasts a dedicated community of scientists, engineers and technicians.

MPIA's technical departments are the engineering design department, the precision mechanics workshop, the electronics, software, and instrumentation departments. These departments with their workshops and design offices participate in the development and construction of cutting-edge astronomical instruments which are then deployed at sites such as Calar Alto Observatory, the telescopes of the European Southern Observatory (ESO), the large binocular telescope, or aboard ESA or NASA space telescopes.

Structural extension of the precision mechanics workshop

The precision mechanics workshop develops and produces a diversity of high-precision components for astronomical research that cannot be purchased commercially. At present, the workshop is in an ongoing phase of modernization, which will equip it for the tasks of the future. This includes astronomical instrumentation notably for the E-ELT. In phase one in 2014, several of the old workshop machines, which had been in use for up to forty years, were replaced by more powerful and modern models. The new machines satisfy not only higher scientific requirements, but also improved safety standards. As the size of astronomical telescopes increases, so do the dimensions of the instruments for these

Fig. III.5.1: Architect's sketch for the extension of the precision mechanics workshop.

Credit: HWP Hauss Walla + Partner GmbH Architekturbüro / MPIA

Credit: M. Pössel / MPIA

Fig. III.5.2: The new CNC machine has found a temporary home in one of the experimentation halls at MPIA, and will be moved to the new part of the building in due course.

telescopes. This requires the manufacture of ever larger components in the workshop, which in turn means larger machinery.

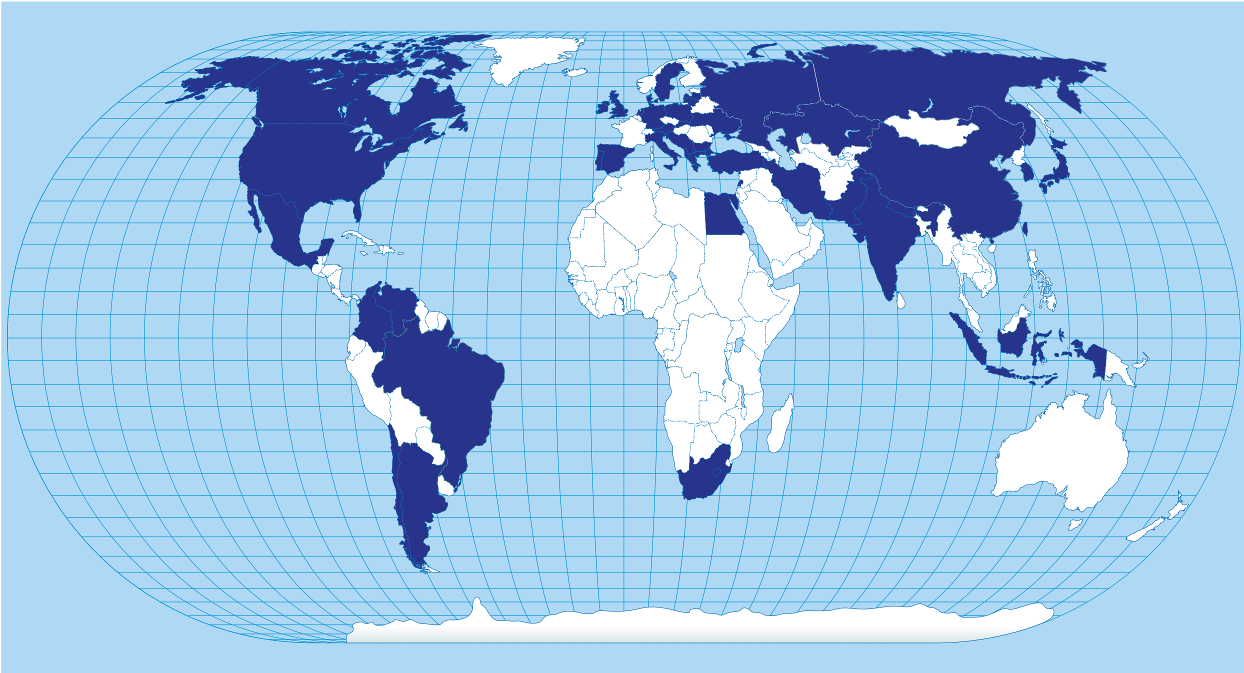
Currently, five CNC (computerized numerical control) machines are employed in addition to several conventional machines. Not only are the new machines bigger, they also require higher safety distances between machines in accordance with the floor plan.

As part of the second phase of modernization, work began in late fall on a structural extension of the workshop, which will increase the available floor space for machinery. The addition includes a new roller shutter door that will facilitate transporting large equipment in and out the workshop. The extension building is slated for completion in Summer 2016.

IV. Academics, Education and Public Outreach

IV.1 Academics, Education and Public Outreach

Academics



Credit: Graphics Department / MPIA

As a research institute, MPIA takes its responsibility for fostering future generations of scientists seriously. Our involvement begins at the undergraduate level. Both the directors and the research group leaders are involved in teaching at Heidelberg University. For instance, this year MPIA scientists were involved in teaching the lecture courseson galaxy formation (A. Macciò) and on statistics and data analysis (C. Bailer-Jones) as well as offering numerous tutorials, seminars and more advanced courses on more specialized astronomical subjects.

Fig. IV.1.1: Group picture of the 2015 IMPRS Summer School on the Dynamics of the Interstellar Medium and Star Formation.

Fig. IV.1.2: Countries of origin of the IMPRS-HD students (current fellows and alumni).

MPIA also offers bachelor and masters students from Heidelberg University or from other universities the opportunity to conduct research for their theses at the institute. For students intent on gaining research experience, there is a successful international summer internship program (coordinator: B. Goldman).

Training PhD students is one of the focus areas of academics at MPIA. More generally, International Max Planck Research Schools (IMPRS) are a key part of the Max Planck Society's efforts to promote PhD stu-

Credit: C. Fendt / MPIA

dents. MPIA is one of the partners of the International Max Planck Research School for Astronomy & Cosmic Physics at the University of Heidelberg (IMPRS-HD), a graduate school offering a doctoral program in astrophysics. IMPRS-HD, whose enrolment numbers remain constant at around 90 PhD students, is coordinated by MPIA's Christian Fendt.

September 2015 marked the tenth anniversary of IMPRS-HD, which began hosting its first generation of students in 2005. Since then, IMPRS-HD has accepted a total of 285 PhD students, for an average of 25 new students per year. About 150 IMPRS students have completed the program and graduated.

In mid-June, the IMPRS underwent its regular evaluation by a visiting committee of external referees. Every IMPRS must undergo an evaluation of this type every 6 years; the outcome determines whether or not the IMPRS will continue to operate. The evaluation included a presentation of the school's program by IMPRS spokespersons Hans-Walter Rix (for the participating Max Planck Institutes) and Stefan Wagner (for the participating University institutes) and by IMPRS coordinating scientist Christian Fendt. IMPRS students presented their research results in a joint poster session, and were engaged in lively discussion by the referees.

The afternoon session was devoted to closed sessions of the committee with students and supervisors. Following the evaluation, IMPRS received a very positive report that highlighted the school's international visibility, the scientific quality of the participating institutions, and a strong identification of IMPRS students with their school. As a result, the IMPRS program was granted an extension for an additional 6 years: from 2017 till 2022.

IMPRS-HD is international: Among the 193 applicants for 20 new IMPRS places in 2015, 18 were from Germany, 58 from other European countries, 24 from the Americas, 68 from Asia and Australia, 20 from the Middle East and 5 from Africa. In the end, a record number of 36 new students joined IMPRS-HD; the particularly high number is in part due to the highly successful partnership between IMPRS and the collaborative research center SFB 881 "The Milky Way System".

A map showing the countries of origin for the more than 250 students who have become IMPRS-HD fellows since the school's foundation in 2004 can be seen in figure IV.1.2.


Credit: C. Fendt / MPIA

Fig. IV.1.3: Students working out exercises at the 2015 IMPRS Summer School.

The program includes not only a central application and admission process that pairs candidates with suitable advisors, but also offers regular thesis committee meetings to supervise student work and education, and to assist the student with charting their academic course. It also has a mandatory astronomy curriculum, ensuring that graduates have a well-rounded astronomical education when they finish their degrees. IMPRS fellows regularly meet, present their work and discuss ideas in the weekly IMPRS seminars. Yearly workshop retreats provide an even more intensive exchange between the IMPRS fellows, complemented by social events for the students.

Another feature of IMPRS-HD is its yearly international summer school. The IMPRS summerschool 2015 was on the topic "Dynamics of the Interstellar Medium and Star Formation". The scientific program was organized by Ralf Klessen and Simon Glover (ITA), and featured lectures by Mordecai-Mark Mac Low (American Museum of Natural History), Peter Schilke (University of Cologne), Alexander Tielens (Leiden University), and Stefanie Walch (University of Cologne). The school was attended by 80 international participants, including 20 local IMPRS students.

Christian Fendt

IV.2 Academics, Education and Public Outreach

Outreach

Astronomy is a fascinating subject, and the astronomers at the Max Planck Institute for Astronomy see it as their responsibility to reach out to the general public, to teachers and pupils, and to the media.

Open Day

At no other time 2015 was public fascination with our astronomical research more palpable than on our Open Day on June 21, which attracted 3700 visitors. The institute prides itself on the enthusiasm with which MPIA staff took up the challenge of creating an engaging and diverse experience for the visitors.

At 44 different stations all over the MPIA campus, visitors could listen to lectures or planetarium presentations, experiment with infrared radiation, learn about missions such as Euclid or Gaia, gain hands-on experience with spectroscopy and learn about its astronomical applications, and see for themselves the technical expertise at MPIA that goes into constructing precision instruments for astronomical observatories. On that count, visitors also had a unique opportunity to see, in situ but protected by a transparent window, the LINC-NIRVANA, just days before the instrument was prepared for shipping to the Large Binocular Telescope (cf. section III.3). Special workshops for children were offered by Haus der Astronomie.

Partners of the Open Day on the MPIA Campus included Heidelberg University's Center for Astronomy (ZAH), the Max Planck Institute for Nuclear Physics, and the Forscherstation (Klaus-Tschira-Kompetenzzentrum für frühe naturwissenschaftliche Bildung).

Research and the public

We communicate our institute's research results both to the media and directly to the general public. For each of the science highlights in chapter II, a press release was created and distributed to selected journalists as well as via the science news service Informationsdienst Wissenschaft (idw). For these and other topics, MPIA scientists are available to help journalists with whatever questions they may have.

And while the Open Day is arguably the most impressive occasion for the public to visit our institute, there are other opportunities: In collaboration with Haus der Astronomie and the Landessternwarte, there are regular guided tours (organized on the part of MPIA by A. Quetz) led by the MPIA Outreach Fellows and their Landessternwarte counterparts: PhD students who are particularly interested in science outreach, and for whom

Fig. IV.2.1: A lively crowd on the MPIA Campus at our Open Day on June 21, 2015.

Credit: A. M. Quetz / MPIA

Credit: M. Pössel / MPIA

Fig. IV.2.2: Open Day visitors listening to an explanation of the James Webb Space Telescope. The institute is involved in constructing this 6.5 meter space telescope.

Fig. IV.2.3: Simple demonstration experiments introducing spectroscopy as one of the main astronomical tools on our Open Day.

we provide opportunities for learning and practicing the outreach craft – as an important contribution to their career-building. In 2015, almost 3300 visitors came to the MPIA campus for these guided tours.

Even if you can't make your way to the Königstuhl, you still might encounter MPIA scientists as they travel to locations throughout Germany (and sometimes beyond) to talk to general audiences about their work.

Credit: M. Pössel / MPIA

Credit: M. Pössel / HdA

Fig. IV.2.4: Astronomical observations via internet using remote telescopes: Girls' Day on April 23, 2015.

Internships and Girls' Day

MPIA also has offers aimed directly at high school students. We regularly participate in the nation-wide Girls' Day, with a one-day program aimed at female pupils aged between the ages of 13 and 18 (organization: S. Scheithauer, M. Ebert, M. Pössel, C. Liefke).

Girls' Day provides female pupils with the opportunity of experiencing professions in which women are underrepresented. For this year's Girls' Day on April 23, a total of 24 young women experienced different facets either of astronomical technology development, courtesy of the MPIA's technical departments, or of observational astronomy at the Haus der Astronomie, in cooperation with the Las Cumbres Observatory Global Telescope Network. At the same time, a Boys' Day event at Haus der Astronomie showed boys how to communicate astronomy to small children (kindergarten or elementary school age).

MPIA closely collaborates with Haus der Astronomie (HdA), the center for astronomy education and outreach on our Königstuhl campus, which is operated by the Max Planck Society. The MPG has delegated the responsibility for Haus der Astronomie to MPIA; the managing scientist of HdA is, at the same time, the head of outreach and communications at MPIA.

Another MPIA tradition is the High School Internship program (organization: K. Meisenheimer), aimed at pupils in 10th and 11th grade. In coorperation with the Landessternwarte and Astronomisches Rechen-Institut (both part of Heidelberg University's Center for Astronomy, ZAH), we have been offering this internship program since 2002. This year's internship program, on October 19–23, introduced 11 participants to basic concepts as well as practical methods of astronomy. The programme included talks about black holes and telescopes as well as practical exercises (e.g. on the subject of how a CCD camera works) and career information ("How can I become astronomer?").

Markus Pössel, Klaus Jäger, Axel M.Quetz,
Silvia Scheithauer, Monica Ebert,
and Klaus Meisenheimer

IV.3 Academics, Education and Public Outreach

Haus der Astronomie
Center for Astronomy Education and Outreach

Haus der Astronomie (HdA; literally "House of Astronomy") is the Center for Astronomy Education and Outreach on MPIA Campus. Its mission: to communicate the fascination of astronomy to the general public, to support astronomy education, and to foster the exchange of knowledge between scientists.

Haus der Astronomie is an unusual institution at the interface between science and the public. Its custom-built, galaxy-shaped building hosts an active team of astronomers and astronomy educators, dedicated to developing and producing materials and resources for the public or for use in schools. In 2015, the HdA building received more than 10,000 visitors: members of the general public coming for guided tours or popular talks, student groups from kindergarden to university level, educators and teachers participating in workshops or lectures, and astronomers and engineers attending meetings or conferences.

Fig. IV.3.1: Haus der Astronomie in Autumn 2015.

Astronomy for the public

Our outreach activities for the general public combine the tools of classic public relations, online outreach, and the organization of public events. As German node of the ESO Science Outreach Network, we provide support for the German-language outreach activities of ESO, the European Southern Observatory.

On-site events for the public included our monthly series of talks "Fascinating Astronomy" with a total of 15 events and "Sunday a.m. Astronomy" with 4 events. On the occasion of the International Year of Light, our Sunday series was dedicated to the theme of cosmic light. Events in our "HdA Highlights" series included a presentation of astronomical time-lapse photography by Bernd Pröschold, a special lecture for the 25th anniversary of the Hubble Space Telescope by Kai Noeske (formerly of the Space Telescope Science Institute, and now at MPIA/HdA), and a presentation by astrophotographer Stefan Seip about eclipses and the Venus transit.

Credit: M. Pössel / HdA

Abb. IV.3.2: Posters announcing talks in the Haus der Astronomie, created by the MPIA's Graphics Department.


Credit: M. Pössel / HdA

Fig. IV.3.3: Gravitational lens, simulated with the help of the (detached) foot of a wine glass: teacher training "100 years of general relativity" at Haus der Astronomie in November 2015.

We tested a new public format with our "Back to the Future Movie Night" on October 21, 2015, which combined a brief presentation on the physics of time travel with a showing of Robert Zemeckis's "Back to the future" trilogy. Stay tuned for more movie nights at HdA!

March 20 provided the rare opportunity for observing a partial solar eclipse in Germany. HdA provided the possibility for (semi-)public viewing, with 150 visitors observing the eclipse through various small telescopes. All in all, these on-site events drew an audience of almost 2900 visitors (excluding the Open Day, see below).

For particularly interested members of the public and in particular for students at the University of Heidelberg, Markus Pössel (with Björn Malte Schäfer) offered a lecture "Vom Schwarzen Loch bis zum Urknall – Einsteins Relativitätstheorie in der Astrophysik für Nicht-Physiker" in the winter term, which was also included in the university's Marsilius program of general studies.

As in previous years, the largest external science event we participated in was "Explore Science", July 8–12, the Klaus Tschira Foundation's five-day family science festival, attended by more than 50,000 visitors. HdA staff also gave more than a dozen public talks in various locations throughout Germany.

Open Day

Not included in these numbers is the joint astronomical Open Day on Königstuhl on June 21, which brought an additional 3700 visitors. We participated in the Open Day with a non-stop planetarium program, a special childrens' program for 380 of the youngest visitors, presentations of our partners throughout the building, and public viewing with telescopes in front of the HdA.

Scientific exchange

Haus der Astronomie is regularly used as a venue for scientific conferences, with the central auditorium and the workshop rooms suitable for hosting meetings with up to 90 participants.

The 2015 MPIA Summer Conference July 6–10 "A 3D View of Galaxy Evolution: From Statistics to Physics" brought 80 scientists from around the world to Heidelberg, for talks, workshops and discussions on the dynamical structure and formation history of galaxies, large-scale star formation, the interstellar phenomena, and energetic phenomena.

Additional conferences this year were the "Frontiers of Spectroscopy in the Local Group and Beyond" meeting in April, and the "Far-Infrared Fine Structure Lines Workshop" in June.

Notable not for its size, but for its consequences for MPIA work, was the "Preliminary Acceptance Europe" meeting for the instrument LINC-NIRVANA in May, as a crucial step towards that instrument's voyage to the Large Binocular Telescope (see section II.3).

In addition, there were 30 smaller scientific and organizational meetings. In total, 1150 scientists and engineers used the HdA as a place for meetings, discussions, and presentations.

Astronomy for schools and kindergardens

Our flagship education project remains “Wissenschaft in die Schulen!” (literally “Science into the schools!”, abbreviated WIS) in cooperation with the popular astronomy magazine Sterne und Weltraum, which is part of the Spektrum der Wissenschaft family of magazines. WIS astronomy is led by HdA senior staff member Olaf Fischer who, with his team of (mostly external) authors created 15 sets of curricular materials helping teachers bring cutting-edge astronomy into their classrooms, kindly supported by the Reiff Foundation for Amateur and School Astronomy.

Additional educational material for secondary schools was developed by Cecilia Scorza for the Collaborative Research Center “The Milky Way System” (SFB 881) at Heidelberg University, for which HdA is a key outreach partner. Translations into English and Spanish were also distributed to our cooperation partners in the Andean countries (Venezuela, Colombia, Ecuador, Peru, Bolivia and Chile) and in South Africa.

