Max Planck Institute for Astronomy

Heidelberg-Königstuhl

Annual Report 2008

MAX-PLANCK-GESELLSCHAFT

Cover Picture:

In the visual light, the spiral galaxy Messier 83 appears as a sharply defined, almost circular structure. But on this deep image taken by the GALEX satellite observatory in the near and far Ultraviolet (coded in green and blue respectively), numerous newborn stars become visible, which were formed far outside the main body of the galaxy. A map of the radio emission of neutral hydrogen (coded in red) demonstrates, that in fact there is plenty of diffuse material available for building the new stars – probably because recently one or more dwarf galaxies were dissolved by gravitational interaction with Messier 83.

(Frank Bigiel, Fabian Walter, NASA/JPL-Caltech/VLA/MPIA)

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Max Planck Institute for Astronomy

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Preface

This Annual Report delineates the scientific activities at the Max Planck Institute for Astronomy (MPIA) in Heidelberg. It is intended for our colleagues worldwide as well as for the interested public.

The year 2008 has brought a rich scientific harvest at topics ranging from the structure of the universe to exoplanets.

There was also excellent, steady progress on crucial, upcoming facilities, including the LBT's first observations with the new infrared instrument Lucifer, second generation VLT and VLTI instruments, and JWST instrumentation, laying the foundation for future astronomical discoveries. First instrument studies started for the European Extremely Large Telescope (E-ELT).

The year 2008 was also a very special year for the Heidelberg astronomical community with the decision to build the "Haus der Astronomie", a new education and public outreach facility on the Königstuhl.

In addition to brief presentations of a broad range of current scientific results, we report in more depth on a few selected research areas at the MPIA.

We hope that this Annual Review will give the reader a flavour of the research and work at the MPIA.

Thomas Henning, Hans-Walter Rix

Heidelberg, August 2009

I. General

I.1 Scientific Goals

Research at the Max Planck Institute for Astronomy (Fig. I.1) is aimed at exploring and understanding the nature and evolution of planets, stars, galaxies and the universe as a whole. This is pursued through the development and operation of telescopes and their instrumentation, by designing, executing and analysing observing programs and surveys, and by connecting to the physical nature of the observed phenomena through theoretical studies and numerical simulations. The MPIA focuses its observational capabilities on the optical and infrared spectral regions, taking a leading role in both ground-based and space-based instrumentation.

The research at the MPIA is organized within two scientific departments: Galaxies and Cosmology, and Planet and Star Formation. In addition to the staff in these departments, the Institute has eight independent Junior Research Groups (four Emmy Noether groups supported by the German Science Foundation DFG, and four groups supported by the Max Planck Society). In the course of the year 2008, there were a total of 50 postdoctoral stipend holders, 88 PhD students, and 26 diploma and master's students and student assistants working at the institute. Strong ties exist between the Institute and the University of Heidelberg, with its Center for Astronomy (ZAH), both in teaching and research, for example through the International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics.

The main research fields of the two departments are complementary in both scientific and practical terms. Obviously, star formation is a critical aspect of the formation and evolution of galaxies, and the instrumentation capabilities required by both departments share strong commonalities: e.g. requirements for high spatial resolution, powerful survey capabilities, and the importance of access to the infrared and millimeter spectral regions.

Fig. I.1: Aerial view of the MPIA.

Galaxies and Cosmology

The "Realm of Galaxies"

Shortly after the Big Bang, the Universe was rather "simple" and nearly homogeneous. Now it is beautifully complex, with rich "hierarchical" structure over a wide range of physical scales: from the filamentary distribution of galaxies on large scales (the "cosmic web") to galaxies themselves, down to clusters of stars, stars, and their planets. The formation of this wealth of structure appears to be driven by gravitational instabilities, but to make things ‘work’ these instabilities must arise in good part from a dominant, but yet to be identified, dark matter component.

The galaxies we observe in the present-day universe represent a central layer in this hierarchical order, each consisting of millions to billions of stars, gas, and dust, all embedded in halos of dark matter. As Edwin Hubble already realized 80 years ago, these “island universes” do not show the full variety of morphology (or visual appearance) and structures that seem physically possible. On the one hand, the variety of galaxies seems vast: galaxies as an object class span ten orders of magnitude in their stellar masses, and the rate of new star formation varies similarly; the physical sizes of different galaxies still vary by a factor of 100. While some galaxies apparently do not have a black hole at their centers, in other galaxies this central black hole has the mass of more than one billion suns. On the other hand, observations have shown, particularly in the last 15 years, that only a small fraction of the possible combinations of the characteristic galactic quantities (stellar masses and ages, size, central black hole, etc.) 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 contains a constant mass fraction of the spherical star distribution ten million times its size. While spiral galaxies are the most common galaxy type, no such galaxy is among the most massive ones.

This means that the “realm of galaxies”, as Hubble called it, shows a high degree of order. How this order developed from the random mass fluctuations existing after the Big Bang is a 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:

1. Observed galaxies represent the only stable configurations.
2. The galactic parameters that have been realized directly result from the limited set of cosmological initial conditions.
3. The overall process of galaxy formation results in a limited set of outcomes because it is self-regulating due to different feedback processes.

What questions would we like to answer?

Many of the projects that the MPIA researchers are pursuing ultimately address when and where these three mechanisms play a role. Some of the specific questions being discussed by researchers in this department are:

- During which cosmological epoch did most of the stars form?
- Is cosmic star formation now coming to its end? Why has the star formation rate declined over the last six billion years?
- Which galaxies reside in which dark matter halos?
- How did the central black holes in galaxies form and grow? Why is it possible to predict the properties of the small-sized central black hole from the overall size of a galaxy?
- Which processes determine the structure and morphology of galaxies and when do these processes occur?
- What is the state of the interstellar medium, the raw material from which new stars form?
- Can the various observations be understood *ab initio* within a comprehensive model?
- How did the Milky Way, our Rosetta Stone of galaxy evolution, form?

What do we do to find the answers?

The approaches used at the MPIA to tackle these questions comprise three aspects: the detailed study of galaxies in the present-day Universe; the direct study of galaxies at earlier cosmic epochs through the observation of distant (high-redshift) objects; and the comparison of observations with physical models. The observational capabilities for the field require survey telescopes, large telescopes for sheer photon collecting power on faint sources, and particular techniques such as Adaptive Optics and Interferometry to achieve high spatial resolution. Comprehensive studies of galaxy evolution require observations from the X-rays to the radio wavelengths.

The MPIA has been an important partner in several of the surveys that have brought, or promise to bring, breakthroughs in these areas: the Sloan Digital Sky Survey (SDSS and SEGUE) for the Milky Way and Local Group, to be followed by the PanSTARRS-1 survey now starting – and since last year, this suite was complemented by the completion of the LBC cameras of the LBT; the 2.2 m telescope on La Silla has enabled the COMBO-17 galaxy evolution survey; the VLT and soon the LBT will follow-up this survey work; the IRAC and MIPS instruments on the SPITZER Space Telescope; and (starting in 2009) the PACS Instrument of the HERSCHEL mission to study star formation and the interstellar medium, complemented by the VLA, the Plateau de Bure Interferometer, APEX and soon ALMA at radio and sub-millimeter wavelengths. The Galaxies and Cosmology department truly carries out multi-wavelength astrophysics.

Planet and Star Formation

The link between stars and galaxies

The formation of stars is a fundamental process in the Universe, shaping the structure of entire galaxies and determining their chemical state. The formation of individual stars can be best studied in nearby molecular clouds. The study of star formation in other galaxies allows us to understand this process under physical conditions which can be very different from those in the Milky Way. Our studies of star formation in the Magellanic Clouds allow an investigation of the effect of metallicity on the star formation process, which is certainly an important factor in understanding star formation in the early Universe.

Stars are born in the dense and cold cores of molecular clouds, which become gravitationally unstable and, in general, fragment to form binaries and multiple stellar systems. The role of magnetic fields or turbulence in controlling the onset of star formation remains one of the open key questions. This question is immediately related to the shape of the initial (sub)stellar mass function in different environments. Dynamical interactions in multiple systems may be a crucial factor for the formation of Brown Dwarfs. Massive star formation takes place in clusters, leading to complex star-forming regions. The rapid evolution of massive protostars and the associated energetic phenomena provide an enormous challenge in identifying the formation path of massive stars.

Looking 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 "glow" at near- and mid-infrared wavelengths, and finally become visible at optical wavelengths. Our observing programs cover a wide range of wavelengths with a special emphasis on infrared and (sub)millimeter observations.

The formation of planets and planetary systems is a natural by-product of low-mass star formation. Because of angular momentum conservation, accretion of matter onto the central protostar happens predominantly through a circumstellar disk. Disks around T Tauri stars are the natural birthplaces of planetary systems, resembling the solar nebula 4.5 Gyr ago. During the active accretion phase, bipolar molecular outflows and ionized jets are produced, which in turn play an important role in the evolution of star-disk systems. We are presently starting to use protoplanetary disks as laboratories for understanding the formation of our own solar system and the diversity of other planetary systems detected so far.

The research of the Planet and Star Formation department is focused on the understanding of the earliest phases of stars, in both the low and high stellar mass regime. Observations with space observatories such as Spitzer and HST and very soon with the Herschel Observatory, as well as ground-based infrared and (sub-) millimeter telescopes, allow the detection and characterization of massive protostars and their subsequent evolution. The vigorous use of submillimeter facilities is preparing the department for the Atacama Large Millimeter Array (Alma), which will soon commence operation.

The investigation of Brown Dwarfs, which were first detected in 1995, is another important research topic. How do Brown Dwarfs form? Are young substellar objects also surrounded by disks? What is the binarity fraction and the exact mass of these objects? What is the composition of their atmospheres? These are among the burning questions which are attacked by MPIA scientists.

The formation of planetary systems and the search for other planets

With the detection of the first extra-solar planets, the study of planet formation in protoplanetary disks entered a new phase of explosive growth. The department is well-positioned to play an important role in these studies, with a combination of infrared and sub-millimeter observations, numerical (magneto-) hydrodynamical simulations, and radiative transfer studies. Imaging with the Hubble Space Telescope and the wealth of data from the Spitzer Telescope is providing new insights into the earliest stages of planet formation. Improved spatial resolution from our adaptive optics program, infrared interferometry with large telescopes and long baselines, and the use of millimeter interferometers provide insights into disk structure and evolution on spatial scales relevant to planet formation. Gas evolution in disks is studied by high-resolution infrared spectroscopy and the accretion behaviour by multi-object spectroscopy.