Our most successful product continues to be “Universe in a Box,” an astronomy kit for use with kindergarden or elementary school children (developed by Cecilia Scorza with contributions from Natalie Fischer). The kit is in use in more than 70 countries, and even received a prize this year: the Scientix Resource Award for “Best STEM Teaching Material Addressed to Teachers” from the EU STEM education initiative Scientix. The prize was handed over at a special networking event in Brussels in mid-June.

One welcome consequence is that the Universe in a Box-booklet will now be translated into all 24 languages spoken within the EU. Interested schools and kindergardens can directly borrow Universe in a Box kits from Haus der Astronomie.

Meanwhile, development work has started for another EU-funded Horizon 2020 project, EU Space Awareness, in which HdA is a partner. The project will develop resources related to space technology, the history of navigation, and earth observation / climate change.

In 2015, a total of 2500 pupils and pre-school children visited HdA for a total of 128 workshops for various age groups. Such workshops typically involve hands-on activities, make use of our digital planetarium, and are often used to field-test newly developed materials. We developed new workshop concepts in cooperation with Junge Uni Heidelberg, for this year’s Explore Science, and for the Open Day.

Another possible astronomy experience for children and adolescents are “Astro Camps,” organized by Astronomieschule e.V.. Participants stay over night on the Königstuhl to observe; in unsuitable weather, or as a diversion, Astro Camp groups will also visit the HdA’s digital planetarium.

External events for pupils included the JuniorAkademie Baden-Württemberg in Adelsheim (C. Liefke).

Reaching out to communicators and educators

Teachers and educators play a key role in science outreach – helping them develop a passion for cutting-edge research, and giving them the right tools to pass this passion (and the science itself!) on to their students, is probably the most effective outreach strategy there is.

Fig. IV.3.4: Smaller telescopes in front of the HdA: Visitors on the occasion of the partial eclipse on March 20, 2015.

Credit: C. Liefke / HdA

Pre-service training included two seminars (C. Liefke), the annual block course "Introduction to Astronomy for pre-service teachers" (O. Fischer, C. Liefke, M. Pössel, C. Scorza) and a workshop on practical astronomy at the Heidelberg Student Days 2015 (C. Liefke), all at the University of Heidelberg, while Natalie Fischer lectured on "Basic Astronomy in School" at Heidelberg's University of Education (Pädagogische Hochschule).

In-service training included our nationwide three-day training course "Hitchhiker's Guide to the (Milky Way) Galaxy" in November, funded by the Wilhelm und Else Heraeus foundation and, on the occasion of the General Relativity Centenary, a teacher workshop "Astronomy in Einstein's Footsteps" for secondary teachers in collaboration with Regierungspräsidium Karlsruhe of the State of Baden-Württemberg, also in November.

For primary school and kindergarten teachers, there were 14 training sessions and numerous consultations. In an important step forward, we developed and implemented teacher training specifically targeting primary school teachers, as part of our collaboration with the Forscherstation.

External training events included workshops in Thuringia and Baden-Wurttemberg, while this year's mobile teacher training, supported by the Reiff Foundation, took place in Niedersachsen and Bremen (Göttingen, St. Andreasberg, Hildesheim, Hannover, Burgwedel, Hittfeld, Bremen, and Osnabrück; O. Fischer with B. Nissel).

The "Telescope Driver's Licence" workshop qualifying teachers for the use of small telescopes in school went into another round in February in Ebern, Bavaria and in November in Adelsheim (O. Fischer/C. Liefke). The course also qualifies teachers for HdA's telescope lending program.

Our bi-national German-Italian Summer School, funded by the Wilhelm and Else Heraeus foundation, continued in Jena this September, on the timely topic of Gravitational Waves. Members of the UNAWE Network coordinated by Natalie Fischer received support in the shape of astronomical resources for teacher training workshops.

Research with high-school students

HdA provides first-hand research experience for high-school students in several different programs. In the framework of the IASC-Pan-STARRS asteroid search campaigns, high-school students search for asteroids in Pan-STARRS image data, with a realistic chance of discovering previously unknown main belt asteroids. Within this framework, we supported a total of 50 German high-school groups participating in four search campaigns (C. Liefke).

Fig. IV.3.5: Do-it-yourself comets: Crowds of children at the HdA booth for younger children at the Klaus Tschira Foundation's Explore Science in Luisenpark, Mannheim in July 2015.

Credit: N. Fischer / HdA

In the field of remote observing (telescopes that can be controlled via the Internet; C. Liefke), 2015 saw a return to business as usual for the Faulkes/LCOGT telescopes, with the new scheduling system in place, although some reliability issues and problems to use the data archive remained. That was why we did not expand school participation in the project for the moment, although we did include the telescopes in the HdA/MPIA Girls' Day program this year.

Early in 2015, the users of the ROTAT remote observatory at Observatoire de Haute Provence, both amateur astronomers and school users from all over Germany and also from France, gathered in Tübingen to discuss the current status and future prospects of the telescopes. The fruitful meeting was considered a success by all attendees. Unfortunately, Prof. Dr. Hanns Ruder, the founder of ROTAT, passed away on October 17th. The HdA will continue to support the ROTAT project and carry on Prof. Ruder's legacy.

Our internship program in 2015 once more consisted of career orientation (BOGY internships) and of programs for the benefit of particularly talented/interested students, notably in collaboration with the Hector Seminar or the Heidelberger Life Science Lab (C. Liefke), including a week-end seminar on cosmology for the Life Science Lab at the beginning of the year (M. Pössel with Björn Malte Schäfer).

Our three-week International Summer Internship which regularly includes participants from the International Summer Science School Heidelberg, went into another round this year (K. Noeske). The seven participants came from Germany, Italy, the UK and the US. The project was supported by a long-term intern who acted as tutor (S. Kopf).

Networking

Internationally, our main collaborations are in the framework of the EU-UNAWE network as well as cooperating institutions in Chile (in cooperation with the Heidelberg University's Center for Astronomy and its Centre of Excellence in Chile).

Regionally, we continued our fruitful collaboration with Forscherstation, the Klaus Tschira Center for Early Science Education in Heidelberg. The collaboration includes a joint appointment (N. Fischer) for the development of educational materials and teacher workshops.

Our collaboration with ESO on the "ESO Supernova" (ES), a younger (and larger) sibling for HdA now under construction, continued with technical consultations and in particular through the work of Cecilia Scorza, who is deeply involved in creating educational content for ES. This content is used to develop planetarium shows, exhibition content for K-13, an educational guided tour, and school workshops. Contributions include teacher training development, a strategy for building a teacher network at the ES, and the collaborative project "Astronomical Concepts" together with partners at Leiden Observatory, to increase astronomy literacy in European schools.

Markus Pössel, Sigrid Brümmer, Natalie Fischer, Olaf Fischer, Carolin Liefke, Alexander Ludwig, Markus Nielbock, Kai Noeske, Matthias Penselin, Tobias Schultz, Cecilia Scorza, Jakob Staude

Haus der Astronomie is the result of a partnership between the Klaus Tschira Foundation, which has financed and built the spectacular HdA building, the Max Planck Society operating the HdA (via MPIA), and the City of Heidelberg and the University of Heidelberg supporting our operations with staff positions.

V. People and Events

V.1 People and events

Honours, Grants and Awards

As in the preceding years, MPIA staff members received a number of awards, for their achievements in astronomy and beyond.

The Frontier Research Grants scheme of the European Research Council is one of the most sought-after scientific grant programs. Applicants must demonstrate the groundbreaking nature and ambition of the project as well as the excellence of the investigator. This year, a total of three MPIA researchers were awarded ERC grants – a remarkable success!

ERC Consolidator Grant for Henrik Beuther

Henrik Beuther, staff scientist in MPIA's Planet and Star Formation Department, has been awarded a €1.6 million ERC Consolidator Grant. The grant will allow Beuther to create a working group consisting of three postdocs and one PhD student over the next five years. Beuther's project aims to study the full cycle of cloud formation, star formation and eventual feedback into the interstellar medium. Beuther led an Emmy Noether Group at MPIA starting in 2005, and has been a staff member since 2009.

Star Formation is a hierarchical process, from the formation of large clouds of interstellar gas and dust to the assembly of stars and their surrounding planetary systems. Beuther's ERC project will study the multi-scale processes of this remwarkable and complex conversion from diffuse gas to stars. The fundamental data of the project are provided by two PI-led large observing programs at two of the most advanced radio and millimeter interferometers: the Very Large Array (VLA) in New Mexico (USA) and the Plateau de Bure Interferometer (PdBI) in France.

Consolidator grants are the intermediate stage of the ERC program. They are awarded to scientists who obtained their PhD between seven and twelfe years ago, are leading a research group of their own, and can already look back on a substantial amount of excellent research.

Fig. V.1.1: Dr. Henrik Beuther.

Credit: MPIA

Fig. V.1.2: Dr. Arjen van der Wel.

Credit: A. van der Wel / MPIA

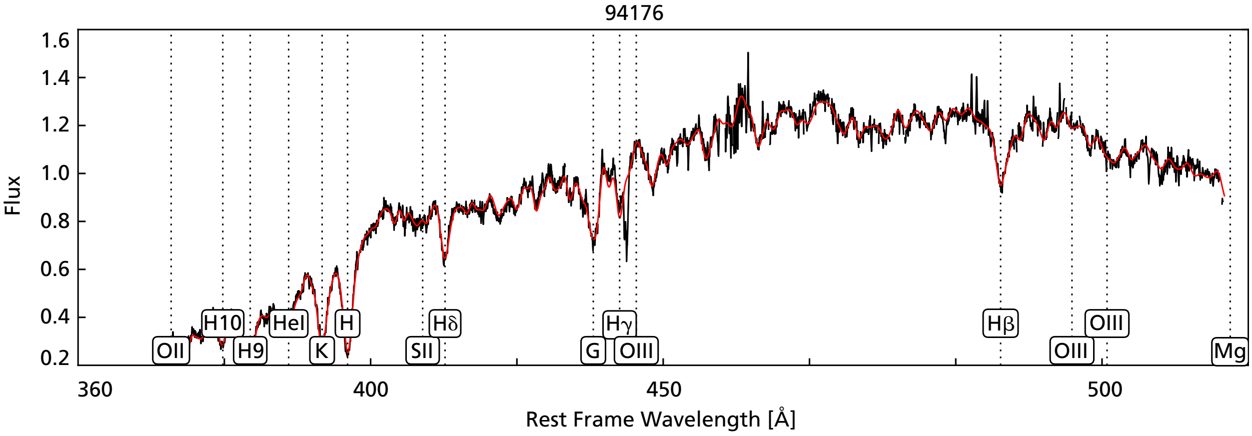
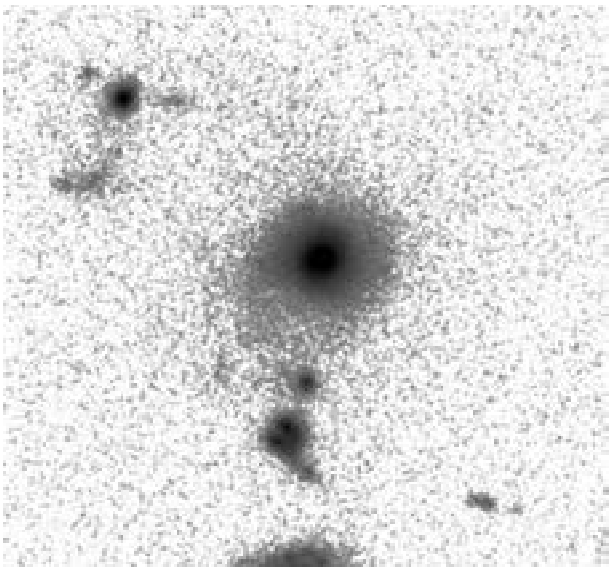


Fig. V.1.3: Sample spectrum (left, with many characteristic spectral features) and Hubble Space Telescope image of one of the more than 3000 galaxies in the LEGA-C survey. The galaxy´s redshift of 0.697 corresponds roughly to a look-back-time of half of the total age of the universe. Thus, such a huge sample of galaxy spectra spread over a wide redshift range and different cosmic epochs allows tracing the evolution of galaxies.



Credit: A. van der Wel / MPIA, NASA / ESA / Hubble

ERC Consolidator Grant for Arjen van der Wel

Another ERC Consolidator grant worth € 1.9 million was awarded to Arjen van der Wel, staff scientist in the Galaxies and Cosmology Department. Van der Wel's project is built around the LEGA-C survey: an extensive extragalactic observing program at ESO's Very Large Telescope (VLT) in Chile to study galaxy evolution. The grant, which starts in April 2016, includes funding for a research group leader, two postdocs and two PhD students to leverage this unique and voluminous dataset.

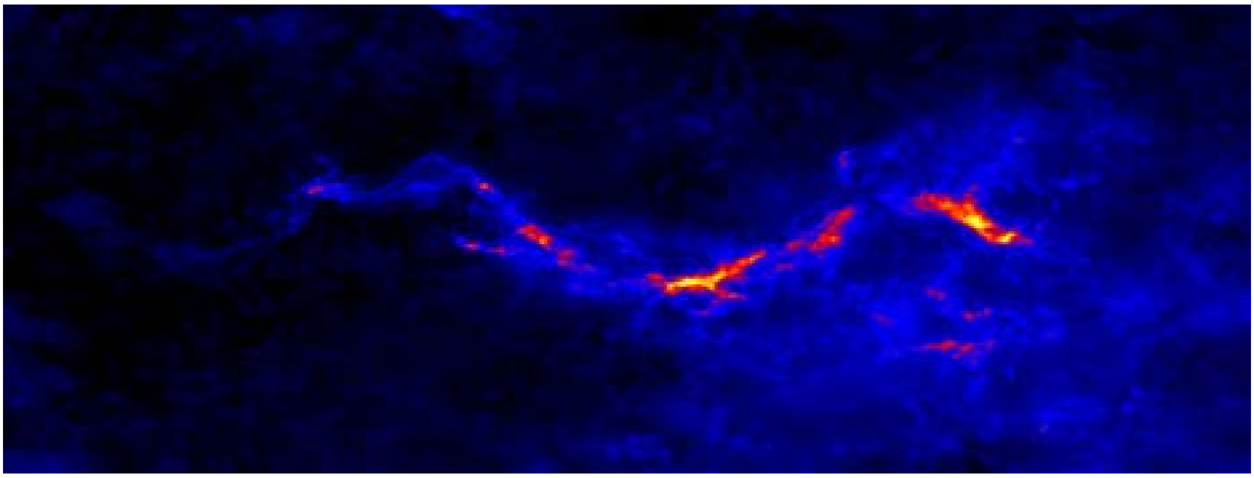
The LEGA-C survey represents the largest time allocation so far for extragalactic observations at the Paranal observatory in Chile of the European Southern Observatory (ESO). By using the VIMOS multi-object spectrograph mounted at one of the four huge 8.2 m telescopes, van der Wel and his group measure and analyse the physical properties of more than 3000 distant galaxies (up to redshift $z{\sim}1$) in unprecedented detail. This includes the ages and chemical composition of their stellar populations, as well as their kinematics to constrain their dynamical masses and the relation to their dark matter halos. Such information is crucial to link the violent, early formation phases of galaxies to the relatively sedate population we see in the present-day universe.

Fig. V.1.4: Dr. Jouni Kainulainen.

Credit: J. Kainulainen

ERC Starting Grant for Jouni Kainulainen

An ERC Starting Grant, worth € 1.3 million, was awarded to Jouni Kainulainen in the Planet and Star Formation Department. It will allow Kainulainen to build his own research group for the next five years, funding not only himself, but also two postdocs and a PhD student.



Credit: J. Kainulainen et al. 2013

Fig. V.1.5: Column density map of the giant filamentary cloud astronomers call "The Snake." Kainulainen's group will construct similar maps for thousands of molecular clouds in the Milky Way to study how the clouds fragment and form new stars.

The main goal of Kainulainen's project is to explore how the fundamental physical processes like gravity, turbulence and magnetic fields regulate the formation of new stars in our home galaxy, the Milky Way.

In our current understanding, important quantities like star formation rates and efficiencies of galaxies are linked to the internal structure of individual molecular clouds in which the stars form. But the detailed internal cloud structure is known with some certainty only for clouds close to our Sun. Furthermore, these clouds are only the birthplaces of relatively low-mass stars. What about higher-mass stars?

The main goal of Kainulainen's group is to map in great detail now also the internal structure of the more massive molecular clouds in the Milky Way by using a new observational technique. Near-infrared observations of tens of millions of stars that shine through the clouds will be combined with mid-infrared images to build a database that contains very accurate maps of thousands of clouds in the Milky Way. The unique observational data will be combined with numerical simulations of the interstellar medium to address the key questions: Which physical processes drive the formation and evolution of molecular cloud structure? How does the molecular cloud structure affect and trigger the star formation? Supported by the ERC, Kainulainen will be able to address these and other questions here at MPIA.

Sofja Kovalevskaja-Prize of the Humboldt-Foundation for Karin Lind

The Sofja Kovalevskaja prize, awarded by the Alexander von Humboldt Foundation, is one of the most highly endowed scientific awards in Germany. The prize is meant to enable outstanding international young scientists to build up a working group for an innovative project at a German research institute. Among this years six prize winners was Dr. Karin Lind from Sweden, who started her own research group at the Max Planck Institute for Astronomy in October 2015.

The main scientific goal of Lind's work is the exploration of the production of chemical elements in the early universe through stellar spectra. It is well known that the lightest chemical elements, hydrogen, helium and lithium, originated minutes after the big bang, while all heavier elements result from the fusion processes in the core regions of stars and from supernovae. Determining and understanding the abundances of these chemical elements makes for one of the most powerful probes of the composition of the early universe and of the physics of the earliest stars. Abundances of this kind are best probed by measuring the composition of the atmospheres of the oldest stars through stellar spectroscopy. Karin Lind is a world leader in creating physical models for the spectra of stars. Comparing these models with observed spectra, Lind is able to derive abundance measurements with an accuracy that was impossible just a few years ago. On that basis, Lind was already able to refute a prominent claim the abundances of a certain isotope of Lithium posed a challenge to the standard big bang theory.

Over the next years, Karin Lind will bring her spectral modelling approach to bear on the vast new sky surveys currently under way, which will provide over a million detailed spectra of stars.