We have started new observing programs to search for extra-solar planets through direct imaging, the transit technique, and astrometry. With the Spectral Differential Imaging facility (SDI) at the VLT, we provided a new mode for high-contrast imaging with the adaptive optics instrument Naco. This system presently outperforms any other similar device in the world and is paving the way for the development of Eso's Sphere instrument. The department actively participates in the planet search program Seeds with the Subaru telescope.

The theoretical program of the PSF department focuses on complex numerical simulations of protoplanetary disk evolution, including the interplay between radiation, dynamics, chemistry, and grain evolution. The study of the formation of massive stars constitutes another topic for theoretical studies. Multi-dimensional radiative transfer codes, both for molecular lines and the dust continuum, have been developed in the department. These theoretical studies are also well integrated with the various observational key projects.

The understanding of many of the microphysical processes and the composition of dust and gas requires dedicated laboratory studies. Such a laboratory astrophysics unit is part of our department, and is located at the Institute for Solid-State Physics of the University of Jena. This group investigates the spectroscopic properties of nanoparticles, as well as molecules in the gas phase.

I.2 Observatories, Telescopes, and Instruments

The MPIA has been a key driver and partner in the construction and operation of two large ground-based observatories. During the 1970s and 1980s the construction of the Calar Alto Observatory, still the largest observatory on the European continent, had been the central focus of the MPIA, and the 2.2 and 3.5 m telescopes are scheduled for competitive observing programs. Since 2004 the observatory is jointly operated as Centro Astronomico Hispano Aleman (Caha) by the Max Planck Society, represented by the MPIA, and the Consejo Superior de Investigaciones Científicas (CSIC), represented by the Instituto de Astrofísica de Andalucía (IAA), as an organization of Spanish law. Since 1997, the MPIA has been the coordinating institute for the German participation in the Large Binocular Telescope (LBT) on Mt. Graham near Tucson, Arizona. By the end of 2007, the second prime-focus camera was installed. The camera is now user for regular science programs. Presently, we are in the commissioning process for the Lucifer instrument, jointly built by the LSW, the MPIA, the MPE, the AIRUB and FHTG. The MPIA also uses its 2.2 m telescope on La Silla, Chile, operated by the European Southern Observatory (Eso), with 25 percent of the time available to MPG researchers in 2008.

The MPIA has a prominent and successful tradition of developing and building instruments for ground-based and space-based astronomical observations. Such observations are, almost by necessity, complementary. Ground-based telescopes usually have larger mirrors and therefore more light-gathering power than space telescopes. By using cutting-edge techniques such as adaptive optics and interferometry – which the MPIA has played a leading role in developing – they can also achieve higher angular resolution. Space telescopes, on the other hand, are the only way to carry out observations in wavelength regions where our atmosphere absorbs the radiation or generates a bright background, as is the case, for example, in wide regions of the infrared spectral regime.

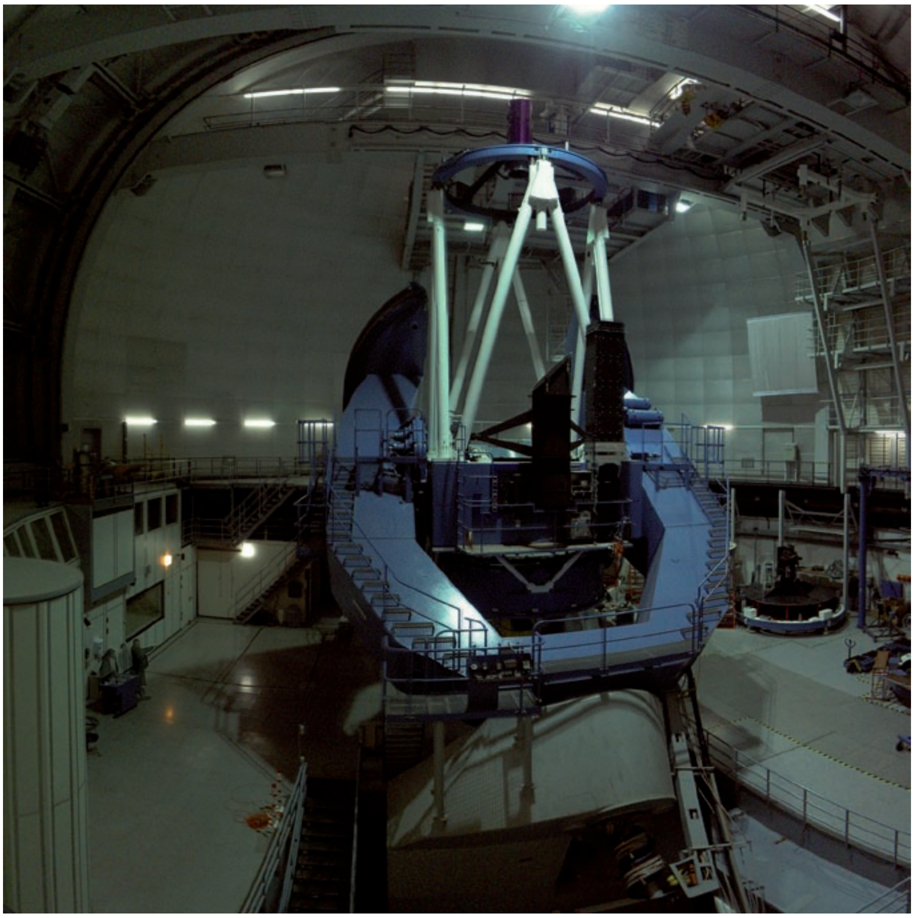


Fig. I.2: The 3.5 m telescope on Calar Alto.

Since the pioneering days of infrared astronomy in the 1970s, the MPIA has been a leading instrument developer for this field of astronomy. In particular, the construction and implementation of Isophot, one of four scientific instruments aboard Iso, the first Infrared Space Observatory of the European Space Agency Esa, was led by the MPIA. From 1996 to 1998, it acquired excellent data, particularly in the previously inaccessible far-infrared range. The knowledge gained with Iso was the basis for MPIA's prominent role in ongoing space projects such as the Herschel Space Observatory and the James Webb Space Telescope (JWST). At present, astronomers at the MPIA are also actively participating in legacy science programs with the Spitzer Infrared Observatory.

The new generation of instruments for 8m-class telescopes and space missions are too large and expensive to be built by a single group, such as the MPIA. At present, the Institute is therefore participating in, or leading a number of international collaborations for building scientific instruments for new large telescopes, thereby gaining access to the world's most important observatories. An example in the southern hemisphere is the Eso Very Large Telescope (VLT) in Chile, with its four 8 m telescopes that can be linked to form a powerful interferometer. In the northern hemisphere, the MPIA is participating in the Large Binocular Telescope (LBT) in Arizona. This extraordinary telescope is equipped with two mirrors of 8.4 m diameter each, fixed on a common mount, making it the world's largest single telescope. With routine scientific use of the first prime focus camera and commissioning of the second prime focus camera in 2007, the LBT has become a productive world-class observatory. In 2007, MPIA intensified its collaboration in the international PanStarrs1 (PS1) project, which grants full access rights to the data from a 1.8 m wide-field telescope on Haleakala/Maui (Hawaii). The 1.4 Gigapixel camera – the largest digital camera ever built – was installed in August 2007 at this telescope.

These collaborations enable MPIA astronomers to observe the northern and the southern sky with first-class telescopes. At the same time the MPIA is participating in studies for the instrumentation of next-generation large telescopes, the so-called Extremely Large Telescopes (ELT).

Instrumentation for Ground-based Astronomy

The currrent activities of the MPIA in the area of ground-based instrumentation concentrate on interferometric instruments for the Eso VLT Interferometer (VLTI), high-fidelity imaging instruments for the LBT and the VLT, and survey instruments for both Calar Alto and the Wise

Fig. I.3: The Very Large Telescope at Cerro Paranal, in the Northern Chilean Andes. (Eso)

Observatory (Israel). The MPIA is also involved in studies for future instruments for the European ELT (E-ELT).

VLTI instrumentation

In September 2008, the differential delay lines for the dual-feed VLTI system Prima were installed on Cerro Paranal, Chile. These units were built by the MPIA together with Geneva Observatory and Landessternwarte Heidelberg. In the related science project Espri, the differential delay lines will be used in the combined K-band light from two 1.8 m VLT Auxiliary Telescopes, in order to measure the separation of a stellar target from a reference star with micro-arcsecond precision. The goal is the dynamical determination of the masses of extrasolar planets by precise astrometric measurements of the orbital reflex-motions of planetary host stars.

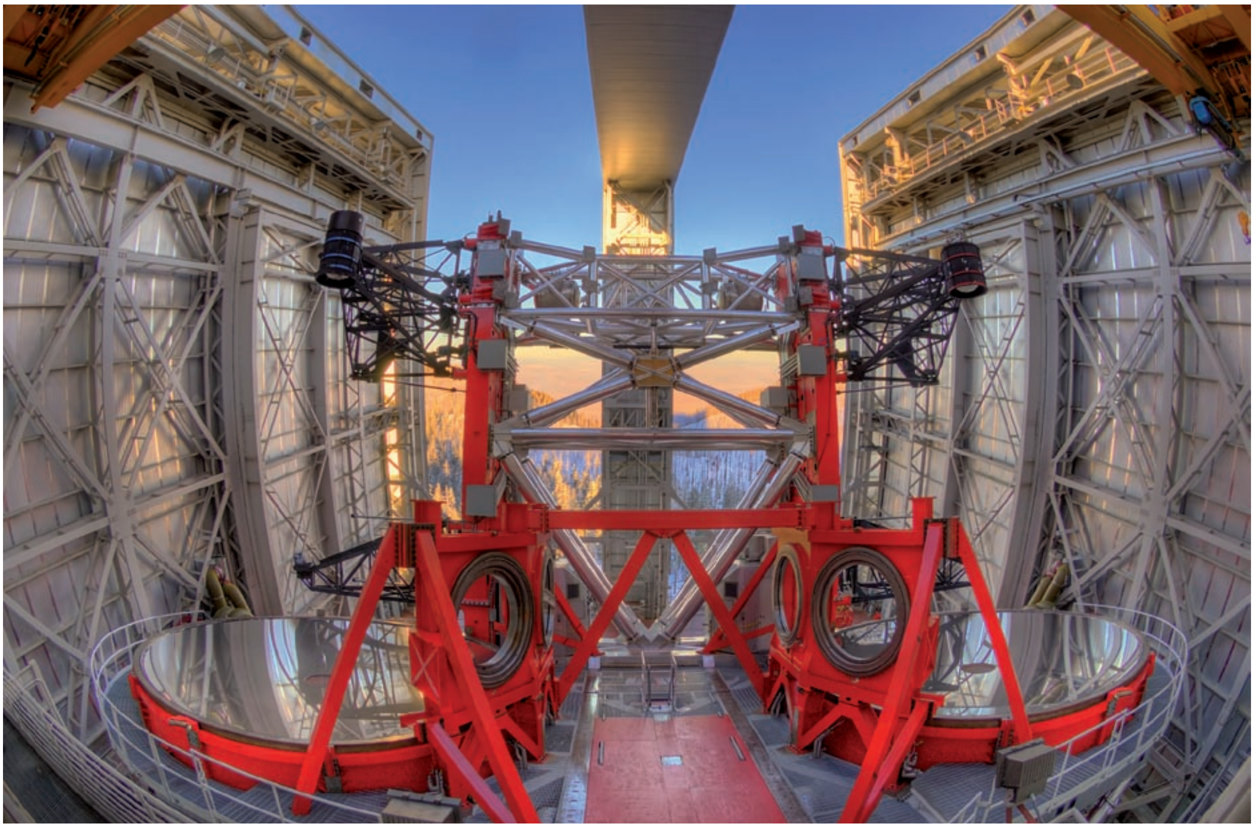
MPIA is participating in the second generation VLTI projects Matisse and Gravity. Matisse is a successor of the very successful Midi instrument built by the MPIA which has been in operation on Paranal since September 2003. The Matisse consortium consists of nine institutes led by the Observatoire de la Côte d'Azur. Matisse will combine the light from all four VLT 8.2 m telescopes in the mid-infrared for high spatial resolution image reconstruction on angular scales of 10 – 20 milli-arcseconds. The scientific applications range from studies of Active Galactic Nuclei (AGN) to the formation of planetary systems and of massive stars, and the study of circumstellar environments.