Patzer Prize 2015

The annual Ernst Patzer Prize honours the best publications by young scientists (namely graduate students or postdocs less than three years after completion of their PhD). The publication must have been accepted by a refereed journal.

The prize was donated by the art-lover and philosopher Ernst Patzer and established by his widow. The foundation awards its prizes every year to young resear-

Credit: Humboldt-Foundation/Bettina Ausserhofer

Fig. V.1.6: Left to right: Dr. Karin Lind, Cornelia Quennet-Thielen (State Secretary at the Federal Ministry of Education and Research), and Prof. Dr. Helmut Schwarz (President of the Humboldt Foundation) during the award ceremony in Berlin in November 2015.

Fig. V.1.7: Patzer Prize winners 2015 from left to right: Dr. Simon Bihr, Dr. Melissa Ness, and Dr. Jonathan Stern.

Credit: M. Rugel / MPIA

chers at MPIA and other institutes in Heidelberg and wishes to support research particularly in the field of Astronomy. The selection committee consists of two scientists from MPIA and one external scientist from Heidelberg.

This year's Patzer Prize winners are:

- Dr. Simon Bihr (MPIA-Department Planet and Star Formation) – for his Publication "THOR: The HI, OH, Recombination line survey of the Milky Way: The pilot study: HI observations of the giant molecular cloud W43" (Bihr et al. 2015, Astronomy & Astrophysics, 580, A112)
- Dr. Melissa Ness (MPIA-Department Galaxies and Cosmology) – for her Publication "The CANNON: A data-driven approach to stellar label determination", (Ness et al. 2015, Astrophysical Journal, 808, 16)
- Dr. Jonathan Stern (MPIA-Department Galaxies and Cosmology) for his Publication "Spatially resolving the kinematics of the < 100 mas quasar broad-line region using spectroastrometry" (Stern et al. 2015, Astrophysical Journal, 804, 57)

The award ceremony was held on November 27 in the auditorium of the Max Planck Institute for Astronomy.

Fig. V.1.8: MPG trainee award winner Felix Sennhenn (front) demonstrating his homemade lathe.

Credit: D. Anders / MPIA

Trainee Award 2015 of the Max Planck Society for Felix Sennhenn

The Max Planck Society Trainee Award for outstanding achievements in vocational training has been awarded yearly since 2007. One of the winners for 2015 is Felix Sennhenn from MPIA's Precision Engineering department.

With this award, the MPG honours not only the outstanding professional and academic performance during their training, but also the personal development and the social commitment of the trainees. The selection committee consists of four educators and trainers and one member of the Central Works Council and the Trainee Council.

Felix Sennhenn received the award for outstanding achievements in the field of metal-processing professions. Impressively, Sennhen's commitment goes much further than usual. In fact, he has designed and built a lathe of his own in his spare time. This exceptional performance exceeds expectations for trainees in this line of work.

Additional awards, appointments and grants

- Tri L. Astraatmadja received the Global Neutrino Network (GNN) Dissertation Prize 2015, awarded by a partnership of four neutrino telescope experiments (ANTARES, Baikal, IceCube, and KM3NeT) for his outstanding thesis, which contributed significantly to the project. The full title of the dissertation is "Starlight beneath the waves: In search of TeV photon emission from Gamma-Ray Bursts with the ANTARES Neutrino Telescope".

- Joe Hennawi and Laura Inno's discovery of the first Quasar Quartet was ranked number four in Astronomy Magazine's top 10 Space Stories of 2015.

- Laura Inno was awarded an ESO Fellowship.

- Ryan Leaman received a Postdoctoral Fellowship at the National Sciences and Engineering Research Council of Canada.

- Nadine Neumayer was elected a Member of the Elisabeth-Schiemann-Kolleg of the Max Planck Society.

- Fabian Walter was invited for the Caltech Biard Lectureship and appointed a Caltech Visiting Associate in Astronomy.

- Gabor Worseck received funding from the German Space Agency DLR (Program 50OR1512, 71729 Euro).

V.2 People and Events

Events and Conferences

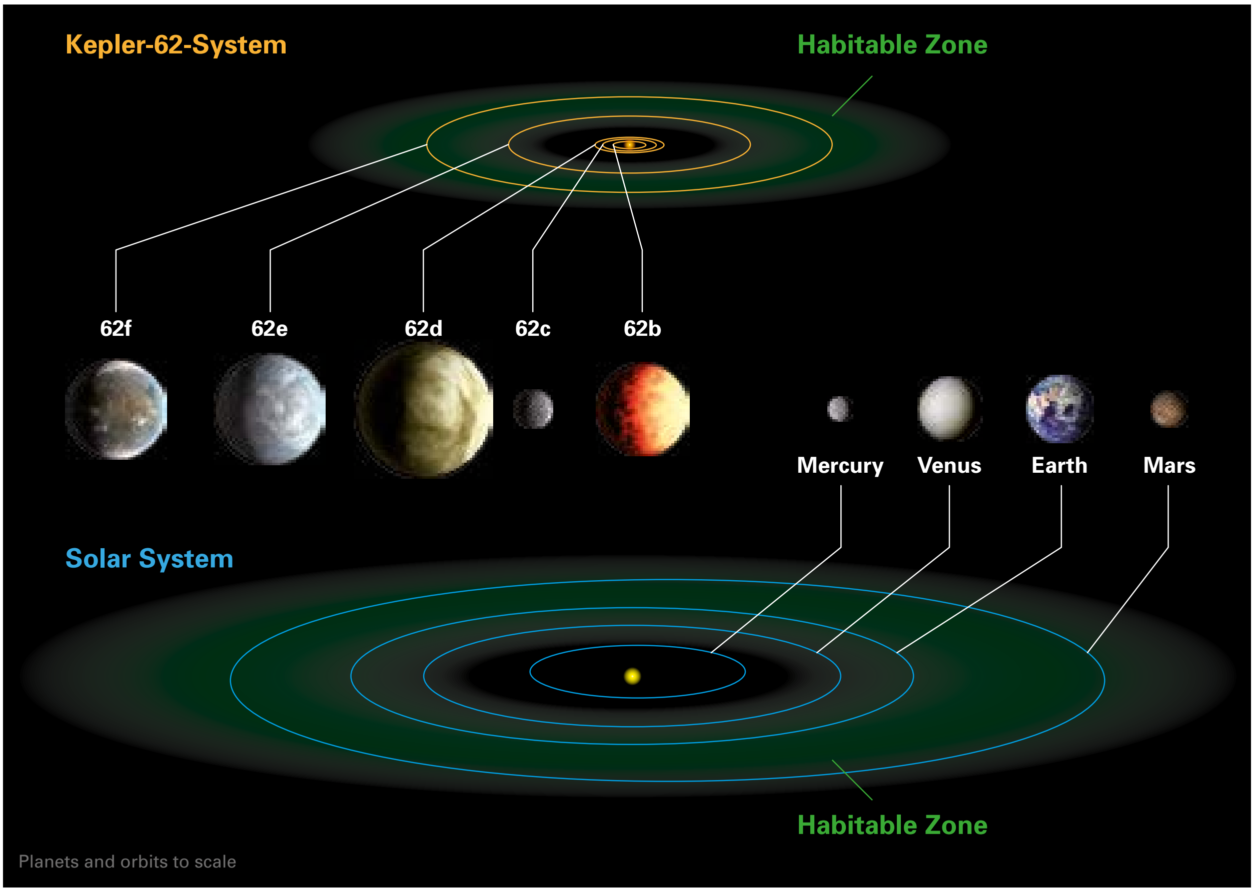
Heidelberg Origins of Life Initiative (HIFOL) established

In March 2015, the Max-Planck-Institute for Astronomy, the Max-Planck-Institute for Nuclear Physics, the Heidelberg Institute for Theoretical Studies and the University of Heidelberg, established the Heidelberg Initiative for the Origins of Life (HIFOL). This initiative brings together top researchers from astrophysics, geosciences, chemistry, and life sciences to foster, strengthen and bundle scientific efforts to unravel one of the most challenging mysteries in the universe: what are the conditions for the origin of life? During the spring term of 2015, HIFOL established also a monthly colloquium series with world-leading speakers in the field.

Since the discovery of the first extrasolar planets around sun-like stars in the nineties, the academic debate on life beyond our solar system has become one of the most exciting scientific fields. Today we know that the formation of planetary systems is not a rare exception but instead a normal part of star formation. This raises the interesting question of which of these many planetary systems might allow for the formation of life.

Which physical and biochemical circumstances must exist for life to arise? And what kind of signatures in the data of observed Exoplanets would constitute a clear a sign of biological activity? In 2014, this topic became one of the Research Perspectives of Max-Planck-Society.

Fig. V.2.1: Comparison of the planetary system around the star Kepler-62 with our own Solar System. The relative size of the planetary orbits (top and bottom) is to scale. The planets (center) are also to scale, relative to each other. The habitable zone – the zone around the star that allows for liquid water on the surface of a planet orbiting at that distance – is shown in green. Kepler-62e and Kepler-62f are good candidates for habitable planets: solid planets orbiting their host star in the habitable zone. Discoveries like these fertilize this area of work immensely.



Credit: NASA

One of the crucial ingredients for life as we know it is liquid water. While Earth possesses a water-rich surface, the origin of this water is still unclear. Scientists have found clues by studying the isotopic composition of meteorites, suggesting that the water has most likely been delivered to Earth by asteroids or comets. Unlike terrestrial planets that have been assembled from rocks in the inner, hot region of the solar nebula where water was in a gaseous phase, comets and asteroids have formed at much greater distances from the young sun, and have been able to retain some of the water as ice. Additional questions concern the conditions for complex biochemical reactions, the composition of planetary atmospheres and the self-assembly of organic molecules.

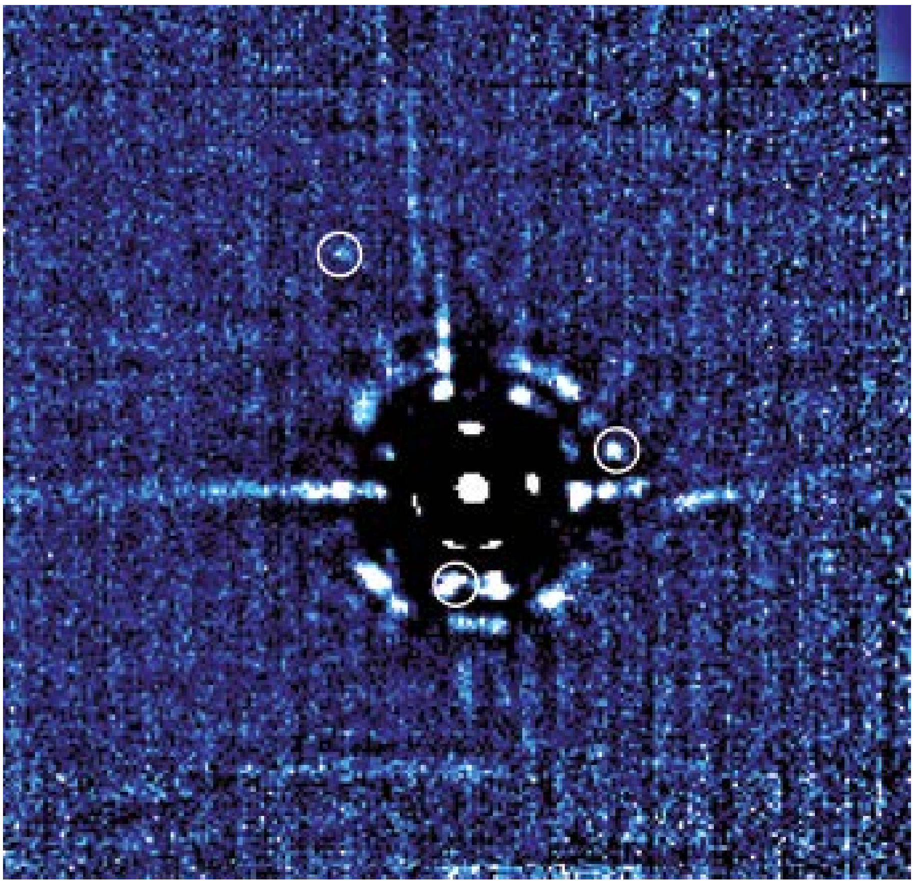
The discovery of numerous exoplanets ignited lively discussions on the definition of habitable zones around stars. Earth-like conditions are relatively strongly restricted to planets with stable orbits with appropriate parameters (for the distance to the star, the temperature and the like). But with the moons Enceladus, Titan, and Europa, scientists have found in the outer and much colder regions of the solar system locations for biological activity that are more promising even than the long-time favorite, Mars. More information can be found on the initiative's web pages at http://www.mpia.de/HIFOL.

Oliver Trapp appointed as MPG-Fellow at the Max Planck Institute for Astronomy

Related to the founding of HIFOL is the appointment of Prof. Dr. Oliver Trapp from the Institute of Organic Chemistry of the University of Heidelberg as MPG-Fellow at the Max Planck Institute for Astronomy at the end of the year. With its fellowship program, the Max Planck Society (MPG) promotes the collaboration with excellent scientists from outside the Max Planck Institutes.

Oliver Trapp received his PhD in Chemistry at the University of Tübingen in 2001. From 2004, after a postdoctoral phase at Stanford University in California (USA), he initially headed an Emmy Noether Junior Research Group funded by the German Science Foundation (DFG) at the Max Planck Institute für Kohlenforschung in Mülheim an der Ruhr. In 2008, Trapp was appointed to a professorship at the Organic Chemistry Institute of

Fig. V.2.2: Image of the HR 8799 system. In the center, the host star HR 8799. In 2010, observing one of the three planets directly visible in the image, MPIA astronomers managed to obtain a direct spectrum the first such spectrum for a planet orbiting a distant, Sun-like star, providing direct data about the composition of the planet's atmosphere. Such "chemical fingerprinting" is a key technique in the search for habitable planets around other stars. As such, the result represents a milestone in the search for life elsewhere in the Universe.



Credit: W. Brandner / MPIA

Credit: O. Trapp

Fig. V.2.3: Prof. Dr. Oliver Trapp.

Heidelberg University. In the same year, he was awarded the DFG's Heinz Maier-Leibnitz Prize.

Trapp's research aims in particular to a better understanding of catalytic chemical reactions at the molecular level. Investigation and analysis of large numbers of such processes is usually not only costly, but also very time-consuming. However, by combining the classical chemical analysis with means of modern information technology, Trapp has succeeded in increasing enormously the efficiency and quality of such analyses, allowing researchers to examine as many reactions in short time. Using a bar code-controlled supply of samples, Trapp is able to produce many chromatograms simultaneously, which can then be analysed 50 times faster than by usual means. This is called multiplexing gas chromatography, and has also proved very valuable for other kinds of analyses, notably as a tool for investigating mixtures of substances.

The study of processes at the molecular level is of fundamental importance for the understanding of procedures as well as the necessary environmental conditions for the formation of building blocks of life, and the appointment of Oliver Trapp as an MPG Fellow is a key step towards the kind of interdisciplinary collaboration needed to answer the question of the origin of life in a cosmic context.

Tandem Agreement with Valparaiso University Signed

In October, an agreement was signed between the Max Planck Institute for Astronomy and the Department of Physics and Astronomy of the University of Valparaiso, Chile, to set up the first Tandem-Group in the field of Astronomy in Chile. The cooperation agreement was signed by the Rector of the University of Valparaiso, Aldo Valle, and the Managing Director of the Max Planck Institute for Astronomy Heidelberg, Thomas Henning. The ceremony in Chile was also attended by the Dean of the Faculty of Sciences of the UV, Juan Kuznar, the head of the university's doctoral program in Astrophysics, Matthias Schreiber, the General Secretary of the university, Osvaldo Corrales, as well as by researchers and students.

This is the first agreement of its kind in the research field of Planet and Star Formation between a renowned German institution and a Chilean university. This first

Fig. V.2.4: Signing of the cooperation agreement between MPIA Director Thomas Henning (left) and the Rector of the University of Valparaiso, Aldo Valle, on October 2, 2015.

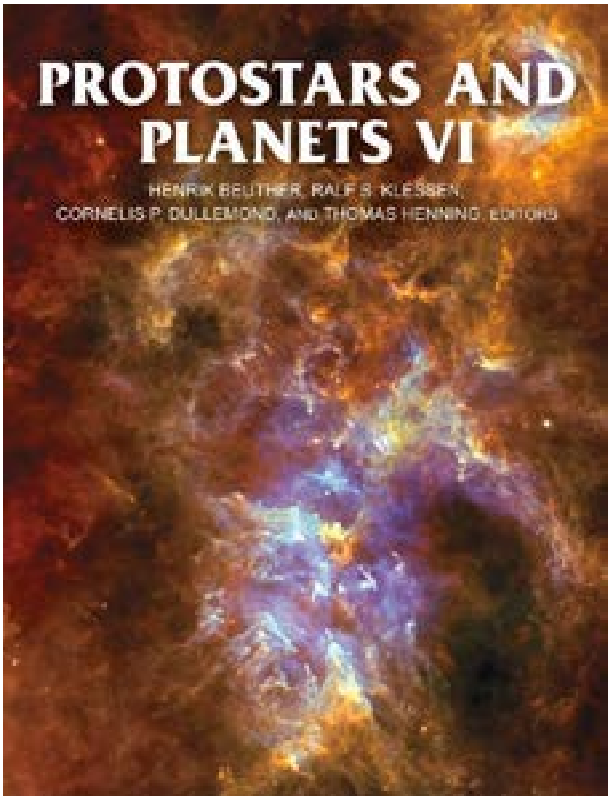
Credit: Universidad de Valparaiso

stage of the agreement will strengthen general cooperation in the field of exoplanets, planet formation and numerical astrophysics. The University of Valparaiso is the only university in Chile which had previously established a similar connection to the Max Planck Society (MPG), namely in the life sciences. The basic function of the tandem agreement is to enable scientists to apply for leadership of a research group with five years duration with a Max Planck Institute as partner.

The agreement is made to not only support research on the formation of planets and stars, but also to open up new opportunities for the exchange of students – i.e. that Chilean students can easily visit the MPIA and vice versa. Both partners should benefit from the resulting improvement in their research networks.

With this agreement, a research group in Chile will be established and lead by a MPIA tandem group leader, after a careful selection of candidates from around the world to do research at the highest level.

Astronomers traditionally have a strong connection to Chile, given the outstanding observatories in the northern part of the country. Therefore, MPIA´s traditionally important work on the development of high-tech instruments for the biggest telescopes can also benefit from this cooperation. The Astronomy Department of Valparaiso University is a very good partner, due to its successful history and scientific excellence.