Gravity is the successor of Prima. Like Matisse it will combine four VLT 8.2 m telescopes, but in the near-infra-red. The Gravity consortium is led by MPE Garching; the partners include MPIA, l'Observatoire de Paris, and the University of Cologne. 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″. This will permit astronomers to study motions to within a few times the event horizon size of the massive black hole in the Galactic Center, and potentially test General Relativity in its strong field limit. Other applications are the direct detection of intermediate mass black holes in the Galaxy, dynamical mass determinations of extrasolar planets, the origin of protostellar jets, and the imaging of stars and gas in obscured regions of AGNs, star forming regions, or protoplanetary disks.

High-resolution cameras

After its integration at MPIA, Lucifer 1, the first of two identical mid-infrared cryogenic imaging cameras and multi-object spectrographs for the LBT, was shipped to Mt. Graham in August 2008, where it is currently be-

Fig. I.4: The Large Binocular Telescope (LBT) with its two 8.4 m mirrors on Mt. Graham, Arizona. (LBTO)



ing commissioned. This instrument built together with the Landessternwarte Heidelberg, the MPE Garching, the University of Bochum, and the Fachhochschule for Technology and Design in Mannheim, will be ready for scientific exploitation in September 2009. It provides a $4' \times 4'$ field-of-view in seeing limited mode. Once the adaptive secondary mirrors have been installed at the LBT, diffraction-limited performance can be expected for the two LUCIFER instruments over a field of about $0\farcm5 \times 0\farcm5$. Adaptive optics will also permit users to achieve spectral resolving powers of several tens of tousands. Scientific applications for the multi-mode LUCIFER instruments are many, including studies of star formation in nearby galaxies.

By far the largest instrumentation project at the MPIA is the near-infrared beam combiner LINC-NIRVANA for the LBT. LINC-NIRVANA IS currently undertaking integration and testing at the MPIA. As the PI institute, the MPIA leads a consortium with the Italian Observatories (INAF), the MPIfR Bonn, and the University of Cologne. By coherent combination of the two LBT primary mirrors via Fizeau interferometry, LINC-NIRVANA will provide diffraction-limited imaging over a $10\farcm5 \times 10\farcm5$ field of view in the 1 – 2.4 μm regime, with the spatial resolution of a 23 m telescope. Multi-conjugated adaptive optics with up to 20 natural guide stars will ensure large sky coverage. Due to the panoramic high-resolution imaging and astrometric capabilities of LINC-NIRVANA, scientific applications range from supernova cosmology, galaxy formation, and extragalactic stellar populations and star formation, to extrasolar planets, stellar multiplicity, the structure of circumstellar disks, and the imaging of solar-system planets and their atmospheres.

As Co-PI institute in a consortium with the Laboratoire d'Astrophysique de l'Observatoire in Grenoble, the Laboratoire d'Astrophysique in Marseille, ETH Zürich and the University of Amsterdam, the MPIA co-leads the development of SPHERE, a VLT instrument specialized for the imaging of Jupiter-like extrasolar planets. To overcome the huge brightness contrast between the planet and its host star, SPHERE will use eXtreme Adaptive Optics (XAO), coronography, and three differential imaging-capable focal plane sub-instruments that will, respectively, employ polarimetry in the visual, dual imagery in the near-infrared, and integral field *J*-band spectroscopy.

Survey instrumentation

The current workhorse for MPIAs survey efforts is the OMEGA 2000 near-infrared imager, in operation at the prime focus of the Calar Alto 3.5 m telescope since 2003. It provides a field of view of $15\farcm4 \times 15\farcm4$, and z to K-band sensitivity.

The successor of OMEGA 2000 will be PANIC, the Panoramic Near-infrared Camera, which is a wide-field general purpose instrument for the Calar Alto 2.2 m telescope. PANIC is a joint development of the MPIA and the Instituto de Astrofísica de Andalucía. With four HAWAII2-RG detectors, it will provide a field of view of $30' \times 30'$. Surveys of extragalactic, galactic, and solar system objects will be possible as well. Some of the numerous possible science cases are gamma-ray burst hosts, supernovae, distance scales, high-redshift quasars, accretion disks, post AGB-stars, and X-ray binary counterparts.

MPIA has also build LAIWO, the Large Area Imager for the Wise Observatory (Israel). It is an optical camera that was installed at the observatory's 1 m telescope in October 2007. A mosaic of four CCD detectors with $4\,\mathrm{K} \times 4\,\mathrm{K}$ pixels each provides a field of view of one square degree. The main scientific application is the photometric search for transiting extra-solar planets of Jupiter size.

The HAT-South project is a network of 24 small-sized automated telescopes with the goal to survey a large number of nearby stars to search for transiting extra-solar planets. These telescopes are located at three sites: Las Campanas in Chile, the HESS site in Namibia, and Siding Springs in Australia. MPIA is responsible for the site preparation and operations of the Namibian node. The survey is expected to start at the beginning of 2010, and to detect about 25 planets per year. The HAT-South project is a collaboration between Harvard, the Australian National University, and MPIA.

Instruments for next generation telescopes

In preparation for the future, MPIA is participating in two studies for instruments for the 42 m E-ELT telescope: METIS and MICADO. The METIS concept is a thermal/mid-infrared imager and spectrograph whose wavelength coverage will range from L-band to at least 20 μm. A wide range of selectable resolving powers is planned. Adaptive optics will permit diffraction-limited observations. Science cases are conditions in the early solar system, formation and evolution of proto-planetary disks, studies of the galactic center and of the luminous centers of nearby galaxies, high-redshift AGNs and high-redshift gamma-ray bursts.

In December 2008, several concepts of the MICADO study were evaluated and down-selected for a phase A study. 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) by a factor of 6 to 7. It will have a sensitivity down to 29 mag in bandpasses from I to K. Applications range from young stellar objects in our galaxy to star formation in high-redshift galaxies. The achievable astrometric precision will further advance studies of stellar orbits around the black hole in the galactic center and of the proper motions of globular clusters in the galactic halo. With MICADO, detailed mapping will be possible on scales as small as 80 pc of the structure, the stellar populations, and the interstellar dust distribution in galaxies with redshifts $z = 1$.

Fig. I.5: The European Herschel Infrared Observatory, being weighted in Kourou before launch in May 2009. (Esa)

Instrumentation for Space-based Astronomy

The MPIA is one of the largest partners in the development and construction of Pacs, the far-infrared camera and spectrometer, which will operate aboard the European infrared space observatory Herschel (Fig. I.5) (see Chapter IV.6). MPIA provied the focal plane chopper – a vital cryomechanism within Pacs – and plays a major role in setting up and operating the Instrument Control Center. Herschel's 3.5 m mirror will be the largest one ever used in space, providing unprecedented observations of very cold, distant and poorly known objects. The satellite and its cryogenic instruments are currently undergoing extensive ground tests. The launchis scheduled for May 2009.

The MPIA is the leading institute in Germany for the development of instrumentation for the James Webb Space Telescope (JWST, Fig. I.6), to be launched in 2013 as the successor to the Hubble Space Telescope. JWST will be equipped with a folding primary mirror about 6 m across, as well as four focal-plane instruments. As a member of a European consortium, MPIA develops the cryogenic wheel mechanisms for the positioning of the optical components in JWST's mid-infrared instrument Miri, which is designed for the wavelength range from 5 to 28 micron, and consists of a high-resolution camera and a spectrometer of medium resolving power. Miri is being developed and built in a European-US collaboration.