Credit: University of Arizona Press

Fig. V.2.5: Front cover of the book "Protostars and Planets VI", published by the University of Arizona Press.

Standard work on protostars and planets published

When it comes to learning the latest results in a fast-paced area of research, conferences like those of the conference series Protostars and Planets play an important role: at each conference, dozens of high-profile speakers introduce their audience to the state-of-the-art of the various aspects of research on planet and star formation. After the conference, their contributions are collected in a conference volume that serves as the field's standard compendium for years to come – this is the way things have been handled since the first Protostars and Planets volume in 1978.

Now, the 6th edition of the prestigious book series has been delivered to conference participants, after having gone on sale in late 2014. The book is the result of a close collaboration between researchers at the Max Planck Institute for Astronomy (MPIA) and the Institute of Theoretical Astrophysics (ITA), part of Heidelberg University's Center for Astronomy (ZAH). The book is edited by Henrik Beuther (MPIA), Ralf S. Klessen (ITA), Cornelis P. Dullemond (ITA) and Thomas Henning (MPIA), and published by the University of Arizona Press. The book grew out of the Protostars and Planets VI conference that drew more than 800 to Heidelberg in July 2013. In 38 review articles on more than 900 pages, the book covers all aspects of current research into the birth of stars and their planets.

Conferences and meetings

Conferences and meetings are an integral part of scientific life at the institute. This year, the insttute hosted more than 30 smaller or larger events with a variety of international guests.

Between April 27 and April 30, the international conference Frontiers of Stellar Spectroscopy in the Local

Fig. V.2.6: Thomas Henning (left) and Dietrich Lemke together with Martin Harwit (right), one of the pioneers of infrared astronomy, who visited MPIA during the „Workshop on far-IR fine-structure lines" in Summer.

Credit: H. Zinnecker

Group and Beyond was held at the Haus der Astronomie. Spectroscopy in all its variations is still the most important tool of observational astronomy, independent of the specific scientific topic. Both the program as well as the different working fields of the participants were characterized by a variety of topics ranging from exoplanet atmospheres to the most distant galaxies.

A little more specific was the Workshop on far-IR fine-structure lines to study interstellar matter (June 8–11) at the same location, bringing a host of experts from galactic and extragalactic research areas to the institute. The particular goal of the conference was to bring together observers and theorists.

This year's MPIA summer conference was called A 3D View on Galaxy Evolution: from Statistics to Physics. The fourth conference of this now well-established series, conference's main aim was to bring together scientists from the fields of optical and radio astronomy.

On December 10 we held Scientific Colloquium on the occasion of the retirement of Reinhardt Mundt from the Planet and Star Formation department. Special guests and speakers included Tom Ray (Dublin Institute for Advanced Studies), Joachim Eislöffel (Karl Schwarzschild Observatory), and Bill Herbst (Wesleyan University Middletown).

Klaus Tschira (1940 – 2015)

The Max Planck Institute for Astronomy is saddened by the loss of Dr. h.c. Klaus Tschira. The long-time member of MPIA's Board of Trustees passed away in Heidelberg on March 31, 2015. Tschira, one of the co-founders of the software company SAP, had long been active in fostering research and outreach activities in the natural sciences, mathematics, and computer science.

Tschira's particular interest in astronomy had resulted in numerous fruitful collaborations between the Klaus Tschira Foundation and MPIA over the past decade. The most visible result of these is the Haus der Astronomie (HdA, cf. section IV.2), the center for astronomy education and outreach on the MPIA campus. The center's characteristic, galaxy-shaped building was gifted to the Max Planck Society by the Klaus Tschira Foundation.

With Tschira's death, MPIA and, more generally, all those who support science outreach, lose a champion not only of science, but of finding ways to communicate the fascination of science to a young audience.

V.3 People and Events

Work and Family: Dual Careers and Work Life Balance

Science offers the opportunity for careers that are demanding and rewarding – but which also come with their own challenges. At a certain time of their lives, young scientists will face the problem of balancing their work and a fulfilled family life. Creating a family-friendly environment is also seen as a key element for creating equal opportunities in science for men and women alike.

A career in research demands both flexibility and mobility. In particular in its early stages, during the PhD and postdoc phases, scientists regularly change their places of work (and, not infrequently, their country or even continent of residence). For dual career couples, in which both partners pursue a scientific career, this creates significant challenges. That is why an institute's family-friendly strategy must necessarily include a concept for how to handle the challenges of dual careers, creating adequate career opportunities also for the spouse or partner of scientists newly joining the institute.

Credit: Glückskinder

A more general perspective is that of work-life balance – of a well-rounded life in which both work and career on the one hand, and play and family life on the other have their proper place.

The Max Planck Institute for Astronomy has long striven to create family-friendly conditions both for its scientific and its non-scientific staff – with success, as is shown, among other things, by several awards the program has received. In 2014, the qualification project for apprentices, "Career and Family – My Life" was awarded the Max Planck Society's Vocational Training Price (Ausbildungspreis).

Family-friendly MPIA

- Flexible work times and work locations in special situations (e.g. when child care is needed, time for caring for elderly relatives, or in dual career situations)
- Reserved places in child care facilites for children between the ages of 8 weeks and 6 years; a total of approx. 30 places for the MPIs in Heidelberg
- Child care room and baby-friendly office in the institute
- Child care during conferences
- Offers for child care during the school holidays via Bündnis für Familie Heidelberg
- Dual career programs
- "Keep in touch" program for employees who require temporary leave from their job in special situations
- Support for fathers' parental leave
- Support program for finding accomodation, suitable schools and child care as new employees move to Heidelberg, by the institute's International Office
- PME Familienservice clearing house for child care, senior care, house-cleaning and similar services

New counseling service for Max Planck Society

When it comes to achieving work-life balance, good counseling in matters of childcare, emergency childcare, au pair, care for the elderly, private kindergardens, creches, holiday programs, and home care can make a crucial difference.

Fig. V.3.1: Kindergarten Glückskinder – interior view.

Credit: Glückskinder

Fig. V.3.2: Kindergarten Glückskinder - interior view.

Until June 2015, counseling services for the Max Planck Society were provided by the company "Besser betreut" (which translates as something along the lines of "Cared-for in a better way"). From July 2015 onwards, these services have been provided by a different company, namely pme Familienservice GmbH, which will support MPG employees in matters of childcare and elderly care.

The company has created a special web page for MPIA employees, and operates a dedicated MPG hotline. The web pages also list the various pme offices, allowing employees to arrange for direct contact.

Childcare

MPIA has extended their cooperation with the childcare facility "Glückskinder" (literally, "Children of luck"). For MPIA employees, that means a current contingent of childcare places at four different locations:

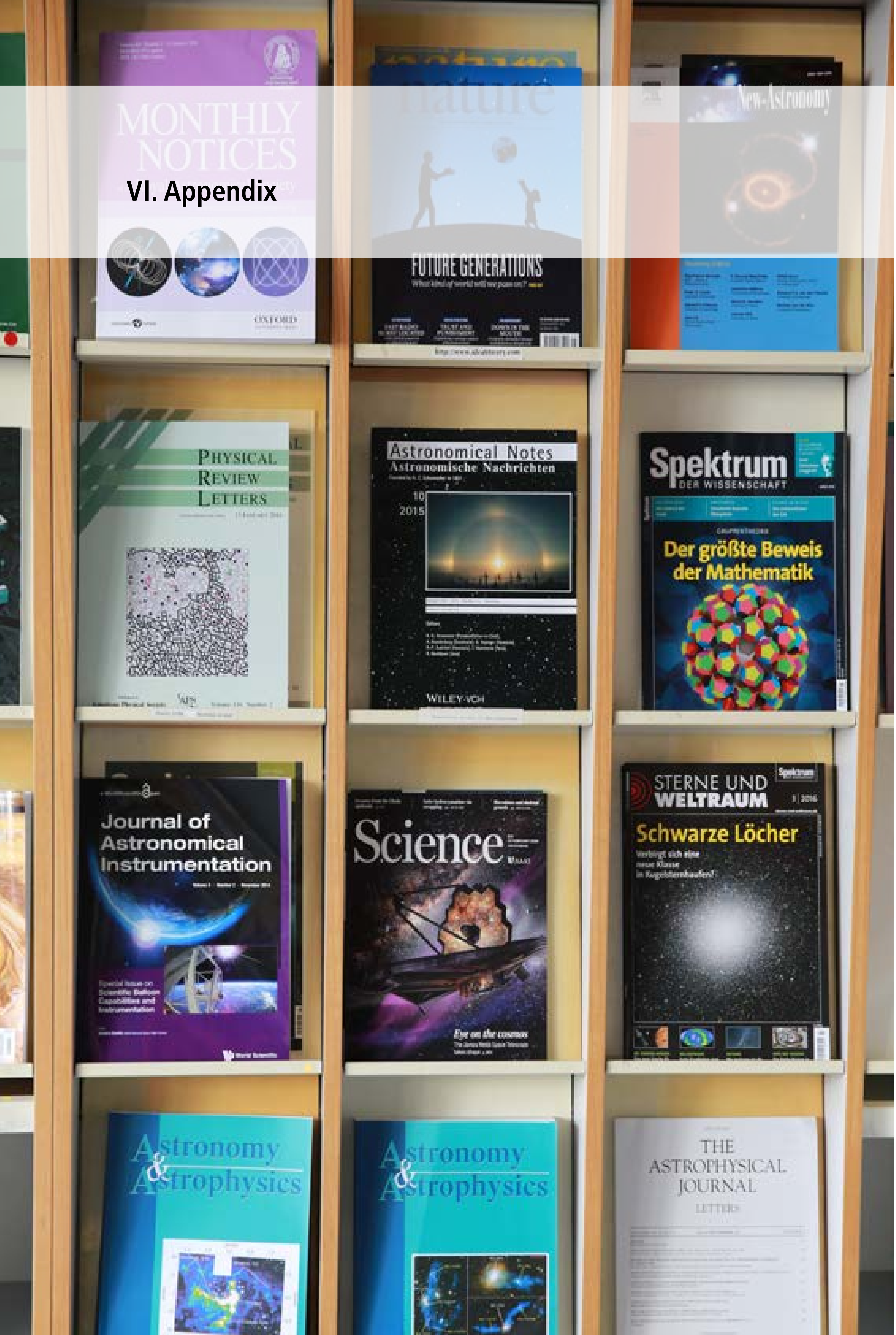
- Quantenzwerge, Kinderzentren Kunterbunt (MPIK)
- Die Wichtel (Im Neuenheimer Feld)
- Uni-Kinderkrippe (Im Neuenheimer Feld)
- Glückskinder (Heidelberg/Bergheim)

More generally, the childcare situation in Heidelberg for children less than 3 years of age shows some improvement. Both the extensions of the municipal childcare program by the city of Heidelberg and the contingent of places reserved for the Max Planck Institutes in Heidelberg are having a positive effect on our employees' childcare prospects.

Waiting time for creche places is currently rather short. This is of particular importance to those scientists who have newly joined MPIA, and who profit from this state of affairs. A good support system for achieving work-life balance helps those newcomers with their fresh start, at a new stage of their career in science and research.

Ingrid Apfel

VI. Appendix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STERNE UND WELTRAUM
Schwarze Löcher
Astronomy & Astrophysics
Astronomy & Astrophysics
THE ASTROPHYSICAL JOURNAL
LETTERS

VI. Appendix

VI.1 Staff

Department: Planet and Star Formation

Director: Thomas Henning

Infrared Space Astronomy: Oliver Krause, Zoltan Balog, Jeroen Bouwman, Örs Hunor Detre, Ulrich Grözinger, Ulrich Klaas, Hendrik Linz, Friedrich Müller, Silvia Scheithauer, Jürgen Schreiber, Amelia Stutz

Star Formation: Henrik Beuther, Aida Ahmadi, Jorge Abreu, Simon Bihr, Roxana Chira, Bertrand Goldman, Jouni Kainulainen, Joe Mottram, Michael Rugel, Sarah Sadavoy, Yuan Wang, Shiwei Wu

Brown Dwarfs/Exoplanets: Thomas Henning, Reinhard Mundt, Roy van Boekel, Esther Buenzli, Simona Ciceri, Carlos Eiroa, Markus Feldt, Malcom Fridlund, Eric Gaidos, Siddarth Hedge, Viki Joergens, Ralf Launhardt, Anne-Lise Maire, Luigi Mancini, Elena Manjavacas, Andre Müller, Dimitry Semenov, Adriana Pohl, Paula Sarkis, Richard Teague, Johan Oloffson, Fei Yan, Liu Yao

Theory (PSF): Hubertus Klahr, Hans Baehr, Tilman David Birnstiel, Michael Butler, Kai Martin Dittkrist, Aiara Lobo Gomez, Natascha Manger, Mykola Malygin, Christoph Mordasini, Gabriel-Dominique Marleau, Maurice Paul Molliere, Andreas Schreiber

Laboratory Astrophysics: Cornelia Jäger, Daniele Fulvio, Walter Hagen, Sergy Krasnokutsky, Gael Rouillét

Adaptive Optics: Wolfgang Brandner, Xiaolin Dai, Casey Deen, Alexandr Golovin, Stefan Hippler, Zoltan Hubert, Taisiya Kopytova, Matthias Samland, Maria Wöllert

MPG Research Group: Thomas Robitaille, Francesco Biscani, Christine Koepferl, Esteban Morales

Frontiers of Interferometry in Germany FRINGE: Thomas Henning, Uwe Graser, Ralf Launhardt, Jörg-Uwe Pott, Roy van Boekel

Department: Galaxies and Cosmology

Director: Hans-Walter Rix

Galaxy Evolution and Milky Way: Hans-Walter Rix, Priscilla Chauke, Nina Hernitschek, Jakob Herpich, Laura Inno, Benjamin Laevens, Marie Martig, Michael Maseda, Melissa Ness, Edward Schlafly, Branimir Sesar, Gregory Stinson, Wilma Trick, Arjen van der Wel, Xiangxiang Xue, Zhitai Zang

Gaia Galactic Survey Mission: Coryn Bailer-Jones, René Andrae, Tri Astraatmaja, Fabo Feng, Morgan Fouesneau, Dae-Won Kim, Sara Rezaeikhoshbakht, Kester Smith

Interstellar Matter and Quasars with high Redshift: Fabian Walter, Eduarodo Banados Torres, Anahi Caldú Primo, Roberto Decarli, Emanuele Farina, Carl Ferkinhoff, Alexander Hygate, Roger Ianjamasimanana, Maria Kapala, Nico Krieger, Chiara Mazzuchelli, Bram Venemans, Laura Zschaechner

High Definition Astronomy: Thomas Herbst, Derek Kopon, Rosalie McGurk, Kalyan K. Radhakrishnan

Astrophysical Jet: Christian Fendt, Dennis Gassmann, Qian Qian, Christos Vourellis

Active Galactic Nuclei: Klaus Meisenheimer, Bernhard Dorner

Extragalactic Star Formation: Eva Schinnerer, Emer Brady, Kathryn Kreckel, Sharon Meidt, Mark Norris, Miguel Querejeta, Kazimierz Sliwa, Neven Tomicic

Coevolution of Galaxies and Black Holes (Emmy Noether Group) and EUCLID Mission Group: Knud Jahnke, Felix Hormuth, Matt Mechtley, Gregor Seidel, Robert Singh, Stefanie Wachter

Inter- and Circumgalactic Medium (Sofia Kovalevskaja Group): Joe Hennawi, Fabrizio Arrigoni Battaia, Frederic Davies, Anna Christina Eilers, Cristina Javiera Garcia, Hector Hiss, Ilya Khrykin, Girish Kulkarni, Khee-Gan Lee, Jose Onorbe, Tobias Schmidt, Daniele Sorini, Jonathan Stern, Gabor Worseck, Michael Walther, Heilker Theiss

Structure and Dynamics of Galaxies: Glenn van de Ven, Paolo Bianchi, Alina Boecker, Remco van den Bosch, Alex Büdenbender, Chen Fanyao, Ryan Leaman, Ying Chi Leung, Sophia Milanov, Anna Sippel, Athanasia Tstasi, Akin Yildirim, Ling Zhu, Yulong Zhuang

Galaxy Formation in a Dark Universe (independent Max Planck Research Group): Andrea Macciò, Tobias Buck, Salvatore Cielo, Aaron Dutton, Nikolaos Fanidakis, Jonas Frings, Thales Gutcke, Aura Obreja, Camilla Penzo, Liang Wang

Instrumentation, Black Holes and Accretion: Jörg-Uwe Pott, Santiago J. Barboza, Michael Boehm, Johannes Esser, Martin Glück, Gabriele Rodeghiero, Joel Sanchez, Kirsten Schnuelle

Stellar spectroscopy and populations (Max Planck Group): Maria Bergemann, Joachim Bestenlehner, Steffen Brinkmann, Mikhail Kovale, Valeriy Vasilyevv

Galactic Nuclei (Max Planck Group): Nadine Neumayer, Mayte C. Alfaro Cuello, Anja Feldmeier-Krause, Iskren Y. Georgiev, Nikolay Kacharov, Alessandra Mastrobuono-Battisti, Arianna Picotti

Stellar Physics and the Evolution of Chemical Elements (Sofia Kovalevskaja Group): Karin Lind, Sven Buder

Other staff

Scientific coordinator: Klaus Jäger

MPIA Observatories: Roland Gredel

Public Relations: Markus Pössel (Head), Klaus Jäger, Axel M. Quetz

Haus der Astronomie: Markus Pössel (Managing Scientist), Sigrid Brümmer-Wissler, Natalie Fischer, Olaf Fischer, Carolin Liefke, Markus Pössel, Cecilia Scorza de Appl, Elena Sellentin; *Trainees, Interns, Student assistents:* Sophia Appl (15.8. until 31.10.), Heiko Depping (since 1.11.), Jan Eberhardt (since 1.6.), Fabian Gebhart (since 15.9.), Sophia Haude, Simon Kopf (1.5. until 14.8.), Sebastian Neu (since 31.8.), Benjamin Nissel (1.6. until 30.6.), Katja Reichert, Valentina Rohnacher (1.11. until 30.11.), Elisabeth Zepf (1.11. until 30.11.)

Technical Departments: Martin Kürster (Head)

- **Engineering Design:** Ralf-Rainer Rohloff (Head), Harald Baumeister (Deputy), Monica Ebert, Armin Huber, Norbert Münch; *Trainees, Interns, Student assistents:* Jochen Müller (17.8. until 6.11.)
- **Precision Mechanics Workshop:** Armin Böhm (Head), Stefan Meister (Deputy), Mario Heitz, Tobias Maurer, Nico Mayer (28.2. until 31.8.), Klaus Meixner, Alexander Specht (28.2. until 31.8.), Tobias Stadler; *Trainees, Interns, Student assistents:* Nico Mayer (until 27.2.), Francisco Ortiz, Lukas Reichert, Leon Schädel (since 1.9.), Matthias Schend, Christoph Schwind, Felix Sennhenn, Alexander Specht (until 27.2.) Larissa Stadter (since 1.9.)
- **Electronics:** Lars Mohr (Head), José Ramos (Deputy); Tobias Adler, Mathias Alter, Heiko Ehret, Ralf Klein, Michael Lehmitz, Ulrich Mall, Achim Ridinger, Frank Wrhel; *Trainees, Interns, Student assistents:* Peter Pflanzl (until 28.2.), Alahmed Qutaish (1.3. until 31.8.), Mohammed Sabber (1.3. until 31.8.)
- **Software:** Florian Briegel (Head), Udo Neumann (Deputy), Jürgen Berwein, José Borelli, Frank Kittmann, Martin Kulas, Richard Mathar, Alexey Pavlov, Clemens Storz
- **Instrumentation:** Peter Bizenberger (Head), Thomas Bertram (Deputy), Wolfgang Gässler, Uwe Graser (bis 28.2.), Dieter Hermann, Ralf Hofferbert, Werner Laun, Markus Mellein, Javier Moreno-Ventas, Eric Müller, Vianak Naranjo (parental leave since 22.4.), Johana Panduro, Diethard Peter; *Trainees, Interns, Student assistents:* Jonathan Slawitzky (until 31.1.)

Administrative and Technical Service Departments:

- **Library:** Monika Dueck
- **IT Department:** Donald Hoard (Head), Björn Binroth (Deputy), Ulrich Hiller, Andreas Hummelbrunner, Marco Piroth, Frank Richter
- **Photographic Lab:** Doris Anders
- **Graphics Department:** Axel M. Quetz (Head), Karin Meißner, Carmen Müllerthann (parental leave since 1.3.), Judith Neidel (since 1.2.)
- **Secretariats:** Sandra Berner (until 30.9.), Marina Gilke (since 1.11.), Carola Jordan, Susanne Koltes-Al-Zoubi, Sabine Otto, Daniela Scheerer, Heide Seifert, Huong Witte-Nguy (parental leave until 30.11.)
- **Technical Services and Cafeteria:** Frank Witzel (Head), Markus Nauß (Deputy), Hartmut Behnke, Sascha Douffet, Gabriele Drescher, Marion Jung, Pascal Krämer, Frank Lang, Britta Witzel, Elke Zimmermann
- **Administration:** Mathias Voss (Head), Ingrid Apfel (Deputy), Danuta Hoffmann, Arnim Wolf

Purchasing Dept.: Arnim Wolf, Doris Anders
Finances Dept.: Danuta Hoffmann, Doris Anders, Heidi Enkler-Scharpegge, Marc-Oliver Lechner, Manuela Reifke, Christine Zähringer
HR Dept.: Ingrid Apfel, Jana Baier, Christiane Hölscher, Silke Hofmann (until 31.05.2015), Lilo Schleich, Tina Wagner
Information: Ina Beckmann, Madeline Dehen
Trainees, Students: Henock Lebasse, Anica Till

Former Staff Members Acting for the Institute:
Christoph Leinert, Dietrich Lemke

VI.2 Visitors List

Scientific visitors: Sebastian Thielen, Univ. Heidelberg, 1. Nov. – 30. Apr.; Steffen Brinkmann, 1. Feb. – 30. Apr.; Carlos Escudero, API La Plata, 22. Feb. – 6. March.; Nichola Boardman, Univ. St. Andrews, 28. Feb. – 26. Apr.; Simon Diaz Garcia, Univ. Oulu, 30. March – 30. Apr.; Nikolai Voshchinnikov, St. Petersburg, 2. Apr. – 23. Apr.; Guiseppe Raia, Univ. Naples, 13. Apr. – 10. July; Samuel Earp, Univ Lancashire, 27. Apr. – 17. May; André Müller, ESO, 27. Apr. – 22. May; Anna Sippel, Swinburne Univ., 10. May – 5. June; Yuan-Sen Ting, Harvard Univ., 24. May – 20. Aug.; Alberto Bolatto, Univ. Maryland, 1. June – 31. Aug.; Kevin Theophile, Univ. Paris, 1. June – 31. Aug.; Ci Xue, Univ. Xiamen, 1. June – 31. Aug.; Gerard Zins, ESO, 2. – 19. June; Greg Rudnick, Kansas Univ., 3. June – 7. July; Sladjana Knezevic, Weizman Inst., 7. – 20. June; Brent Groves, ANU, 7. – 27. June; Steve Beckwith, Univ. Berkeley, 8. – 21. June; Iraj Eshghi, NYU, 9. June – 25. Aug.; Rachel Bezanson, Univ. Arizona, 19. June – 4. July; Tyler Desjardins, Kansas Univ., 20. June – 4. July; Alexia Lewis, Univ. Washington, 8. July – 10. Aug.; Dan Weisz, Univ. Washington, 8. July – 10. Aug.; David Hogg, NYU, 11. July – 31. Aug.; Adrian Price-Wheelan, Columbia Univ., 24. July – 14. Aug.; Julyanne Dalcanton, Univ. Washington, 26. July – 23. Aug.; Steffi Yen, Univ. Maryland, 1. – 15. Aug.; Emily Wisnioski, MPE, 2. – 15. Aug.; Trevor Mendel, MPE, 2. – 15. Aug.; Michael Smith, Kent Space School, 27. Aug. – 14. Sep.; Trifon Trifonov, Univ. Hong Kong, 12. – 30. Sep.; Yancy Shirley, Steward Obs., 13. Sep. – 3. Oct.; Olga Zakhozhay, NAS Ukraine, 15. – 29. Sep.; Paula Sarkis, Univ. Beirut, 15. Sep. – 15. Nov.; Mose Giordano, Univ. Salento, 21. Sep. – 21. Dec.; Somayeh Sheiknezami, School of Astronomy, Teheran, 3. Oct. – 21. Dec.; Vitaly Akimkin, INASAN, 4. Oct. – 1. Nov.; René Plume, Univ. Calgary, 9. Oct. – 28. Nov.; Kathrin Passig, DAI Heidelberg, 29. Oct. – 20. Nov.; Masafusa 15/16 Onoue, NAO, 17. Nov. – 29. Jan.; Christine Köpferl, Univ. St. Andrews, 26. Nov. – 18. Dec.; Laurent Pallanca, ESO Paranal, 30. Nov. – 18. Dec.; Laurent Pallanca, ESO Paranal, 30. Nov. – 18. Dec.; Eduardo Banados, Carnegie Obs., 10. Dec. – 10. Jan. 2016

Due to our regular international meetings and workshops further guests visited the institute, not listed here individually.

VI.3 Meetings and Talks

Meetings organized at MPIA:

THOR team meeting, HdA, Feb. 2–3 (Henrik Beuther)
LINC-NIRVANA Consortium Meeting, Mar. 19 (Martin Kürster)
3rd DAGAL Annual Meeting, Mar. 23–27 (Athanasia Tsatsi)
Conference "Frontiers of Stellar Spectroscopy in the Local Group and Beyond", HdA, Apr. 27–30 (Maria Bergemann, Joachim Bestenlehner, Susanne Koltes-Al-Zoubi, Markus Pössel, Sigrid Brümmer-Wissler, Valeriy Vasilyev)
LINC-NIRVANA Preliminary Acceptance Europe, May 4–7 (Martin Kürster)
FIR Fine Structure Line Workshop, June 8–11, HdA (Roberto Decarli, Carl Ferkinhoff, Maria Kapala, Laura Zschaechner)
Horizontal Project Management ... and how to avoid it, June 25 (Martin Kürster)
MPIA summer conference "A 3D View on Galaxy Evolution", Heidelberg, July 6–10 (Kathryn Kreckel, Marie Martig, Miguel Querejeta, Eva Schinnerer, Neven Tomicic, Glenn van de Ven)
International Summer Science School Heidelberg–HdA/MPIA, July 18 – Aug. 15 (Thomas K. Henning, Hans-Walter Rix)
MATISSE science group meeting Sep. 21–22 (Roy van Boekel)
IMPRS Summer School, Dynamics of the Interstellar Medium and Star Formation, Heidelberg, Sep. 21–25 (Christian Fendt)
PSF retreat, Oct. 26–28 (Roy van Boekel)
CARMENES Science Meeting MPIA and LSW, Nov. 19 (Martin Kürster)
Scientific Colloquium in honor of Reinhardt Mundt, Dec. 10 (Klaus Jäger)

Other Conferences Organized or Supported:

ARGOS SX Wavefront Sensor shipping review, Florenz, Italy, Jan. 4–5 (Wolfgang Gässler)

ALMA Cycle 3 astrochemistry meeting, MPE Garching, Jan. 12–15 (Dmitry Semenov)

4MOST Electronic handover meeting, Universitätssternwarte Munich, Jan. 19–20 (Wolfgang Gässler)

ARGOS Consortium meeting, Sterzing, Jan. 21–23 (Wolfgang Gässler)

METIS science group meeting, ETH Zürich, Feb. 25–26 (Roy van Boekel)

MRI confronts observations, Ringberg Castle, Apr. 13–17 (Hubert Klahr)

Python in Astronomy, Lorentz Center, Leiden, Netherlands, Apr. 20–24 (Thomas Robitaille)

Heidelberg-Harvard Meeting for Star Formation 2015, Cambridge, USA, May 18–21 (Henrik Beuther)

1st Advanced School on Exoplanetary Science, Vietri sul Mare, Italy, May 25–29 (Luigi Mancini)

The Physics of Evolved Stars – a conference dedicated to the memory of Olivier Chesneau, Nizza, France, June 8–12 (Christoph Leinert)

The Physics behind the Radio-FIR Correlation, EWASS session,Tenerife, Spain, June 22–26 (Eva Schinnerer)

European Interferometry Initiative (EII), Science Council meeting, EWASS 2015, Tenerife, Spain, June 26 (Jörg-Uwe Pott)

Workshop "Stellar Streams in the Local Universe", Ringberg Castle, July 20–24 (Melissa Ness, Branimir Sesar)

Stellar Streams in the Local Universe; Ringberg Castle, July 20–24 (Branimir Sera, Melissa Ness, Hans-Walter Rix, Wilma Trick, Nicolas Martin)

Japanese German Frontiers of Science meeting, Physics/Astronomy Session, Kyoto, Japan, Sep. 3–6 (Knud Jahnke)

8th VLTI Summer School, "High angular resolution in astrophysics: optical interferometry from theory to observations", University of Cologne, Sep. 6–13 (Jörg-Uwe Pott)

Meeting of the Astronomische Gesellschaft "From the first quasars to life-bearing planets: From accretion physics to astrobiology", Kiel University, Sep. 14–18 (Klaus Jäger)

Gaia DPAC CU8 plenary meeting, Uppsala, Schweden, Sep. 15–17 (Coryn Bailer-Jones)

AG Splinter Meeting: Science with the LBT, AG-Meeting, Kiel University, Sep. 16 (Roland Gredel)

Meeting "Public Outreach in der Astronomie", Kiel University, Sep. 16 (Klaus Jäger, Markus Pössel)

IMPRS Summer School, Dynamics of the Interstellar Medium and Star Formation, Max-Planck-Haus, Heidelberg, Sep. 21–25 (Christian Fendt)

ARGOS Consortium meeting, Bozen, Italy, Sep. 22–23 (Wolfgang Gässler)

From Clouds to Protoplanetary Disks: The Astrochemical Link, Harnack Haus, Berlin, Oct. 3–5 (Dmitry Semenov)

Galactic nuclei at high resolution in many dimensions, Alajar, Spain, Oct. 3–11 (Nadine Neumayer)

Observational Evidence for Accretion on Galaxies, Charlottesville, VA, USA, Oct. 8–10 (Fabian Walter)

International PhD School "F. Lucchin": Science and Technology with E-ELT (XIV Cycle II Course), Erice, Sicilia, Italy, Oct. 8–20 (Laura Inno)

PSF Retreat, Tagungshaus Schönenberg, Ellwangen, Oct. 26–28 (Silvia Scheithauer)

METIS consortium meeting, Leiden, Netherlands, Oct. 28–30 (Roy van Boekel)

MPIA-External Retreat, Bad Dürkheim, Nov. 9–10 (Klaus Jäger, Thomas Henning, Hans-Walter Rix, Carola Jordan, Sandra Berner, Marina Gilke)

Gaia DPAC consortium Meeting, Splinter session: Cross Unit Validation and Instrument features, Leiden, Netherlands, Nov. 16–20 (Morgan Fouesneau)

MATISSE workshop, Nizza, France, Dec. 18–20 (Roy van Boekel)

Invited talks and colloquia:

Jorge Abreu-Vicente: Instituto de Astrofisica de Canarias (IAC), La Laguna, Tenerife, Spain, Dec. 17 (Colloquium)

Tri L. Astraatmadja: "Gaia: Exploring the Milky Way", Southeast Asian Young Astronomers Collaboration (SEAYAC) 2015 Meeting, Krabi, Thailand, Dec. 3 (Talk)

Coryn Bailer-Jones: "Frontiers of Stellar-Spektroskopie in der Lokalen Gruppe und darüber hinaus", MPIA, Heidelberg, Apr. 27–30 (Talk); "Measuring the Universe with Gaia", Maynz University, July; "Measuring the Cosmos with Gaia", National Astronomy Observatories of China, Beijing, Oct.; "Astroimpacts: Astronomical impacts on the Earth", Lund University, Dec.

Maria Bergemann: "Chemical abundance analysis in the era of large surveys", The Milky Way and its Stars, Santa Barbara, USA, Feb. 2–6 (Talk); "Stellar and Galactic Archaeology with Bayesian Methods", Bayes Forum, Max-Planck-Institut für Astrophysik, Garching, July 24 (Seminar); "High-precision stellar spectroscopy and fundamental parameters of stars", SFB-Seminar, Heidelberg, July 1 (Seminar); "Stellar parameters at high precision", Fall meeting of the AG, Kiel University, Sep. 14–18, Kiel (Plenary Talk); "Milky Way Disk and Bulge High-Resolution Survey", 4MOST All Hands Meeting, Cambridge, UK, Sep 28 – Oct. 2 (Talk); "Chemical abundances of the Sun and solar-like stars", Solarnet III / HELAS VII / SpaceInn Conference, Freiburg, Aug 31 – Sep. 4 (Talk)

Henrik Beuther: Colloquium at University of Geneva, Jan. (Colloquium); ESO, Apr. (Colloquium); Soul of high-mass star formation, Puerto Varas, Chile, May 15–20 (Talk); Heidelberg-Harvard Meeting for Star Formation, May 18–21 (Talk); Conditions and impact of star formation, Zermatt/Switzerland, Sep. 7–11 (Talk)

Til Birnstiel: From clouds to protoplanetary disks: the astrochemical link Berlin, Harneckhaus, Oct. 4–8 (Talk); Observatoire de Bordeaux Bordeaux, France, Nov. 23 (Colloquium)

Venemans Bram: First stars, galaxies, and black holes: Now and Then, Groningen, The Netherlands, June 15–19 (Talk)

Roberto Decarli: ALMA Community Days, Bonn, Mar. 25–26 (Talk)

Aaron Dutton: The Most Massive Galaxies and their Precursors, Sydney, Australia, Feb. (Talk)

Emanuele Paolo Farina: Instituto de Fisica y Astronomia, Universidad de Valparaíso, Valparaíso, Chile, July 14 (Colloquium); Exploring the high-z Universe with Pan-STARRS1 or: How I Learned to Stop Worrying and Love Quasars (Talk)

Christian Fendt: How to make astrophysical jets, Mayn Colloquium, Max Planck Institute for Radio Astronomy, Bonn, Mar. 6 (Colloquium); How to make astrophysical jets?, Leibniz Institute for Astrophysics Potsdam, Potsdam, June 25 (Colloquium)

Morgan Fouesneau: Gaia Astrophysical parameter pipeline Workshop: Spectral energy fitting, Rockport, USA, Oct. 18–21 (Talk); While waiting for Gaia data release 1, Strasbourg observatory, France, Nov. 12 (Colloquium)

Roland Gredel: C_{60} as a probe for astrophysical environments, Observatorio Nacional Rio de Janeiro, Oct. 27 (Colloquium)

Thomas K. Henning: Colloquium Talk – University Kassel, Feb. 12; JWST/MIRI Meeting, Madrid, Spain, Feb. 17–19 (Talk); Workshop "Second Workshop on Experimental Laboratory Astrophysics", Hawaii, USA, Feb. 21 – Mar. 3 (Talk), Conference "The Soul of High-mass Star Formation", Puerte Varas, Chile, Mar. 16 – 20 (Talk); Workshop "Third Chinese-German Workshop on Star and Planet Formation", Nanjing, China, Mar. 22–23 (Talk); Conference "The Magneto-Rotational Instability confronts Observations": Apr. 13–17, Ringberg Castle (Talk); The Magneto-Rotational Instability Confronts Observations, Apr. 22–23 (Talk); Conference "Frontiers of Stellar Spectroscopy in the Local Group and Beyond", HdA, Apr. 27–30 (Talk); Second Harvard-Heidelberg Star Formation Meeting, Boston, USA, May, 18–21 (Talk); Conference "FIR Fine Structure Lines Workshop", HdA, June 8–11 (Talk); EWASS Conference "European Week of Astronomy and Space Science", Tenerife, Spain, June, 21–23 (Talk); A 3D View on Galaxy Evolution, MPIA summer conference, Heidelberg, July 6–10 (Talk); MPI for Biochemistry, Martinsried, July 30 (Colloquium); Goldschmidt Conference, Prague, Czechia, Aug. 16–18 (Talk); Conference "From Interstellar Ices to PAHs", Annapolis, Maryland, USA, Sep. 13–17 (Talk); Workshop "Big Data in Astronomy", Tel Aviv, Israel, Dec. 14–17 (Talk)

Nina Hernitschek: RR Lyrae 2015 Conference: High-precision studies of RR Lyrae stars from dynamical phenomena to mapping the galactic structure, Visegrad, Hungary, Oct. 19–22 (Talk)