The MPIA will also provide crucial parts of the second focal-plane instrument of the JWST, a near-infrared multi-object spectrograph called NirSpec, by delivering electrical components for the filter and grating wheel mechanisms. This contribution, as well as our participation in the NirSpec science team, will provide the

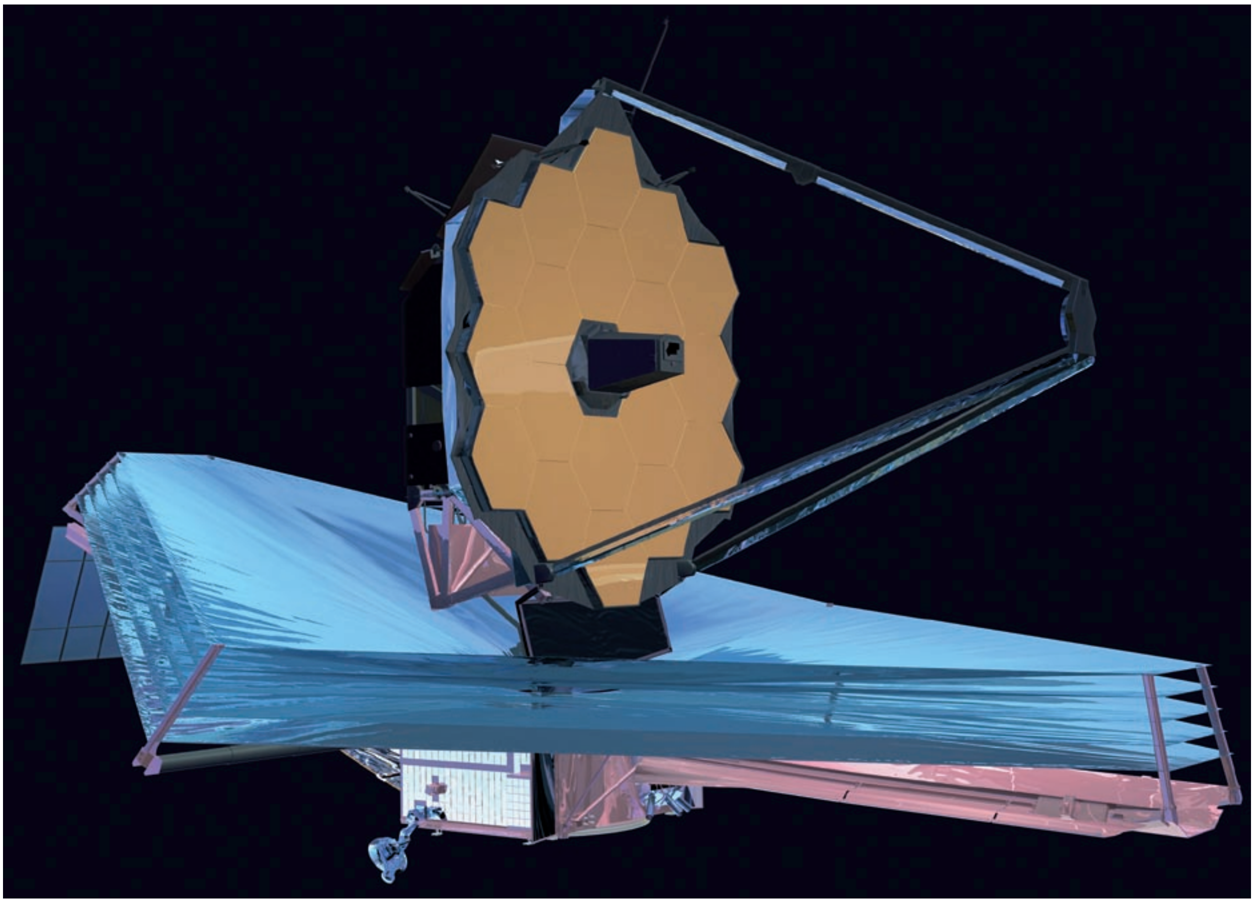


Fig. I.6: Design model of JWST, the successor of the HUBBLE Space Telescope to be launched in 2014, with the large primary mirror and the characteristic sun shield.

astronomers at MPIA with further excellent opportunities for powerful infrared observations. For the development of the precision optics of MIRI and NIRSPEC, the MPIA is closely cooperating with Carl Zeiss Optronics, Oberkochen.

The MPIA is also leading a major data analysis aspect of ESA's GAIA project, a space observatory scheduled for launch in 2011. GAIA will be the successor to

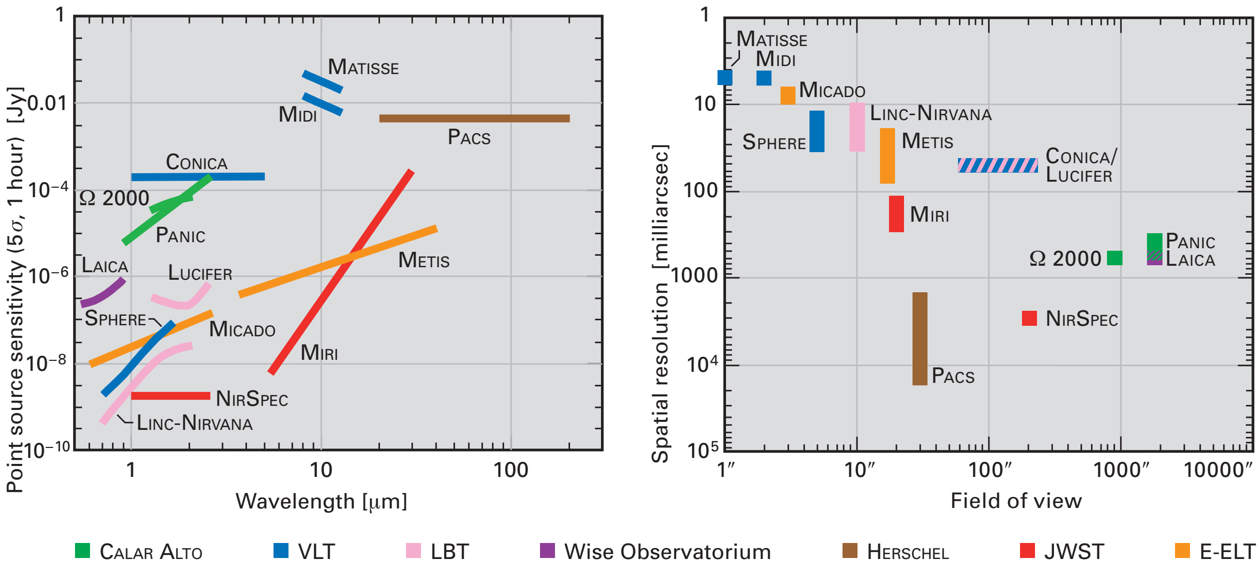


Fig. I.7: Capabilities of MPIA's major instruments. *Left:* sensitivity as a function of wavelength. *Right:* spatial resolution as a function of the field of view.

the Hipparcos astrometry satellite, exceeding the latter's sensitivity by several orders of magnitude. The satellite will measure positions, magnitudes, and radial velocities of one billion stars, in addition to numerous galaxies, quasars and asteroids. The telescope will provide photometric data in 15 spectral bands as well as spectra in a selected spectral range. Unlike Hipparcos, Gaia does not need to be provided with an input catalogue, but will measure systematically all accessible objects. Automatic object classification will thus be of major importance for data analysis. At present, concepts for coping with this demanding task are being developed at the MPIA (supported by a grant from DLR).

MPIA is involved in the mission studies within the Esa Cosmic Vision program. Euclid has the goal of mapping the geometry of the dark Universe by studying the distance-redshift relationship and the evolution of cosmic structures. To this end, the shapes and redshifts of galaxies and galaxy clusters will be measured out to redshifts $z \sim 2$, that is, to a look-back time of 10 billion years, thereby covering the entire period over which dark energy played a significant role in accelerating the expansion of the Universe. The observing strategy of Euclid will be based on baryonic acoustic oscillations measurements and weak gravitational lensing, two complementary methods to probe dark energy. The Euclid survey will produce 20 000 deg^2 visible and near-infrared images of the extragalactic sky at a spatial resolution of $0\farcs30$. It will also yield medium resolution ($R \sim 400$) spectra of about a third of all galaxies brighter than 22 mag in the same survey area.

Plato (PLAnetary Transits and Oscillations of stars) is another Esa Cosmic Vision mission. Its primary goal is to provide the basis for statistical analyses of exoplanetary systems around stars that are bright and nearby enough to allow for simultaneous or later detailed studies of their host stars. Plato will observe 20 000 dwarf stars with a photometric precision better than 27 ppm/hour of observing and more than 250 000 stars to somewhat lower precision. Seismic analysis will lead to the determination of stellar and planetary masses with up to one percent precision, and the detection of Earth-sized planets, with age determinations to within several 100 million years. Plato will provide a very wide field of view (550 square degrees). The required short focal length led to the concept of a bundle of 42 small telescopes, each of which has a collecting area of 0.01 m^2.

Spica, the Space Infrared Telescope for Cosmology and Astrophysics, is the third astronomy mission of Esa's Cosmic Vision in which MPIA is participating in the study phase. The mission is planned to be the next space astronomy mission observing in the far infrared after Herschel. The mission is planned to be launched in 2017 and will feature a cold 3.5 m telescope. This large cold aperture will provide up to two orders of magnitude sensitivity advantage, mostly for spectroscopic observations, over existing far-infrared facilities and Herschel. Spica is led by the Japanese Space Agency Jaxa. Europe has proposed to participate with a Spica Far Infrared Instrument called Safari, the telescope mirror, and support of the ground segment.

Fig. I.7 gives an overview of the major instruments which are already working or are about to be put into operation. Sensitivity is shown as a function of wavelength (left), and spatial resolution as a function of the size of the field of view (right).

I.3 National and International Collaborations

MPIA is strategically well-placed: Heidelberg has become one of Germany's foremost centers of astronomical research. Cooperation with the High-energy Astrophysics Department of the MPI für Kernphysik, and with the institutes of the Center for Astronomy Heidelberg (ZAH), established in 2005, is manifold: the ZAH consists of the Landessternwarte, the Astronomisches Recheninstitut, and the Institut für Theoretische Astrophysik at the University. At present, this collaboration is particularly close within the long-standing DFG-Sonderforschungsbereich No. 439, "Galaxies in the Young Universe", in which all the aforementioned institutes are participating. Also, the "International Max Planck Research School" for Astronomy and Cosmic Physics (IMPRS, see Section I.4) is run jointly by the Max Planck Institutes and the University.

Nationally, cooperation with the MPI für extraterrestrische Physik in Garching and the MPI für Radioastronomie in Bonn, as well as with numerous other German institutes, whose locations are shown in Fig. I.8, is extensive.

The establishment of the German Center for Interferometry (Frontiers of Interferometry in Germany, or FrInGe), located at the MPIA, also emphasizes the Institute's prominent role in Germany in this innovative astronomical technique. The goal is to coordinate efforts made by German institutes in this field and to accomodate the interests of the German astronomical community in the European Interferometric Initiative. Another specific goal is the preparation of the next generation of interferometric instruments. This includes the preparation of second-generation instruments for VLTI, such as Matisse – an imaging interferometer consisting of four telescopes – and Gravity. Further tasks are: participation in the definition of new imaging capabilities of the VLT interferometer. FrInGe, together with other interferometric centers in Europe, is partaking in the establishment of the European Interferometry Initiative. The long-term perspective is to establish a European interferometric center for the optical and infrared wavelength region. In addition to MPIA, the following institutes are participating in FrInGe: the Astrophysikalisches Institut Potsdam, the Astrophysikalisches Institut der Universität Jena, the Kiepenheuer Institut für Sonnenphysik in Freiburg, the MPI für Extraterrestrische Physik in Garching, the MPI für Radioastronomie in Bonn, the University of Hamburg, and the I. Physikalisches Institut der Universität Köln.

The MPIA is participating in a number of EU-networks and worldwide collaborations, in part as project leader. These include:

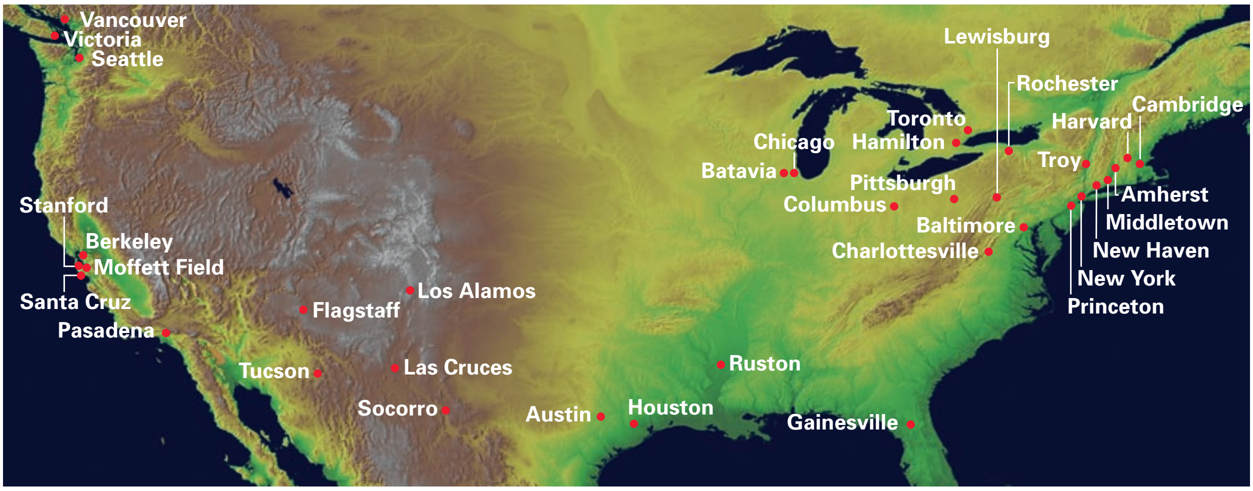
Fig. I.8: German collaborative partner institutes of the MPIA.

Opticon: A network of all operators of major telescopes in Europe, financed by the European Union. Its main goal is to optimize use of scientific-technical infrastructure, in order to increase scientific results and reduce costs. Opticon's other main goal is to coordinate technology development for the next generation of ground-based telescopes.

Espri (Exoplanet Search with Prima): This project aims at carrying out the first systematic astrometric planet search with a measurement accuracy of 10-20 microarcseconds. For this purpose, we have built, in collaboration with Eso, the Landessternwarte Heidelberg, and the Geneva Observatory in Switzerland, differential delay lines for the Prima facility at the VLTI. Our consortium is also developing the astrometric data reduction software. After commissioning of the astrometric mode is completed, probably in late 2010 or early 2011, the 5-year guaranteed time planet search programme will start.

Fig. I.9: Distribution of the international partner institutes of the MPIA.


Stockholm
Helsinki
St. Petersburg
Edinburgh
Hatfield
Durham
Kopenhagen
Moskau
Manchester
Chilton
Amsterdam
Groningen
Dublin
Cambridge
Oxford
Dwingeloo
Leiden
Warschau
Southhampton
London
Liège
Krakau
Paris
Saclay
Basel
Zürich
Padua
Budapest
Versoix
Genf
Mailand
Triest
Grenoble
Genua
Bologna
Marseille
Nizza
Florenz
Rom
Neapel
Madrid
Lissabon
Granada
Calar Alto
Tel Aviv


Vancouver
Victoria
Seattle
Lewisburg
Rochester
Cambridge
Toronto
Harvard
Chicago
Hamilton
Troy
Batavia
Pittsburgh
Columbus
Amherst
Stanford
Baltimore
Middletown
Berkeley
Charlottesville
New Haven
Moffett Field
New York
Santa Cruz
Los Alamos
Flagstaff
Princeton
Pasadena
Tucson
Las Cruces
Ruston
Socorro
Austin
Houston
Gainesville

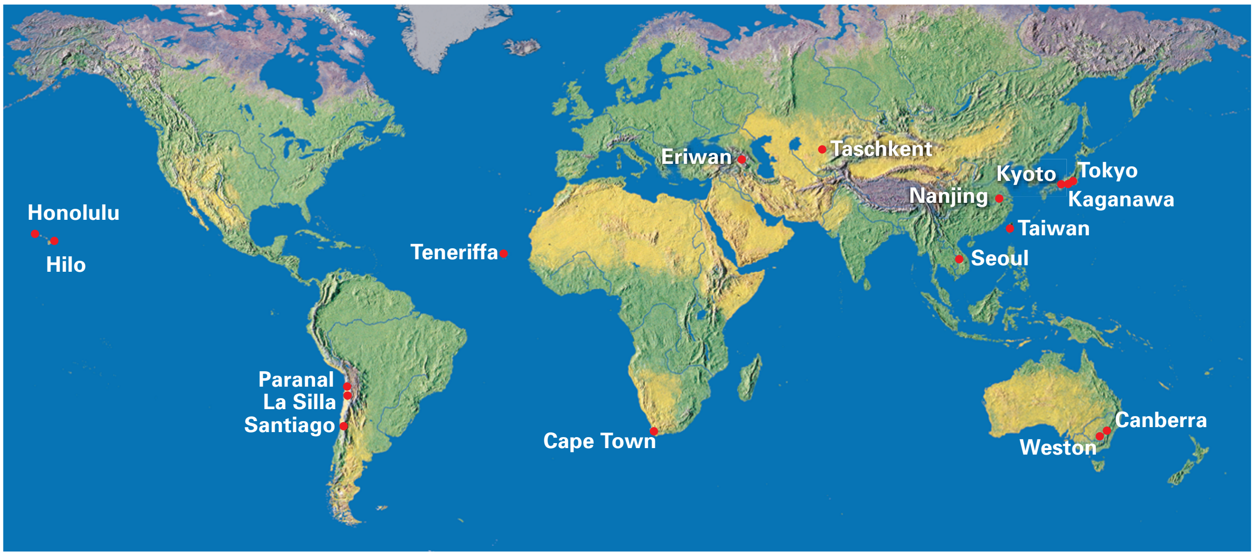

Eriwan
Taschkent
Kyoto
Tokyo
Nanjing
Kaganawa
Honolulu
Taiwan
Teneriffa
Seoul
Hilo
Paranal
La Silla
Santiago
Cape Town
Canberra
Weston

Fig. I.10: This image of M 51 and its interacting neighbour NGC 5195 was taken with the GPC1 camera of PanStarrs 1. It shows an area of about 15′ × 15′ (3300 × 3300 pixels at a scale of 0.″26 per pixel), which represents only about 1 percent of GPC1's entire field of view.

Cid: The "Chemistry In Disks" project is a joint collaboration with Bordeaux, Jena and Iram (Grenoble). The major goal of Cid is the study of physical structure and chemical composition of protoplanetary disks at various evolutionary stages. We focus on a sample of nearby bright protoplanetary disks orbiting low-mass (T Tauri) and intermediate-mass (Herbig Ae) stars. For that, we employ multi-molecule, multi-line observations with the Plateau de Bure interferometer and the Iram 30 m antenna, followed by comprehensive data analysis and theoretical modeling.

Seeds: This is an imaging survey using the Subaru telescope. The main goal is to search for giant planets and protoplanetary/debris disks around 500 nearby stars of solar type or other more massive young stars. This is a collaboration between NAOJ, Princeton and MPIA.

Carolus V is a Spanish-German collaboration whose first goal is the search and characterization of T-type objects in young open clusters. We carry out deep optical and near-infrared searches of sub-stellar objects below the hydrogen and deuterium burning mass limits in three young open clusters. The current members of the network mostly belong to the Instituto de Astrofísica de Canarias and the MPIA, although there are collaborators at other institutions in Spain and Germany.

The MPIA is part of a DFG-funded research network ("Forschergruppe") on the first stages of planet formation. This network involves the University of Tübingen (chair), the MPIA (co-chair), the Institute for Geology and Geophysics in Heidelberg (co-chair), the Kirchhoff Institute for Physics in Heidelberg, the Institute for Theoretical Astrophysics in Heidelberg, the Institute for Planetology in Münster and the Institute for Geophysics and Extraterrestrial Physics in Braunschweig. It combines laboratory astrophysics with theoretical astrophysics and astronomical observations in order to gain a better understanding of how the first planetary embryos are formed out of the circumstellar dust surrounding a young star. The network funds 10 PhD students, most of which started in early 2007.

Sisco (Spectroscopic and Imaging Surveys for Cosmology): This EU network is dedicated to the study of galaxy evolution with the help of sky surveys. The Institute has made pivotal contributions to this network through Cadis, Combo-17, and the Gems surveys. Additional partners are: University of Durham, Institute for Astronomy in Edinburgh, University of Oxford, University of Groningen, Osservatorio Astronomico Capodimonte in Naples, and Eso in Garching.

Elixir, an EU network dedicated to exploit the unprecedented capabilities of the NirSpec instrument on the JWST space mission, scheduled for launch in 2014.

Spitzer Legacy Programs: The Nasa infrared telescope Spitzer started its planned two and a half year mission in August 2003. Within a so-called legacy program, collaborations have the opportunity to carry out large-scale observing programs. The MPIA is participating in approved programs, the first of which is to study star formation in the most nearby galaxies (Sings) and the earliest stages of star formation in the Milky Way. Within the Feps (Formation and Evolution of Planetary Systems) legacy program, together with Steward Observatory and other institutes, MPIA is responsible for the data reduction of the spectroscopic data and actively participates in Feps science. Within Sings, the MPIA is leading the effort on radio data and dwarf galaxies.

Gif (German-Israeli Foundation): Within this collaboration, a program to study gravitational lenses is carried out. The partner of the MPIA is the University of Tel Aviv. Through a separate grant, a wide field camera for the Wise Observatory is being built to search for planet transits.