Laura Inno: International PhD School "F. Lucchin": Science and Technology with E-ELT (XIV Cycle II Course), Light-curve templates in the large-surveys era, Erice, Sicilia, Italy, Oct. 8–20 (Talk)

Cornelia Jäger: Current expectations concerning the interstellar PAH population, International Symposium on Polycyclic Aromatic Compounds, Session: Interstellar PAHs, Bordeaux, France, Sep. 13–17 (Talk); Dust formation and processing in the ISM, International Workshop on Silicates in Space, Kirchhoff-Institute for Physics, Heidelberg, Sep. 28 – Oct. 1; The Characteristics of Dust in Molecular Clouds; Internationale Conference, From Clouds to Protoplanetary Disks: The Astrochemical Link, Berlin, Oct. 5–8 (Talk)

Knud Jahnke: Königstuhl Colloquium, MPIA, Heidelberg, Jan. 23; AstroTechTalk, MPIA, Heidelberg, June 26 (Talk)

Viki Joergens: "Disks around extremely low-mass stars and brown dwarfs", Chemical diagnostics of star and planet formation with Cycle 3 ALMA, Conference, Max Planck Institute for Extraterrestrial Physics, Garching, Jan. 13–15 (Talk); "The origin of free-floating planets and brown dwarfs" Physics Colloquium of the University of Regensburg, June 1 (Colloquium)

Nikolay Kacharov: Instituto de Astrofisica de Canarias, Tenerife, Spain, June 10, (Colloquium)

Jouni Kainulainen: IAU General Assembly/Division H meeting, Honolulu, USA, Aug. 10 (Talk)

Hubert Klahr: Turbulence in Circumstellar Disks (Talk); Conference: Transition disks and planet formation: Leiden, Mar. 2–6 (Talk); Conference: MRI confronts observations, Ringberg, Apr. 13–17 (Talk); Conference: Planetary Systems: a synergistic view, Vietnam, July 19–25 (Talk);

Oliver Krause: Development statuts and science opportunities with MIRI, the mid-IR instrument for JWST; 6th Zermatt ISM Symposium, Zermatt, Sep. 9 (Talk)

Kathryn Kreckel: Kapteyn Astronomical Institute, Groningen, Jan. (Colloquium); The Ohio State University, Columbus, Feb. (Colloquium); NOAO, Tucson, Feb. (Talk); University of Illinois, Urbana-Champaign, Feb. (Colloquium); A 3D View on Galaxy Evolution, MPIA, Heidelberg, July (Talk)

Ryan Leaman: Joint Institute for Nuclear Theory GNASH Workshop, Victoria, Canada, May 27 (Talk); Tuorla Observatory, Turku Finland, Nov. 17 (Colloquium); Leibniz Institute for Astrophysics Potsdam, Potsdam, Nov. 28 (Seminar)

Dietrich Lemke: Verborgene Botschaften im Sonnenlicht, Planetarium Mannheim, Mar. 19; Erforschung des kalten Universums mit Infrarot-Weltraum-Observatorien, Physikalisches Colloquium Universität Marburg, July 2; Das unsichtbare Universum – Forschung mit Weltraumteleskopen, Nationwide Teacher

Training Workshop, University Jena, July 13; Verborgene Botschaften im Sonnenlicht, Nationwide Teacher Training Workshop, University Jena, July 14; Das unsichtbare Universum – Forschung mit Weltraumteleskopen, Olbers-Gesellschaft Bremen, Nov. 10; Das unsichtbare Universum – Forschung mit Weltraumteleskopen, Sternfreunde Nordenham, Nov. 11; Weltraumteleskope – Entdeckungen im unsichtbaren Universum, Haus der Astronomie, Dec. 4

Karin Lind: The accuracy of stellar metallicites, Swedish days of astronomy, Uppsala University, Sweden, Oct. 24 (Talk); How much iron is in our stars? Heidelberg Joint Astronomy Colloquium, Heidelberg, Nov. 24 (Colloquium)

Hendrik Linz: Chemical diagnostics of star and planet formation with Cycle 3 ALMA, at MPE Garching, Jan. 13–15 (Talk)

Luigi Mancini: Networking Qatar Exoplanet Research Workshop: Photometric follow-ups observations of transiting planets, Qatar National Convention Centre, Doha, Katar, Mar. 2–4 (Talk); 7th GAPS Progress Meeting: The KOI-372 planetary system, Catania Astrophysical Observatory, Catania, Italy, Nov. 4–6 (Talk); Exo-planetary atmospheres: models and laboratory analoguesInternational Focus Workshop: Transmission photometry to probe the atmosphere of transiting exoplanets, Osservatorio Polifunzionale del Chianti, San Donato in Poggio, Firenze, Italy, Sep. 15–17 (Talk)

Marie Martig: Modeling Milky Way-type galaxies in the Gaia era, Nizza, France, Dec. 17–18 (Talk)

Nicolas Martin: Stellar Streams Ringberg 2015, Ringberg Castle, July 20–24 (Talk); Mauna Kea Spectroscopic Explorer Science Team Meeting, Kona, USA, Aug. 3–5 (Talk); ESO, Garching, Feb. 19 (Colloquium); Observatoire de Paris-Meudon, France, June, Sep. 12 (Colloquium); University of Surrey, UK, June, Sep. 18 (Colloquium)

Sharon E. Meidt: Kapteyn Institute, University of Groningen, Jan. (Colloquium); Dissecting Galaxies Near and Far, ESO, Santiago, Chile, Mar. (Talk); Bonn Galaxy Workshop, Apr. (Review-Talk); A 3D View on Galaxy Evolution: from Statistics to Physics, Heidelberg, July (Talk)

Melissa Ness: Observatory of Strasbourg, France, Apr. (Colloquium); MIAPP: The New Milky Way, Garching, May (Talk); Max Planck Institute for Extraterrestrial Physics, Garching, May (Seminar)

Nadine Neumayer: Nuclear star clusters – in the Milky Way and nearby galaxies, ARI, Heidelberg, Dec. 15 (Talk); Aspen Conference: Black Holes in Dense Star Clusters, Black holes in Nuclear Star Clusters, Aspen Center for Physics, Aspen, Colorado, USA, Jan. 17–22 (Talk); Oxford workshop: Supermassive black holes, Nuclear star clusters and black holes, Wadham College, Oxford, UK, Mar. 16–19 (Talk); DAGAL meeting at MPIA, The build-up of galactic nuclei, Mar. 26 (Talk); IAU General Assembly, IAUS316: Formation, Evolution, and Survival of Massive Star Clusters, Nuclear Star Clusters, Honolulu, Hawaii, USA, Aug. 11–14 (Talk); Nuclear Star Clusters and Black Holes, AG Meeting, Kiel University, Sep. 16 (Talk); Alajar workshop: Galactic nuclei at high resolution in many dimensions, Observational constraints on central black holes at the lowest detectable masses, Alajar, Spain, Oct. 3–11 (Talk)

Jose Onorbe: Constraining high redshift early heating with first independent measurements of the IGM pressure smoothing, Reionization: A Multiwavelength Approach. Centre for Extragalactic Theory, Kapstadt, Südafrika, June (Talk); Constraining high redshift early heating by measuring the IGM Jeans filtering scale, The Epoch of Reionization. Paralia Katerini, Griechenland, May (Talk); Galaxies on FIRE (Feedback in Realistic Environments): The Role of Stellar Feedback in Dwarf Galaxy Formation, University of Valencia, Spain., May (Colloquium); Characterization of the IGM Jeans Scale and its measurement Using Quasar Pairs, Insitut de Ciencies del Cosmos. Barcelona, Spain, Feb. (Colloquium)

Hans-Walter Rix: AAS & Apogee Collaboration Meeting, “What Gaia will do to enhance spectroscopic surveys?”, Seattle, USA, Jan. 8–11 (Talk); KITP-Workshop, “Why map the Milky Way”; St. Barbara, CA, USA, Jan. 31 – Feb. 13 (Talk); Physics Colloquium, “What galaxies remember about their pre-history?”, University of St. Barbara, CA, USA, Feb. 1–13 (Talk); Colloquium, “How the Milky Way disk was built up?”, University of Lausanne, CH, Mar. 2–3 (Talk); ROE Colloquium, “How the Milky Way disk was built up?”, University of Edinburgh, UK, Apr. 14–16 (Talk); Conference “Frontiers of Stellar Spectroscopy in the Local Group and Beyond”, HdA, Apr. 27–30, NIRSpec IST Meeting, “Galaxy Assembly with JWST”, University of Oxford, Oxford, UK, June 9–10 (Talk); Conference “FIR Fine Structure Lines Workshop”, HdA, June 8–11 (Talk); Annual MPIA Summer Conference, “A 3D View on Galaxy Evolution: from Statistics to Physics”, MPIA, July 6–10 (Talk); Zwicky Workshop, “What do we need to learn about the cosmic star formation history?”, ETH, Braunwald, Switzerland, Aug. 31 – Sep. 4 (Talk); ESO Workshop “Rainbow on the Southern Sky”, “Why and how to map the galaxy with spectral surveys”, MPI Garching, Oct. 5–7 (Talk); Workshop “Big Data in Astronomy”, “How to get the best information out of stellar spectra?”, Tel Aviv, Israel, Dec. 14–17 (Talk)

Gael Rouillé, Optical absorption spectroscopy on cold, isolated molecules, Seminar zur Oberflächenforschung, Institut für Physikalische und Theoretische Chemie, Bonn, Jan. 16 (Colloquium)

Sarah Sadavoy: Western University, London, Canada, Jan. 8 (Colloquium); Canadian Astronomical Society meeting, Hamilton, Canada, 25. May (Talk); Boston University, Boston USA, Sep. 22 (Colloquium)

Eva Schinnerer: IAU GA Division J meeting, Hawaii, USA, Aug. 10 (Talk); ASTRON, Dwingeloo, Netherlands, Apr. 7 (Colloquium)

Eddie Schlafly: European Week of Astronomy and Space Sciences, Tenerife, Spain, June 25 (Talk); Orion Unplugged, Vienna, Austria, July 1 (Talk); Astronomical Observatory of Strasbourg, Straßburg, Oct. 30 (Colloquium)

Dmitry A. Semenov: Surface chemistry and chemo-dynamical evolution of protoplanetary disks, ALMA Cycle 3 astrochemistry meeting, MPE, Garching, Jan. 12–15 (Talk); Legacy of Herschel: what we have learned about protoplanetary disks, From Herschel to ALMA, Zakopany, Poland, May 12–15 (Talk); Delivery of organics and water on Earth: an astrochemical study, 2nd Harvard-Heidelberg Star Formation meeting, Boston, USA, May 18–20 (Talk); WG2: "icy grain chemistry" I. Observational and theoretical perspectives, COST Action 1401 Kick-Off meeting, Prague, Czechia, May 26–29 (Talk); Molecules as probes of physics of the ISM and protoplanetary disks, Academia of Sinica, Institute of Astronomy and Astrophysics, Taipeh, Taiwan, ROC, Nov. 18 (Colloquium)

Branimir Sesar: Radboud University, Nijmegen, May 12 (Colloquium); RR Lyrae 2015, Visegrad, Hungary, Oct. 22 (Talk)

Daniele Sorini: "Predicting the Lyman-alpha Forest from Collisionless Simulations", Imperial College London, UK, July 17 (Talk)

Juergen Steinacker: Silicates in Space, Kirchhoff-Institute for Physics, Heidelberg, Sep. 28 (Talk)

Jonathan Stern: University of California at Santa Cruz, Santa Cruz, CA, USA, Mar. 3 (Talk); University of California at Irvine, Irvine, CA, USA, Mar. 10 (Talk)

Gregory Stinson: Conference Cosmo Sims: from galaxies to large scales, Sesto, Italy, July 1 (Talk); UNAM Mexico City, Mexiko, Feb. 3 (Colloquium); Racah Institute at The Hebrew University, Jerusalem, Israel, Feb. 24 (Colloquium); University of Surrey, UK, Oct. 16 (Colloquium); Durham University, UK, Oct. 19 (Colloquium); Mullard Space Science Laboratory, University of Central London, UK, Oct. 21 (Colloquium); Cambridge University, UK, Oct. 23 (Colloquium); Osservatorio Trieste, Italy, Nov. 10 (Colloquium)

Roy van Boekel: Chinese Workshop on star and planet formation, Nanjing, China, Mar. 23–26 Mar. (Talk)

Arjen van der Wel: Conference "Getting a Grip on Galactic Girths", Kavli IPMU, University of Tokyo, Japan, Feb. 2–5; Conference "Rainbows in the Southern Sky", ESO, Garching, Oct. 5–9 (Talk); Conference: Census, Evolution, Physics, Yale University, New Haven, USA, Nov. 16–19 (Talk); Colloquium, Kapteyn Institute, Groningen, Netherlands, Mar. 23 (Talk)

Stefanie Wachter: EUCLID Consortium Meeting, Lausanne, Switzerland, June 8–12 June (Talk); Landolt Standards and 21st Century Photometry, Baton Rouge, Louisiana, USA, May 19–21 (Talk)

Fabian Walter: Observational Evidence for Accretion on Galaxies, Charlottesville, USA, Oct. 8–10 (Talk); Quasar Conference, KIAA Peking, China, Mar. (Review-Vortrag); Crete Conference "Gas, Dust, and Star-Formation in Galaxies from the Local to Far Universe", Kreta, Griechenland, May 25–29 (Talk); IAU General Assembly: invited talk on "molecular deep fields", Hawaii, USA, Aug. 3–14 (Talk); Talk at ASTRON HI meeting, Apr. 8 (Colloquium)

Xiangxiang Xue: The Halo of the Milky Wa, Koco in MPIA, Heidelberg, June 26 (Colloquium)

Ling Zhu: The CALIFA collaborate meeting, Florenz, Italy, Apr. 19–24 (Talk); The SDSS IV collaborate meeting, Madrid, Spain, July 19–24 (Talk)

Popular science talks:

Jorge Abreu-Vicente: Discovering the Cosmos. School: P. P. Somascos, La Guardia, Galizien, Spain, Dec. 22

Coryn Bailer-Jones: Astronomical Threats to the Earth, MPIA, June

Roberto Decarli: Buchi neri, Lecture for elementary school kids, Varedo, Italy, Jan. 13

Bertrand Goldman: Toutes sortes de planètes, für die Kids University des Jardin des Sciences, Universität Straßburg: ISIS (Institut de Science et d'Ingénierie Supramoléculaires), June 18; ISU (International Space University), Illkirch campus, Nov. 13.

Roland Gredel: Das Europäische Riesenteleskop E-ELT – Auf dem Weg in ein neues Zeitalter der Astronomie, MPIA Open Day, June 21; Der Blick ins All mit Groß- und Weltraumteleskopen, Hohenstaufen-Gymnasium Kaiserslautern, Sep. 21

Thomas K. Henning: Leben auf anderen Planeten – Die Suche hat begonnen, Planetarium Mannheim, Oct. 15; Diskussionsrunde "Ordnung im Chaos", DAI, Haus der Kultur, Heidelberg, Dec. 3; Die Suche nach der zweiten Erde – aktueller Stand und Aussichten für die Zukunft, Fachhochschule Aachen, Nov. 26.

Felix Hormuth: Franken im Weltall, Sportheim Birnfeld, Birnfeld, Apr. 17

Klaus Jäger: Geheimnisvolle Quasare – der Lösung eines Rätsels auf der Spur, Vortrag auf dem MNU Bundeskongress, Universität Saarbrücken, Mar. 31; Der Himmel im Computer – Virtuelle Planetarien, Girls' Day MPIA/HdA, Apr. 23; Das Unsichtbare sichtbar machen – Highlights aus der (Heidelberger) Trickkiste astronomischer Beobachtungen, MPIA Open Day, MPIA/HdA, June, 21; Science at MPIA, International Summer Science School Heidelberg, MPIA, July 23; Wissenschaft auf dem Königstuhl, Vorstandstagung der Industrie- und Handelskammer, Haus der Astronomie, Sep. 4.; Die Jagd nach Licht – Wie Astronomen ihre fantastischen Bilder machen, Astronomie am Sonntagvormittag, HdA, Oct. 4; Die Jagd nach Licht – Wie Astronomen ihre fantastischen

Bilder machen, Astro-Tech-Colloquium, MPIA, Oct. 16, Galaxien und Terabytes – Astronomie im Zeitalter moderner Großteleskope, Schülerpraktikum, MPIA, Oct. 19

Nikolay Kacharov: Origin of elements, Bulgarian Astronomy Summer School, Beli Brezi, Bulgarien, Aug. 4

Hubert Klahr: Planeten – die Kinder der Sterne: Die Geburt unserer Erde und ihrer Exosolaren Geschwister, Mind Akademie, Heidelberg, Sep. 24

Oliver Krause: Das James-Webb-Weltraumteleskop, MPIA Open Day, June 21

Martin Kürster: Wie groß ist das Universum?, MPIA Open Day, June 21; Wie groß ist das Universum?, Faszination Astronomie, HdA, July 9; Wie groß ist das Universum?, MPIA AstrotechTalk, Sep. 17; Wie groß ist das Universum?, Rüsselsheimer Sternfreunde, Dec. 11

Ralf Launhardt: Das bewegte Leben der Sterne, Nationwide Teacher Training Workshop, HdA, Nov. 12

Christoph Leinert: Mehr als Ebbe und Flut – Gezeitenkräfte in der Astronomie, Faszination Astronomie, HdA, Oct. 8

Hendrik Linz: Die Jagd nach dem langwelligen Licht – Radioastronomie heute und morgen, 16. Südthüringischer Astronomischer Tag, Schul- und Volkssternwarte K. E. Ziolkowski, Suhl, Dec. 5

Nadine Neumayer: Giganten der Schwerkraft: Schwarze Löcher in den Zentren von Galaxien, Haus der Astronomie, Heidelberg, Feb. 12, Feb. 26; MPIA Open Day, June 21

Markus Nielbock: Farbenspiele des Lichts–Was sie uns über die Sterne verraten, Engadiner Astronomiefreunde, Academia Engiadina, Samedan, Switzerland, Apr. 18

Hans-Walter Rix: DPG Spring Meeting, Kirchhoff Institut für Physik, Heidelberg, Mar. 25

Dmitry A. Semenov: Molecules in space: living through diversity, MPIA Open Day, June 21

VI.4 Teaching and Service

Academic Teaching

Winter Term 2014/2015

Coryn Bailer-Jones: Introduction to Astronomy & Astrophysics 3 (Bachelor-Obligatory undergraduate seminar)

Henrik Beuther: Königstuhl-Colloquium (Colloquium)