SDSS, the Sloan Digital Sky Survey, has revolutionized wide-field surveying at optical wavelengths. It is the most extensive imaging and spectroscopy sky survey to date, imaging about a quarter of the entire sky in five filters. The final catalogue will provide positions, magnitudes, and colors of an estimated one hundred million celestial objects as well as redshifts of about one million galaxies and quasars. The observations are made with a 2.5 m telescope specially built for this purpose at Apache Point Observatory, New Mexico. The project is conducted by an international consortium of US, Japanese, and German institutes.

The MPIA was the first of what is now twelve European partner institutes in SDSS and the only one to participate since the inception of surveying. In exchange for material and financial contributions to the SDSS, a team of scientists at the MPIA receives full access to the data. In 2005, the "original" SDSS was completed, but an extension, SDSS-II/Segue, focusing on Milky Way structure, was completed in mid 2008.

MPIA is a partner in PanStarrs 1 (PS1), the most ambitious sky survey project since the SDSS, as part of the PanStarrs 1 Science Consortium (PS1SC), using a dedicated 1.8 m telescope and the record-breaking 1.4-Gigapixel Camera (GPC1) with a 7-square-degree field of view A small fraction of one of the first images obtained is shown in Fig I.10. PS1SC is an international collaboration, involving the University of Hawaii, the MPE, Johns Hopkins University, the Harvard-Smithsonian Center for Astrophysics/Las Cumbres Observatory Global Telescope, the Universities of Durham, Edinburgh and Belfast, and Taiwan's National Central University. It will operate the PS1 telescope during 2009 – 2012 to carry out multiple time-domain imaging surveys in its g, r, i, z, y filter set: the "3pi" survey of all of the sky visible from its location on Haleakala (Hawaii), a medium-deep/supernova survey, as well as a dedicated survey of the Andromeda galaxy and a search for transiting planets. Including this planet search, MPIA scientists are leading four out of twelve key science projects within PS1SC, covering in addition the search for the most distant quasars and the coolest stars, as well as a comprehensive study of the Local Group's structure. PS1 is described in detail in Chapter IV.7.

Within the Herschel Space Observatory project, MPIA is the largest Co-I instute in the Pacs instrument consortium, which consists of partners from 6 European countries. All hardware contributions have been delivered and are currently undergoing final tests. Launch is scheduled for May 2009. The institute leads two Herschel Garanteed Time Key Programs on "The earliest phases of star formation" and "The Dusty Young Universe: Photometry and Spectroscopy of Quasars at $z > 2$ and participates in nine other Herschel Open and Guaranteed Time Key Programs. All these observing programs are large international collaborations.

I.4 Educational and Public Outreach. The New “Haus der Astronomie”

Training the the next generation of scientists and communicating astronomy to the public has a longstandig tradition on the Königstuhl. Now a new project was started, which will amplify and strengthen the efforts of Heidelberg astronomers directed to this goal.

Students come from all over the world to the MPIA to carry out research for their diploma or doctoral thesis. A majority of these students are formally enrolled at the University of Heidelberg. In turn, a number of scientists at the MPIA have adjunct faculty status at the University.

Undergraduate students can get a first taste of scientific work at the MPIA. The Institute offers advanced practical courses or enables the students to participate in “mini research projects”. These last about two months and cover a wide range of questions, including the analysis of observational data or numerical simulations, as well as work on instrumentation. These practical courses offer the students an early, practically oriented insight into astrophysical research, and is an eccellent preparatory step for a later diploma or doctoral thesis.

The International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics, which was established by the Max Planck Society and the University of Heidelberg, started in 2005. In 2008, the school offered 78 PhD students from all over the world a three year education under excellent conditions in experimental and theoretical research in the field of astronomy and cosmic physics. It is sponsored by the five astronomical research institutes in Heidelberg.

The institute's mission also includes educating and informing the general public about astronomical research. Members of the institute give talks at schools, education centers and planetaria. They also appear at press conferences or on radio and television programs, in particular on the occasion of astronomical events that attract major public attention. Numerous groups of visitors come to the MPIA on the Königstuhl and the Calar Alto Observatory.

Our initiative for the general public, a series of eight “Public Lectures on Sunday Morning”, which was in its third year in 2008, always leads to a sold-out auditorium at the MPIA. Also, as in previous years, the one week

Fig. I.11: The “Haus der Astronomie” will be erected on the grounds of the MPIA. The building, whose shape is suggestive of a spiral galaxy, was designed by the architects Bernhardt und Partner, Darmstadt.

long practical course which was offered to interested schoolchildren (BOGy), was immediately booked out – applicants came from all-over the country. And again, the MPIA participated in the Girls' Day, an annual nationwide campaign intended to encourage schoolgirls to learn about professions that are still mainly male-dominated. At various stations throughout the MPIA, about 60 schoolgirls got a general idea of the work at an astronomical institute.

As a prelude and introduction to the International Year of Astronomy 2009, in October 2008 we started, in collaboration with the University, a series of 14 public lectures about “Galilei’s first look through a telescope and its consequences today”, which were given by renowned scholars from Heidelberg and abroad. The lectures regularly attracted an audience of more than 400 people to the central auditorium of the University.

Finally, the monthly magazine “Sterne und Weltraum” (Stars and Space, SuW) is published at the MPIA. This journal is intended for the general public and offers a lively forum both for professional astronomers and for the large community of amateurs in the field. A significant fraction of our readers are teachers and pupils. In parallel to SuW, didactic material is produced monthly within our successful project “Science to schools!”, which helps teachers to treat interesting themes of current astronomical research during regular classes in physics and natural sciences. The project “Science to schools!” was sponsored by the Klaus Tschira Foundation since 2005. The didactic material is made freely available through the web and is widely used.

The “Haus der Astronomie” – an Education and Public Outreach Center

At a press conference held on December 10, 2008 in the domicile of the Klaus Tschira Foundation, the Foundation announced that it will build a “Haus der Astronomie” on the grounds of the MPIA. In this facility, the educational and public outreach activities of all astronomers in Heidelberg will be concentrated and developed further. Information for the media and the general public, the development of didactic material, simulations and visualizations, and the training of university students and teachers of physics, astronomy and natural sciences will play a major role. The Klaus Tschira Foundation will finance the building and its technical equipment, and the Max Planck Society will operate the facility. In addition to these Institutions, the City of Heidelberg, the State of Baden-Württemberg, and the University of Heidelberg will contribute to the personnel costs. The University of Heidelberg with its Center for Astronomy will also bring in activities related to public and educational outreach.

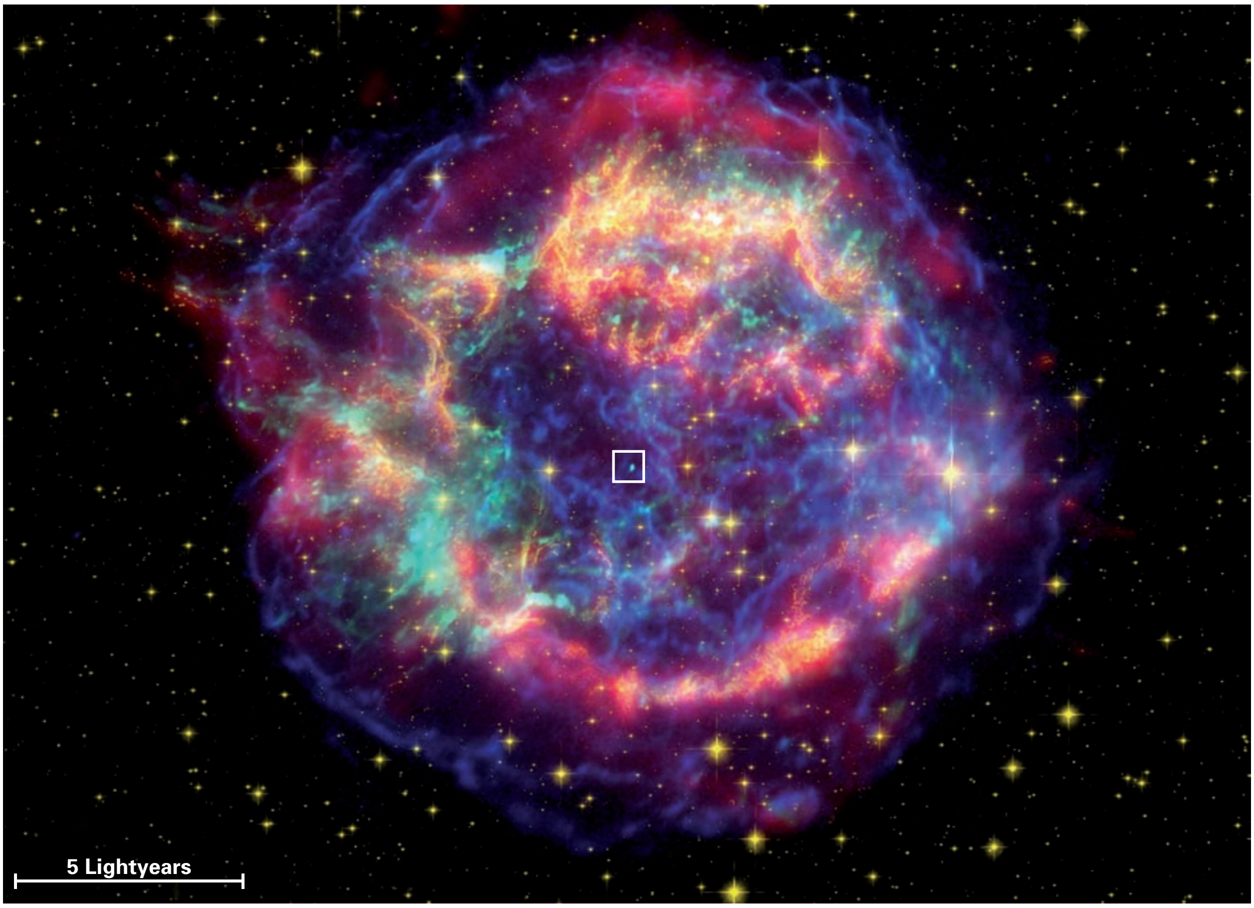
II. Highlights

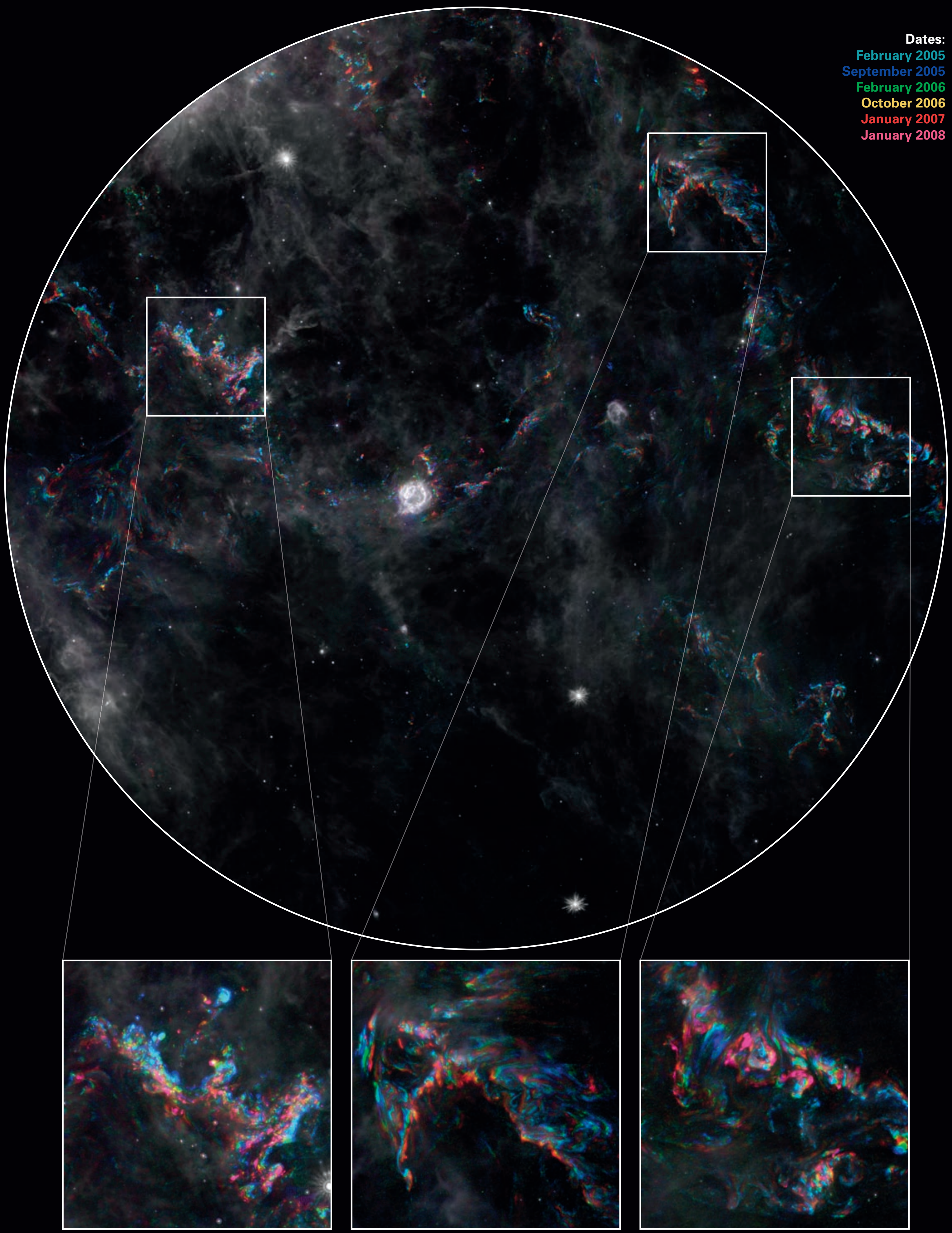
II.1 How two Supernovae were observed »posthumously«, hundreds of years after flaring up

In the entire Milky Way, only about three supernovae explode every century. Moreover, most of these rare events are hidden behind dense clouds of dust and therefore remain unobserved. In their day, the few cases that were visible with the naked eye – Tycho Brahe's supernova in 1572 and Kepler's supernova in 1604, for example – played an important role in the development of cosmology. Nowadays, the focus of interest is on the exact type of the supernova and how the explosion of the star proceeded. Detailed investigations of nearby, known supernova remnants in the Milky Way are making a decisive contribution to our understanding of these cosmic explosions. A team of astronomers headed by the MPIA has now accomplished the extraordinary feat of »posthumously« analyzing the light of the two supernovae from 1572 (Tycho Brahe's) and 1680 (leading to the Cassiopeia A remnant). The team utilized the phenomenon of the light echo, and found that Tycho's supernova was Type Ia, while the Cas A supernova belonged to Type IIb.

Fig. II.1.1: This picture is a superimposition of three images of the supernova remnant Cas A taken by three space telescopes – Chandra in the X-ray spectrum (coded blue and green), Hubble in the visible spectrum (yellow) and Spitzer in the medium infrared spectrum (red). The object in the centre (in the box) is the neutron star remaining after the explosion, which is only visible in the X-ray spectrum.

Fig. II.1.2 (right): Photomontage of infrared images taken by the Spitzer Space Telescope with the bright, round supernova remnant in the middle and interstellar dust clouds further out. The picture is composed of six individual images taken over a period of three years. Infrared radiation that is constant in time appears gray, while the radiation varying due to light echoes is color-coded: blue corresponds to an earlier, red to a later epoch. The radius of the large circle corresponds to 200 arcminutes or 650 light years.




Dates:
February 2005
September 2005
February 2006
October 2006
January 2007
January 2008

Cassiopeia A was due to a Type IIb Supernova

Cas A is the most recent known remnant of the supernova explosion of a high-mass star in the Milky Way and is 11 000 light years away (Fig. II.1.1). From the size and the speed of expansion of the nebula it is possible to date the explosion to around 1680. Surprisingly, no unequivocal observations of the event are available from this time. Only the astronomer John Flamsteed, who was working at Greenwich Observatory at the time, recorded a faint star in his star chart on August 16, 1680 – which could have been the exploding Cas A supernova.

In November 2003, Oliver Krause from the MPIA and his colleagues, working with the SPITZER space telescope, discovered interstellar dust filaments with large apparent motion in the mid infrared in the vicinity of the supernova remnant Cas A. A precise analysis revealed that they were light echoes: The flash of light from the supernova had arrived at distant clouds of dust, heating them up and causing them to emit thermal infrared radiation for several weeks. More than 300 years after the direct flash of light, this radiation had now arrived on Earth (Annual Report 2005, Chap. II.1).

The infrared light echoes mark the position of the light front emanating from the supernova and moving radially outwards in all directions. The astronomers had been using SPITZER over a period of several years to observe this phenomenon at various locations in the vicinity of Cas A (Fig. II.1.2) and using it as an indicator to localize the much fainter light echoes in the visible spectrum – light echoes that consist of the light from the supernova, which has been scattered by the interstellar dust clouds.

In August 2007, a bright infrared light echo flared up in a dust cloud (Fig. II.1.3), and could still be detected in the visual spectrum with the 2.2 m telescope of the Calar-Alto Observatory on October 6. To obtain a more detailed image and a spectrum of this faint light echo, the Institute's astronomers contacted colleagues at the Japanese 8.2 m SUBARU Telescope on Hawaii. At any given point in the sky, the echoes flare up for only a few weeks – about as long as the former supernova was at its maximum brightness – so fast action was called for. Three days later, they had the results.

The light echo was also detected on a long exposure image in the *R* band (Fig. II.1.4b) and a spectrum was obtained, which is shown in Fig. II.1.5. It has numerous emission lines with absorption troughs (P-Cygni profiles). These features are typical of expanding layers of gas and prove that the light echo was produced by the supernova flash. The hydrogen Hα line is prominent, having a half width of 17 000 km/s and a blueshifted absorption with a minimum at – 11 000 km/s. These features are characteristic of Type II supernovae. A supernova of this type flares up when the central core of a high-mass star collapses at the end of its life into a neutron star, blasting off the outer layer of hydrogen. In the case of Cas A, its expansion velocity was about 10 000 km/s.

Owing to the presence of weak helium lines, the type can be more precisely narrowed down to IIb. In this rare type, the star has already shed a large part of its outer hydrogen layer at the time of the explosion so that an almost "naked" helium core below it appears. This interpretation was confirmed by comparing this spectrum with the spectrum of the Type IIb supernova SN1993J in M 81. In this case, it is assumed the progenitor star is a

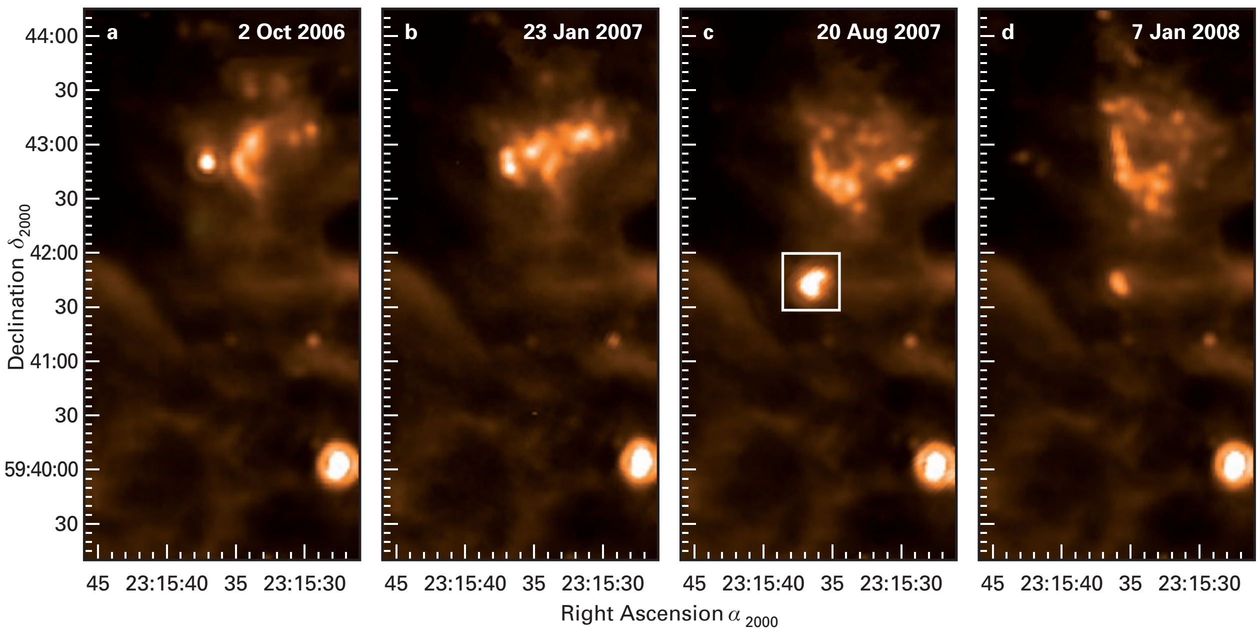


Fig. II.1.3: In this series of infrared images taken with SPITZER, the lighting up of the light echoes is clearly visible (white square in panel c).