Maria Bergemann: Experimentalphysik I (Exercises)

Roberto Decarli: The cycle of gas in galaxies, Università di Milano-Bicocca (Italy), 7.–16. Jan. (Lecture)

Christian Fendt, Klaus Meisenheimer: Current research topics (IMPRS 1) (Advanced Seminar, together with Thorsten Lisker (ZAH/ARI))

Christian Fendt: "Exercises zur Experimentalphysik I (Exercises)

Thomas Henning: Physics of Star Formation (Advanced Seminar)

Cornelia Jäger: "Processing of grains" und "Synthesis of cosmic dust analogs and Processing of grains", summer school "Laboratory Astrophysics", Tabarz, 13.–16. Oct. (Block course)

Cornelia Jäger, Harald Mutschke: Laboratory Astrophysics (Seminar)

Knud Jahnke: Galaxienhaufen (Bachelor-Obligatory undergraduate seminar, together with Thorsten Lisker (ZAH/ARI))

Viki Joergens, Henrik Beuther: Protostars and Planets (Master-Obligatory graduate seminar)

Christine Maria Köpferl: Python for Scientists (Exercises)

Andrea Macciò: Galaxy formation (Lecture)

Klaus Meisenheimer: IMPRS (Seminar)

Klaus Meisenheimer: Heraeus School, Padua (Lecture)

Paul Mollière: Fundamentals of Simulation Methods (Exercises)

Melissa Ness: HGSCP Graduate winter school, Austria (Lecture)

Thomas Robitaille: Programming for Scientists (Block course)

Dmitry Semenov: Kleine Körper des Sonnensystems (Master-Obligatory graduate seminar, together with Hans-Peter Gail, ZAH/ITA)

Daniele Sorini: Introduction to Astronomy and Astrophysics I + II (Lecture, Assistent)

Athanasia Tsatsi: Astro Lab (Exercises)

Glenn van de Ven, Andrea Macciò: Galaxies (Blockkurs mit Exercises)

Glenn van de Ven, Elisabete da Cunha, Fabrizio Arrigoni Battaia: Galaxy Coffee (Seminar)

Michael Walther: Cosmology (Exercises)

Summer Term 2015

Coryn Bailer-Jones: Computational Statistics and Data Analysis (MVComp2) (Lecture)

Maria Bergemann, Henrik Beuther, Reinhard Mundt: Einführung in die Astronomie und Astrophysik III (Bachelor-Seminar)

Christian Fendt, Nadine Neumayer, Dmitry Semenov: Current research topics (IMPRS 1) (Research Seminar)

Christian Fendt: Experimentalphysik I (Exercises)

Christian Fendt: Galaxies, Interstellar Medium and Black Holes (Master-Obligatory graduate seminar)

Morgan Fouesneau: Computational Statistics and Data Analysis, 14. Apr.–21. July (MVComp2)

Joe Hennawi: Advanced seminar on current research topics (IMPRS 3, Research Seminar) (together with Frank Bigiel, ZAH)

Joe Hennawi: JC on circum- and intergalactic media (ENIGMA) (Research Seminar)

Thomas Henning: Physics of Star Formation (Advanced Seminar)

Knud Jahnke, Christian Fendt: Galaxies, Interstellar Medium and Black Holes (Master-Obligatory graduate seminar)

Cornelia Jäger, Harald Mutschke: Laboratory Astrophysics (Seminar)

Thomas Robitaille: Python: Programming for Scientists (Blockkurs)

Eva Schinnerer, Amy Stutz, Arjen van der Wel, Henrik Beuther: Königstuhl-Colloquium (together with Andreas Koch, Stefan Wagner, ITA/LSW)

Dmitri Semenov, Christian Fendt, Nadine Neumayer, Glen van de Ven: Seminar on current research topics (IMPRS 2) (Research Seminar)

Winter Term 2015/2016

Tri L. Astraatmadja: Monte Carlo methods in astronomy, Southeast Asian Young Astronomers Collaboration (SEAYAC) 2015 Meeting, Krabi, Thailand (Workshop, Tutorial)

Maria Bergemann: Experimentalphysik I (Exercises)

Maria Bergemann: E-ELT Summer School, Erice, Sicilia, Italy, 16.–19. Oct. (Lecture)

Thomas Henning, Henrik Beuther: Physics of Star Formation (Bachelor Seminar)

Cornelia Jäger, Harald Mutschke: Laboratory Astrophysics (Seminar)

Knud Jahnke, Hubert Klahr: Entstehung kosmischer Strukturen vom Urknall bis Heute (Obligatory undergraduate seminar, together with Hans-Günter Ludwig, LSW)

Knud Jahnke: Allgemeine Relativitätstheorie: Schwarze Löcher, Haus der Astronomie (Lehrerfortbildung)

Viki Joergens: Protostars and Planets (Master-Obligatory graduate seminar)

Jouni Kainulainen: Star Formation (Master-Obligatory graduate seminar)

Nadine Neumayer: Experimentalphysik 1 (Exercises)

Adriana Pohl: Einführung in die Astronomie und Astrophysik I (Exercises)

Hans-Walter Rix: Experimentalphysik I (Übungsgruppe)

Thomas Robitaille: Python: Programming for Scientists (Blockkurs)

Thomas Robitaille: Python workshop, Universität Vienna (Lecture)

Thomas Robitaille: TIARA summer school in Numerical Astrophysics (Lecture)

Thomas Robitaille: SAMCSS summer school on Monte-Carlo Radiative Transfer (Lecture)

Neven Tomicic: Introduction for Astronomy and astrophysics (Exercises)

Membership in major committees

Coryn Bailer-Jones: Manager of the sub consortium "Astrophysical Parameters" (CU8) at Gaia, Data Processing and Analysis Consortium; Member of the Gaia Data Processing and Analysis Consortium Executive

Zoltan Balog: Member of the NASA Astrophysics Data Analysis Program 2015 Review Panel

Maria Bergemann: Member of the ESO Panel 2015 (OPC 96); Speaker of the Max Planck Head of Research Division in the CPT-Sektion

Henrik Beuther: Member of the ALMA time allocation committee; delegate of the MPIA of the CPT- section of the MPG; Board Member of Patzer foundation; Member of the selection committee for Patzer Prize; Member of the German SOFIA Science Working Group (GSSWG); Member of the APEX time allocation committee; referee at ERC, ANR and DFG

Christian Fendt: Referee at the L'Agence Nationale de la Recherche (ANR), France; referee at Narodowe Centrum Nauke (National Science Center), Poland

Wolfgang Gaessler: Member of the 4MOST Scientific Technical Steering Commitee

Bertrand Goldman: Member of the Science Policy Oversight Committee des PanSTARRS1 consortium, Member the of ESO OPC Panel

Roland Gredel: Member of ELT project science team; Member of the LBT scientific advisory committee; Vorsitzender des LBT queue review and advisory committee; Chair of the Opticon board

Thomas Henning: Member of the Matisse Steering Committee; Member of the ESO Council; Member of an MPI search committee (MPI for Dynamics and Self-Organization); Member of the National Cospar Committee; Member of the LBT Board; Member of the CAHA Executive Committee; Chair of the LBTB; Member of the Evaluation Panel of the University of Turku; Co-Chair of the ERC Advanced Grants (Panel Universe Sciene); Member of the Leopoldina and representative of the Committee for Astronomy; Member of the Stern-Gerlach Prize Committee; Member of several PhD committees in Germany, France and the Netherlands; Editor "Sterne und Weltraum"

Cornelia Jäger: Referee for DFG; Member of the SOC at the Conference "The 8th meeting on Cosmic Dust", Tokio, Japan; Member of the committee of the DFG Priority Program "The Physics of the Interstellar Medium"; Member of the Strategy committee "Laboratory Astrophysics" des RDS

Klaus Jäger: Board member, German Astronomical Society (AG); Delegate of the MPIA directorate to Rat Deutscher Sternwarten (RDS); Advisory Board of the International Summer Science School Heidelberg (ISH); Member of the Organizational Committee, Astronomie in Deutschland website; board member

of the association "Freunde und Förderer des Hauses der Astronomie"
Knud Jahnke: Member of the EUCLID consortium
Hubert Klahr: Member of Gremien von DFG, der AvH, The Danish Council for Independent Research, Natural Science, FNRS/FRS (Belgien)
Hendrik Linz: Service Activities for IRAM
Nicolas Martin: Member of the Pan-STARRS1 Science Collaboration Science Council; Member of the Physics Board of graduate studies (ED 182), Strasbourg University
Sharon E. Meidt: Member of the ESO OPC P96 panel
Nadine Neumayer: Member of the Organising Committee for the Physics Graduate Days, Heidelberg University
Jorg-Uwe Pott: Vice president der European Interferometry Initiative
Hans-Walter Rix: Member of ESA-SSAC, ESA-EUCLID Science Team, ESO Visiting Committee, NOVA Visiting Committee, STScI Visiting Committee, ESA-EUCLID Board, Humboldt-Selection Committee, ESA NIRSPEC-Science Team
Gaël Rouille: Referee bei der National commission for scientific research in the field of physics and chemistry of the interstellar medium
Eva Schinnerer: Member of the NRAO VLA Sky Survey Community Review Panel
Dmitry A. Semenov: Co-Chair of NASA "Exoplanets Research Program" (XRP) Panel; Co-Chair of the Working Group 2: "Icy chemistry", COST Action 1401 "Our Astrochemistry Heritage"; referee für ERC Starting Grants (EU); Member of ANR (France); Member of the NASA XRP
Gregory Stinson: Referee bei DFG postdoc proposals
Roy van Boekel: Member of the MPIA STAC, Member of the belgium VLTI-TAC
Arjen van der Wel: Chair of the CAHA Open Time TAC; Member of the HST Cycle 22 Panel; Member of the MPIA-STAC
Fabian Walter: Scientific Editor at The Astrophysical Journal
Gabor Worseck: Member of the MPIA Strategic TAC (CAHA and LBT)

VI.5 Haus der Astronomie

Managing Scientist: Markus Pössel

Organisational assistance: Sigrid Brümmer

Outreach scientists: Natalie Fischer, Olaf Fischer, Carolin Liefke, Alexander Ludwig, Markus Nielbock (since April), Kai Noeske, Matthias Penselin, Tobias Schultz, Cecilia Scorza, Jakob Staude

We were supported by Esther Kolar who taught workshops for kindergarten and primary school.

Student Assistants: Jan Eberhardt (since May), Sophia Haude, Sebastian Neu (until August), Benjamin Nissel (June), Valentina Rohnacher (Nov.), Katja Reichert, Elena Sellentin, Elisabeth Zepf (Nov.)

Academic Teaching

Summer Term 2015:
C. Liefke: Block course "Praktische Astronomie" as part of the Studierendentage, Universität Heidelberg.
O. Fischer und C. Liefke: "Galaxien" (seminar), Universität Heidelberg.

Winter Term 2015/2016:
N. Fischer: "Grundlagen der Astronomie für die Schule", Pädagogische Hochschule Heidelberg.
O. Fischer, C. Liefke, M. Nielbock, M. Pössel und C. Scorza: "Einführung in die Astronomie für Lehramt an Gymnasien Physik" (Lecture, Seminar and Practical Exercises), Universität Heidelberg.
O. Fischer und C. Liefke: "Extrasolare Planeten" (Seminar), Universität Heidelberg.
M. Pössel with B. M. Schäfer: "Vom Schwarzen Loch bis zum Urknall – Einsteins Relativitätstheorie in der Astrophysik für Nicht-Physiker" (Lecture), Universität Heidelberg.

Membership in major committees

Carolin Liefke is co-opted board member of the Vereinigung der Sternfreunde (Germany's amateur astronomer association) responsible for schools and outreach to young people. She was elected a member of the board of trustees of the Reiff-Stiftung.
Kai Noeske is a founding member of the "Arbeitsgemeinschaft Fulldome" of Gesellschaft deutschsprachiger Planetarien.
Markus Pössel is the International Astronomical Union's National Outreach Contact for Germany.
Cecilia Scorza is German coordinator of the "European Association for Astronomy Education", German Coordinator of EUNAWE program, member of the IAU Education Commission, member of the school committee of the Astronomical Society and member of the Office of Astronomy for Development (OAD/IAU) as adviser for Latin America.
Haus der Astronomie is the German node of the ESO Science Outreach Network (C. Liefke, M. Pössel).

Awards

“Universe in a Box” was awarded the Scientix Resource Award “STEM Teaching Material Addressed to Teachers“ (May).

Events

Events held at HdA

Lecture series “Faszination Astronomie”, 17 talks, 1830 visitors, Jan. 8 – Dec. 12 (organized by C. Liefke)
“Physik am Samstagvormittag” in cooperation with the Max Planck Institute for Nuclear Physics, Mar. 7, approx. 70 participants (K. Noeske)
Observing the solar eclipse, Mar. 20 (C. Liefke)
Four events for families (Mar. 21, Dec. 6) and three lectures “HdA Highlights” with a total of 432 visitors (M. Pössel, C. Liefke, N. Fischer, K. Noeske)
DAGAL-Workshop about scientific writing and outreach, Mar. 23 (M. Pössel with F. Mokler)
Girls’ Day (HdA und MPIA, (C. Liefke, M. Pössel) and Boys’ Day (HdA, E. Kolar) Apr. 23.
Conference “Spektroscopy in the Local Group and Beyond”, Apr. 27 – 30 (M. Bergemann)
LINC-NIRVANA Preliminary Acceptance Europe, May 4 – 7 (M. Kürster)
CTA-Meeting held by the Landessternwarte, May 27 – 29 (T. Abegg)
“FIR Fine Structure Line Workshop”, June 8 – 11 (C. Ferkinhoff, R. Decarli)
HdA and MPIA Open Day: Workshops, panetarium presentations, and information booths, June 21 (the whole HdA team, organized by M. Pössel with K. Jäger)
MPIA Summer Conference 2015 “A 3D View on Galaxy Evolution: from Statistics to Physics”, July 6 – 10 (E. Schinnerer et al.)
Joint lecture series “Astronomie am Sonntagvormittag” in cooperation with MPIA, four talks, Sept. 27 – Oct. 18, with a total of 430 visitors (M. Pössel)
German-wide teacher training in astronomy, funded by the Wilhelm und Else Heraeus-Stiftung, Nov. 12 – 14 (O. Fischer)
Teacher training “Astronomie auf Einsteins Spuren: Relativistische Astrophysik in der Schule” for Baden-Württemberg’s Ministry of Education and the Arts, Nov. 19 (M. Pössel, K. Noeske)
23 smaller scientific meetings with a total of 368 participants
4 trainings for future kindergarten educators with 63 participants (N. Fischer)
Training for kindergarten educators (5 sessions) and for primary school teachers in cooperation with Forscherstation Heidelberg, 11 and 16 participants (N. Fischer)
71 guided tours by HdA-staff, 30 Königstuhl guided tours by the MPIA amd LSW Outreach Fellows and 50 by members of the Astronomieschule e.V. with a total of 3585 visitors
64 workshops for primary schools and kindergardens with a total of 1200 children (N. Fischer, E. Kolar); 24 workshops for families with a total of 248 participants (E. Kolar, S. Schwemmer); 25 holiday programs and similar workshops with a total of 312 participants (N. Fischer, E. Kolar), 32 workshops for students from grade 5 to 13 with a total of 672 participants (A. Ludwig, M. Penselin, T. Schultz, C. Scorza)
30 organizational and other meetings (mainly MPIA) with approximately 400 participants

External events

Life Science Lab Heidelberg, weekend seminar “Kosmologie” in Landau/Pfalz, Jan. 16 – 18 (M. Pössel with B. M. Schäfer)
Teacher training in Unterfranken “Fernrohrführerschein”, Friedrich-Rückert-Gymnasium Ebern, Feb. 11 (C. Liefke)
ROTAT-presentation at the meeting of commissioners for the German Physics Olympiad, Feb. 28 (C. Liefke)
Observing the solar eclipse at various schools, Mar. 20 (N. Fischer, O. Fischer, M. Nielbock, K. Noeske)
Itinerant Teacher Training sessions in Niedersachsen and Bremen, June 8 – 20 (O. Fischer, B. Nissel)
Hands-on stations for elementary school children (N. Fischer, E. Kolar in cooperation with Astronomieschule e.V.) and for secondary schools at Explore Science (Klaus Tschira Foundation) in Mannheim, July 8 – 12 (O. Fischer [Organisation], K. Homann, C. Liefke, M. Nielbock, K. Noeske, M. Pössel, C. Scorza)
Astronomy course, JuniorAkademie Adelsheim, June 12 – 14, Aug. 28 – Sept. 10 and Oct. 16 – 18 (C. Liefke with D. Elsässer, Universität Bochum)
HdA information booth at the Astro-Messe AME, Villingen-Schwenningen, Sept. 19. (C. Liefke)
Presentation of new educational materials for astronomy, UNAWE International Workshop, Universität Leiden, Netherlands, Oct. 5 – 9 (N. Fischer, M. Nielbock)
Presentation and workshop “Infrarotlicht und Treibhauseffekt”, Internationaler Evangelischer Jugendklimagipfel, Lauterbach/Hessen, Oct. 17 (K. Noeske)
Workshop “Der Helioviewer – Sonnenbeobachtung mit dem Computer”, MINT-Tagung des MNU-Landesverbands Franken, Würzburg, Oct. 24 (C. Liefke)
Teacher Training for the Deutsche Museum, Nov. 23 – 24 (C. Scorza)
Teacher training for Chilean teachers, Dec. 1 – 4 (C. Scorza)
Teacher training “Blicke zum Sternhimmel”, Landesschulzentrum für Umwelterziehung in Adelsheim, Dec. 14 – 16 (O. Fischer, C. Liefke)

Other Activities

Natalie Fischer developed and tested educational material for Explore Science, for the open day at MPIA/HdA, and for a workshop at Junge Universität, she was responsible for issuing the "Universe in a Box".

Olaf Fischer wrote a report on the thesis (Dr. päd.) by Simon Friedrich Kraus, Universität Siegen: "Astronomie für Blinde und Sehbehinderte"; he supervised the teacher's master's thesis: "Entfernungsmessungen in der Milchstraße und das Gaia-Projekt" by Jonas Hörrle; he supervised 4 Chilean network teachers (Nov. 29 – Dec. 12).

Carolin Liefke supervised a student research project on geomagnetic surveys in cooperation with Hector-Seminar; she was scientific tutor for the Astrophysik-AG at the Life-Science Lab Heidelberg, supervised German school groups for various campaigns of the International astronomical Search Collaboration using the Pan-STARRS telescope PS 1 (19, 9, 3 and 19 participating schools) for the campaigns Jan 16 – Feb. 20, Mar. 16 – 20, Oct. 4 – Nov. 3 and Nov. 4 – Dec. 9, supervised schools using the Faulkes/LCOGT- und ROTATRemote-Telescope; attended the Kleinplanetentagung (Minor Planet meeting) at the Walter-Hohmann-Sternwarte, Essen; and was in charge of four BOGY internships with a total of 23 students (Mar. 16 – 20, 23 27, Oct. 26 – 30, Nov. 9 – 13).

Markus Nielbock developed various educational materials for the EU Space Awareness program (with C. Scorza).

Kai Noeske wrote instructions "zur sicheren Sonnenfinsternis-Beobachtung" for Spiegel Online (with N. Fischer). He supervised eight participants of this year's "International Summer Internship" (in collaboration with the International Summer Science School of the city of Heidelberg (July 27 – August 15).

Markus Pössel supervised an individual student's internship (May 4 – Aug. 15); he supervised two teacher's master's theses: "Statistische Untersuchungen zur kosmischen Expansion" by Johannes Fröschle and "Adaptive Optik und die Entwicklung eines Demonstrationsexperiments" by Fabian Gebhart; he created an image film presenting the HdA.

Cecilia Scorza supervised the teacher's master's thesis: "Chemische Zusammensetzung von Sternen in Kugelsternhaufen" by Michael Czuray; she was in charge of four Chilean network teachers (Nov. 29 – Dec. 12). She supervised an internship on "Sternbilder im Vergleich").

Talks

Natalie Fischer: Festvortrag anlässlich der Plakettenvergabe der Forscherstation Heidelberg im Planetarium Mannheim, Feb. 9; Vortrag und Zwischenbericht über die durchgeführten Aktivitäten im Rahmen der Kooperation zwischen Haus der Astronomie und der Forscherstation bei der Forscherstation Heidelberg, Nov. 26; Astro- Tech Talk HdA, Nov. 27.

Olaf Fischer: Posterpräsentation zum Teilprojekt "Lehrerfortbildung zur Astronomie in Chile" bei der DAAD-Veranstaltung in Gießen "Exzellenz durch Vernetzung", Apr. 27 – 28; Vortrag im Rahmen der Sonderausstellung "Der Osterburg Zeit geben", Osterburg/Weida, Sept. 17.; "Von den Sternen zur Milchstraße und zurück", Lehrerfortbildung in Bad Wildbad, Oct. 7; "Entdeckungsmaschinen – Große Observatorien am Boden und im Weltraum", Lehrerfortbildung in der Sternwarte Sonneberg, Oct. 10; "Warum wir Kinder der Sonne sind", Kinderakademie Eisenach, Oct. 10 and Kinderakademie Gera, Oct. 14.

Carolin Liefke: "Winter am Sternhimmel", Kindervortrag Heppenheim, Jan 30; "Die größten Teleskope der Welt", Kindervortrag Heppenheim, Mar. 27; "Die Aktivität der Sonne", GIZ Wettzell, April 16.; "Forschen unter südlichen Sternen", Weikersheim, May 20; "Frühling am Sternhimmel", Kindervortrag Heppenheim, May 22; "Forschen unter südlichen Sternen", Heppenheim, June 16; "Erdnahe Asteroiden", Bozen, July 6; TheoPrax-Tag Festvortrag, Nov.12; "Erdnahe Asteroiden", Mannheim, Dec. 2; "Der Stern von Bethlehem", Kindervortrag Heppenheim, Dec. 18.

Markus Nielbock: "Farbenspiele des Lichts – Was sie uns über die Sterne verraten", Academia Engiadina, Samedan, Apr. 18; Vortragsreihe: "Moderne Observatorien am Boden und im Weltraum", Lehrerfortbildung an der Sternwarte Sonneberg, Oct. 10 – 12.; Vortrag zu "Space Awareness", Leiden, Oct. 5 – 9.

Kai Noeske: "Geschichte des Lichts im Universum", MPIA open day, June 21; Astrotech-Talk, MPIA, Oct. 2); "25 Jahre Hubble-Weltraumteleskop", Hildesheimer Gesellschaft für Astronomie, Oct. 14 and Ringvortrag FH Flensburg Nov. 5.

Markus Pössel: "Wurmlöcher, Zeitreisen, Warpantrieb: An der Grenze der Relativitätstheorien zur Science Fiction", DPG-Lehrerfortbildung "Einstein relativ einfach", Bad Honnef, July 21; "Comparing Cosmic Expansion and Gravitational Waves", WE Heraeus Bi-National Summer School "Astronomy from four perspectives", Jena, Sep. 2; "Zeitreisen – geht das wirklich?", Back to the Future Day, HdA, Oct. 21; "Als Raum und Zeit fexibel wurden: 100 Jahre Allgemeine Relativitätstheorie", HdA, Nov. 5 – 6, Planetarium am Insulaner, Berlin, Nov. 25; "Models for teaching (and thinking about!) general relativity", Models of Gravity Workshop (DFG-Graduiertenkolleg), Bremen, Nov. 10; "Allgemeine Relativitätstheorie", Fortbildung "Astronomie auf Einsteins Spuren", HdA, Nov. 19; "Wikipedia sinnvoll für die Instituts-PR nutzen", MPG-PR-Netzwerktreffen, Dec. 11.

Cecilia Scorza: Vortrag zur Bildung für das SKA Board, Brüssel, Jan. 20; Präsentation über Bildung in der Astronomie am Deutschen Museum, München, Jan. 26; Präsentation der Bildungsarbeit der ESO, HITS, Heidelberg, Feb. 9; “Der Mensch im Kosmos”, Heidelberg, Mar. 1; “Bildung und Klimawandel”, Leiden, Mar. 29; “Navigation through the ages”, Leiden, Mar. 30; “Islam-heritage kit”, Leiden, Mar. 31.; “Universe in the Box”, Siegen, Apr. 28; Vortrag über Milchstraßen-Materialien, Siegen, Oct. 29.

Publications

Czuray, Michael: “Chemische Zusammensetzung von Sternen in Kugelsternhaufen”, Staatsexamensarbeit Universität Heidelberg, Dec. 2015.

Fischer, Olaf: “Das Projekt ALMA Mater, Teil 3: ALMA – Eine Beobachtung, die es in sich hat: Kosmischer Baustofftransport”, Wissenschaft in die Schulen! 3/2015.

Fischer, Olaf: “Das Projekt ALMA Mater, Teil 4: ALMA – Eine Beobachtung, die es in sich hat: eine ‘Kinderstube’ für Planeten”, Wissenschaft in die Schulen! 7/2015.

Hörrle, Jonas: “Entfernungsmessungen in der Milchstraße und das Gaia-Projekt”, Staatsexamensarbeit Universität Heidelberg, Dec. 2015.

Nielbock, Markus: Liu, Y.; Joergens, V.; Bayo, A.; Wang, H.: “A homogeneous analysis of disks around brown dwarfs”. Astronomy & Astrophysics 582, A22 (2015).

Pössel, Markus: “100 Jahre und quicklebendig. Die astronomische Bedeutung der allgemeinen Relativitätstheorie”, Sterne und Weltraum 11/2015, pp. 40 – 47.

VI.6 Publications

In refereed journals:

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Arrigoni Battaia, F., Hennawi, J. F., Prochaska, J. X. and Cantalupo, S.: Deep He II and C IV spectroscopy of a giant Lyα Nebula: Dense compact gas clumps in the circumgalactic medium of a $z \sim 2$ quasar. The Astrophysical Journal 809, id. 163 (22 pp) (2015).

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VI.7 Cooperation with External Companies

ADDITIVE, Friedrichsdorf
Adolf Pfeiffer, Mannheim
ADR, Thomery
Aerotech, Nürnberg
ALPHA Übersetzungen, Heidelberg
Alternate, Linden
AMERICA II EUROPE, Mönchengladbach
AMETEK, Meerbusch
Amphenol AIR, Saarlouis
asknet, Karlsruhe
AVIS, Oberursel
AXON'KABEL, Leonberg
B.E.S.T., Forst
Backup Solutions, Stuttgart
Baier Digitaldruck, Heidelberg
Bechtle ÖA direkt, Neckarsulm
BG ETEM, Köln
Bildungshaus Kloster Schöntal, Schöntal
Blickle Räder+Rollen, Rosenfeld
Börsig, Neckarsulm
Breer Gebäudereinigung, Heidelberg
Bürklin, Oberhaching
Büro-Mix, Mannheim
BVS, Stuttgart
CADFEM, Grafing
Carl Roth, Karlsruhe
CHG Meridian, Weingarten
ColorDruck Solutions, Leimen
Computacenter, Ludwigshafen
COMTRONIC, Heiligkreuzsteinach
Conrad Electronic, Wernberg-Köblitz
Cryophysics, Darmstadt
CWS-boco Deutschland, Dreieich
D.H. Frank, Nußloch
Dannewitz, Gelnhausen
dataTec, Reutlingen
Dehn + Söhne, Neumarkt
Dell GmbH, Frankfurt am Main
DELTA-V, Wuppertal
Deti, Meckesheim
DHL Express, Köln
Dipl.-Ing. Robert Baust, Heidelberg
Discipulus, Heidelberg
Distrelec Schuricht, Bremen
DMG, Leonberg
Dörfler Dachtechnik, Oftersheim
DPV Elektronik, Eppingen
EBSCO Information Services, Berlin
Edmund Optics, Karlsruhe
Edwards, Kirchheim
EFB-Elektronik, Bielefeld
Elektro-Steidl, Weinheim
Engelbert Strauss, Biebergemünd
Europcar Inter Rent, Hamburg
EUROstor, Filderstadt
Farnell, Oberhaching
Faulhaber GmbH & Co, Schönaich
Federal Express Europe, Kelsterbach
FEGA & Schmitt, Ansbach
Fels Fritz Fachspedition, Heidelberg
FlowCAD, Feldkirchen
FPS-Werkzeugmaschinen, Warngau
Frankfurter Allgemeine Zeitung, Frankfurt am Main
Fraunhofer IOF, Jena
Friedrich Heuser, Heidelberg
Fritz Zugck, Leimen
Gabler Werbeagentur, München
GAD Elektronik, Plankstadt
Ganter, Walldorf
Geier Metall-u.Stahlhandel, Mannheim
Gleich Service-Center, Kaltenkirchen
Glenair Electronic, Bad Homburg
Gummispezialhaus Martin Körner, Eppelheim
Güniker + Heck, Mannheim
Gutfleisch, Heidelberg
Häfele, Aulendorf
Hagemeyer Deutschland, Heidelberg

Hahn & Kolb, Ludwigsburg
Hamamatsu, Herrsching
Handwerkskammer Mannheim, Mannheim
Harald Tränkle, Heidelberg
Haufe Service Center, Freiburg i. Br.
HDI Global, Hannover
Hebezone, Hanau
HELUKABEL, Hemmingen
Hoffmann Göppingen, Göppingen
Hoffmann Wekzeuge, Nürnberg
Horn, Stutensee
Hupkens Industrial Models, NK Maastricht
HWP Architekturbüro, Heidelberg
IBV – Ingenieurbüro, Heidelberg
IGEFA, Ahrensfelde/OT Blumberg
ILFA Feinstleitertechnik, Hannover
Ingenieurbüro Manfred Steinbach, Jena
Ingenieurbüro Schlossmacher, Unterschleissheim
INNEO Solutions, Ellwangen
INTOS ELECTRONIC, Gießen
IOP Publishing, Bristol
Jacobi Eloxal, Altlussheim
Johann A. Meyer, Wildau
JUMO GmbH & Co, Fulda
Jungheinrich, Hamburg
K.-H.Weidler, Weinheim
KA-WE, Schwetzingen
Kai Ortlieb Buchbinderei, Eppelheim
KAISER + KRAFT, Stuttgart
Karl Scholl, Heidelberg
Kniel, Karlsruhe
KOCO MOTION, Dauchingen
Konica Minolta Businesss, Mannheim
Körber TH., Sensbachtal/Odw.
Kroschke, Braunschweig
L. Funk & Söhne, München
L. + H. Hochstein, Heidelberg
Lagrange TWM, Mannheim
Lapp Kabel, Stuttgart
Laub Druck, Elztal-Dallau
LD Didactic, Hürth
Lehmanns Fachbuchhandlung, Heidelberg
Lemo Elektronik, München
Linde, Mainz-Kostheim
Losberger Modular Systems, Mannheim
LWS-Technik, Heilbronn
LYRECO Deutschland, Barsinghausen
Maas International, Bruchsal
Maschinenfabrik Berthold Hermle, Gosheim
Massmann, Hamburg
Mayer Omnibusbetrieb, Neckargemünd-Dilsberg
Metallbau GLAWION, Eberswalde
Metalux Metallveredelungs, Altlussheim
MICROSTAXX, München
Möller-Wedel Optical, Wedel b. Hamburg
Mura Metallbau, Viernheim
National Instruments, München
Neumann Rupert Druckerei, Heidelberg
Newport Spectra-Physics, Darmstadt
norelem Normelemente, Markgröningen
Ocean Optics B.V., Ostfildern
Oerlikon, Köln
OMEGA Engineering, Deckenpfronn
OWIS, Staufen
Pascal Krämer, Neckarsteinach
PENTAIR, Straubenhardt
Pfeiffer & May, Heidelberg
PFEIFFER VACUUM, Asslar
Phoenix Contact, Blomberg
Physik Instrumente (PI), Karlsruhe
Phytron-Elektronik, Gröbenzell
POG Präzisionsoptik Gera GmbH, Gera
pro-com DATENSYSTEME, Eislingen
Profimess, Bremerhaven
Radiant Zemax Europe, Stansted
Reichelt Elektronik, Sande
Rhein Neckar BUSINESS Travel, Heidelberg
Rhein-Neckar-Zeitung, Heidelberg
RS Components, Mörfelden-Walldorf
Rudolf Hehr, Heidelberg
Sanitär Raess, Heidelberg
SAUTER-Cumulus, Freiburg
Schenker Deutschland, Mannheim
Schenker Spezialverkehre, Hannover
Schulz Versorgungstechnik, Heidelberg
Siemens, Mannheim
Sky Blue Microsystems, München
Sonepar Deutschland, Hannover
SPHINX, Laudenbach
Springer, Heidelberg
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Tautz Druckluft+Sandstrahltech, Mannheim
Technik Direkt, Würzburg
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The MathWorks, Ismaning
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Thermodyne, Osnabrück
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Total Walther, Langen
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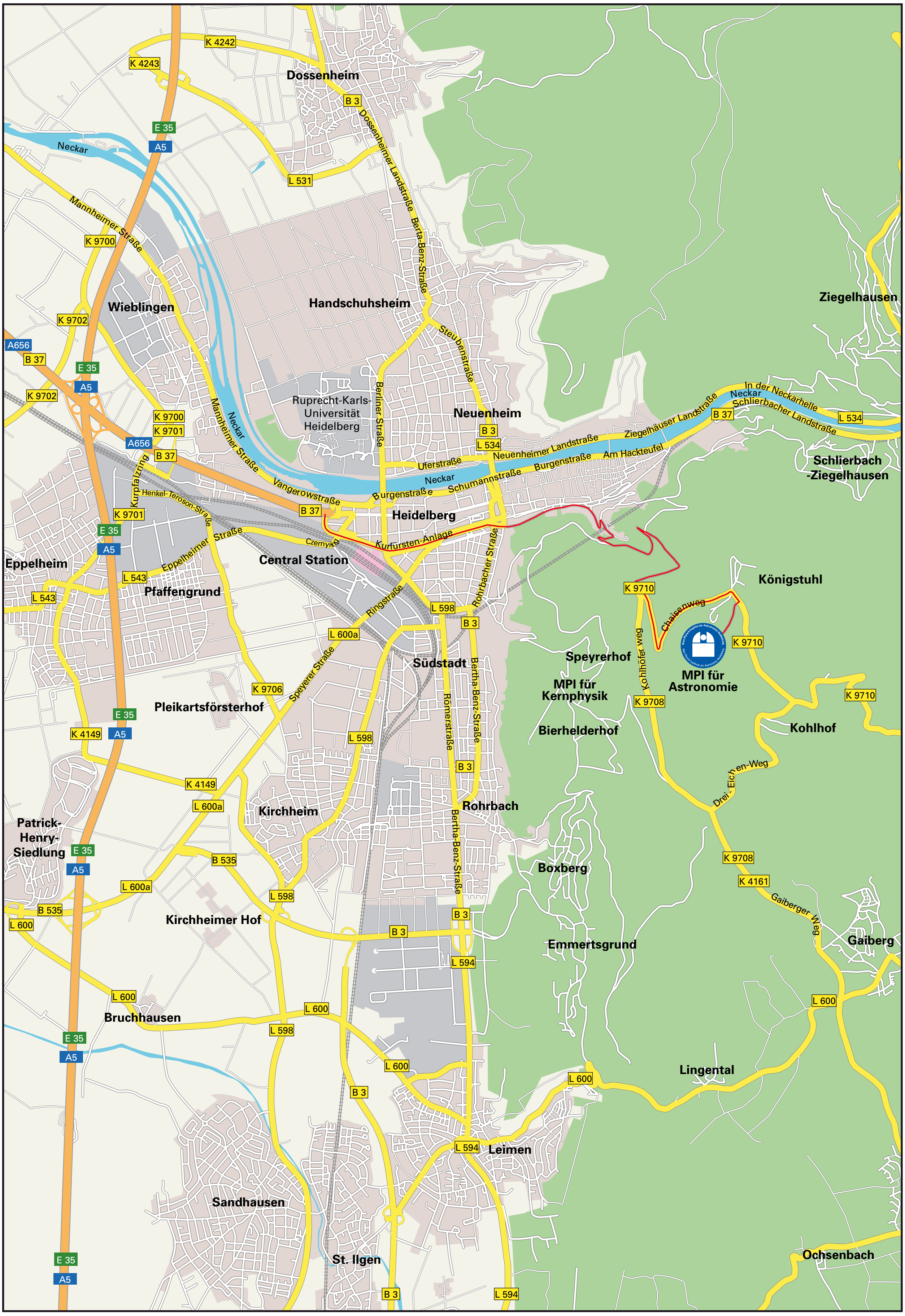
United Parcel Service, Neuss
Vacom, Jena
Vigot, Bremen
Witzenmann, Pforzheim
Witzenmann Rhein-Ruhr, Xanten
Zoltan Hubert, Leimen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