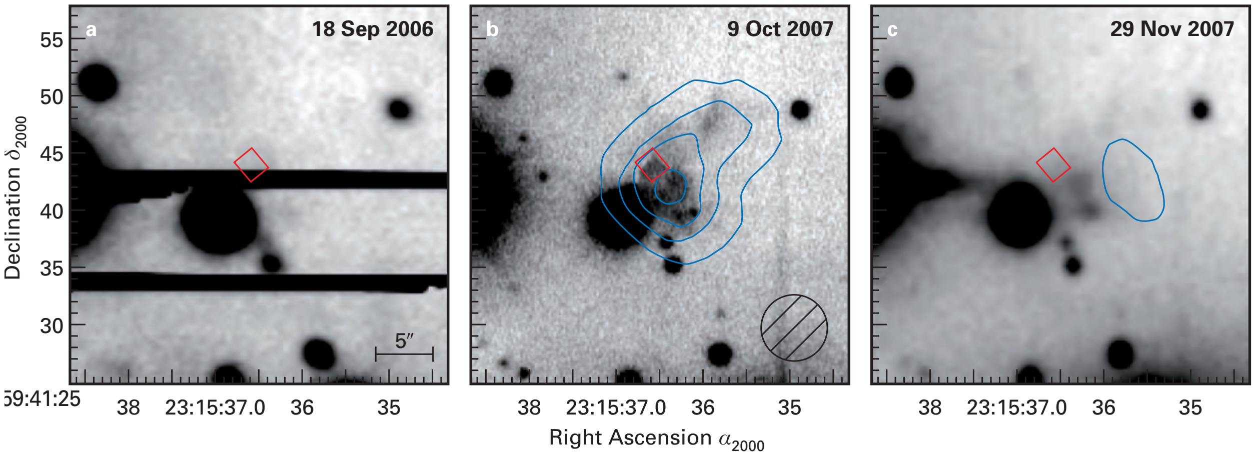


Fig. II.1.4: Three images of the light echo of October 2007 taken with the SUBARU Telescope. In panel b, the contours of the infrared echo are drawn in blue, the light echo in the visual spectrum can also be seen within the red box. The spectrum shown in Fig. II.1.5 was obtained in the area denoted by the small square.

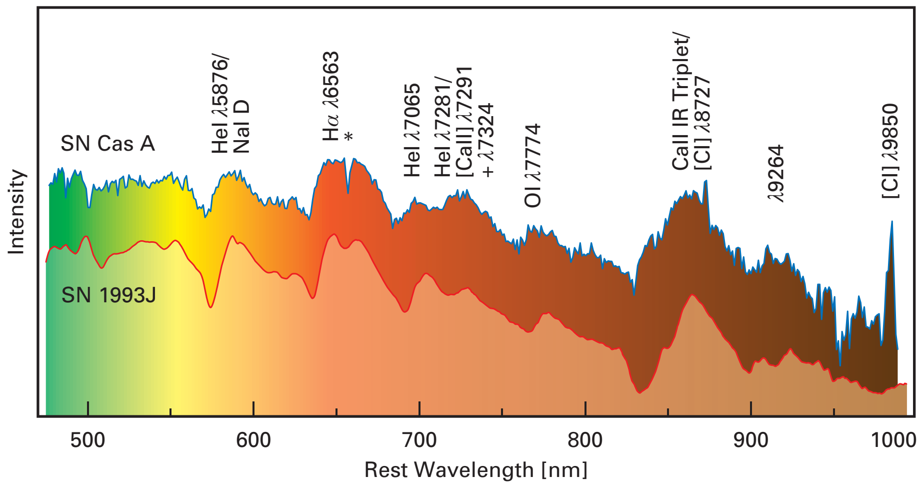
red supergiant with a main sequence mass of between 13 and 20 solar masses.

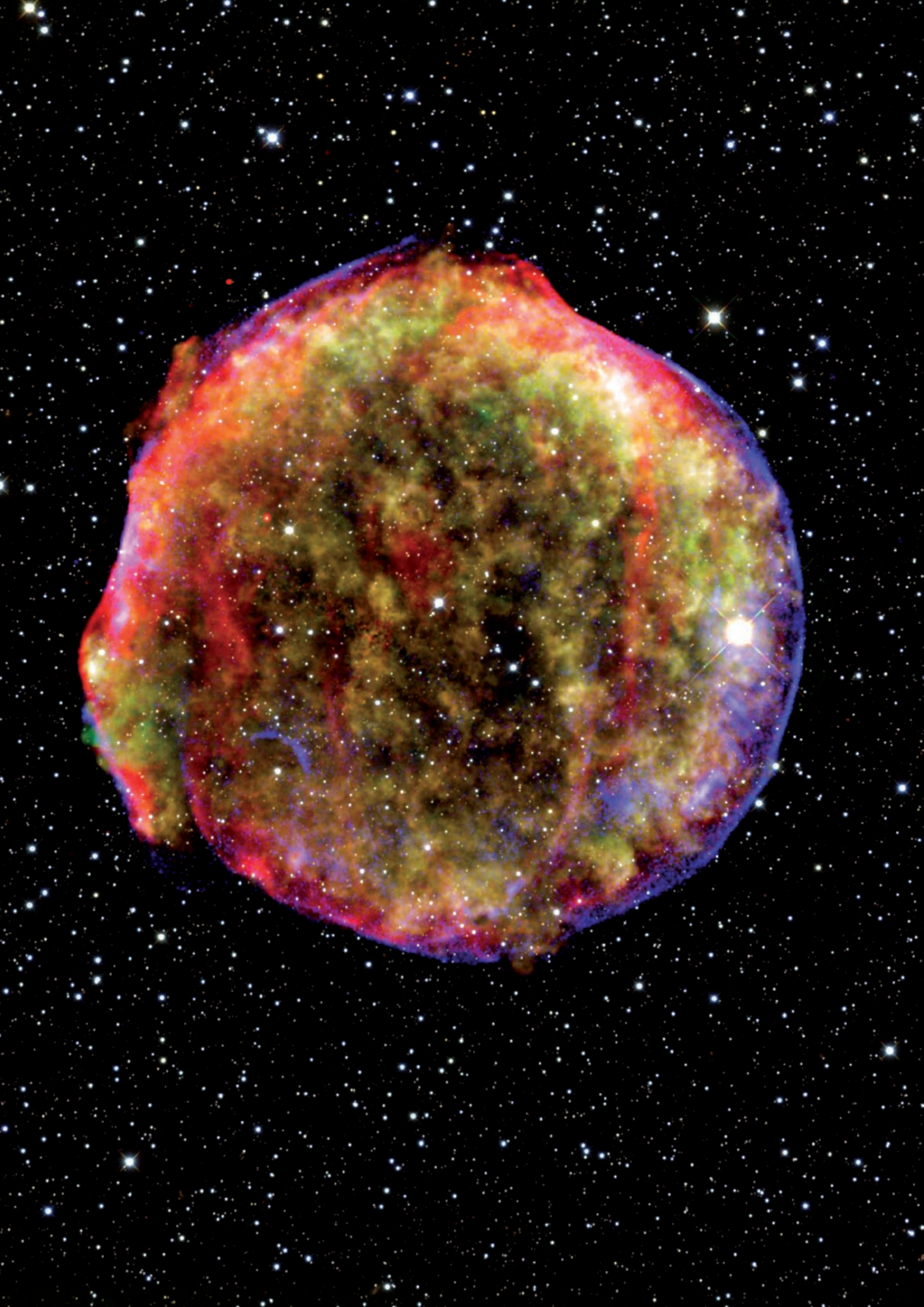
Ten years after observing the explosion of SN1993J, it was possible to prove that the exploded star had belonged to a binary star system. The progenitor star had probably lost matter to its companion before it exploded; such an evolution is at least suggested by model calculations. This situation could also have applied to Cas A. However, since no companion of the neutron star left behind has yet been found, it is also possible that both partners of a close binary star system had fused before they exploded.

This classification could also possibly explain why Cas A was not observed at the time: Type IIb supernovae lose their brightness very rapidly – a couple of cloudy nights would have sufficed to prevent a widespread sighting.

The clever light echo method offers the unique opportunity to construct a 3D model of the supernova explosion. This requires the observation of additional light echoes that were produced at different angles of observation with respect to the supernova. The team headed by Oliver Krause is currently carrying out such observations and trying to find out what caused the asymmetries that can now be observed in the remnant of Cas A.

Fig. II.1.5: Spectrum of the light echo in Cas A, compared to the Type IIb spectrum of the supernova SN1993J. The characteristic broad emission lines of hydrogen and helium are clearly visible.





Tycho's Supernova was Type Ia

Just six months after the publication of the light echoes observed near Cas A, Oliver Krause and his colleagues were able to report a further discovery of a similar kind. This time it concerned Tycho Brahe's supernova. It flared up in the sky in November 1572 and became so bright that for two weeks it could even be seen in daylight. The "Stella Nova", as Brahe called it, only disappeared in April 1574.

It has so far been assumed that the remnant of Tycho's supernova (Fig. II.1.6) is between 7500 and 9000 light years away, making it even a little closer to us than Cas A. Years ago, analyses of the historical records about the way the brightness and color changed had already led to the assumption that it was a Type Ia supernova. However, it was not possible to exclude Type Ib or Type II-L supernovae.

Encouraged by their successes with Cas A, Oliver Krause and colleagues now looked for light echoes from Tycho's supernova in order to determine the type. And on August 23 and September 2, 2008 they were able to chalk up a success with the 2.2 m and the 3.5 m telescopes at the Calar Alto Observatory: On September 24, they used Subaru to successfully obtain a more detailed image and a spectrum of this light echo (Fig. II.1.7), just as they had done earlier with Cas A.

In contrast to the spectra of Type II supernovae, those of Type Ia exhibit no hydrogen emission lines, and differ from the spectra of Type Ib and Ic supernovae in that they exhibit a marked absorption of silicon (Si II) at a wavelength of 635.5 nm. Both characteristics are to be found in the spectrum of the light echo, which proves that Tycho's supernova is Type Ia. From the position of the spectral lines it is possible to deduce that, back then, the explosion cloud moved away from the star at a speed of roughly 12 000 km/s.

Type Ia supernovae occur in binary star systems where the principal component is a White Dwarf. The White Dwarf accretes matter from its companion and this matter accumulates on its surface. This increases the pressure in its core until a thermonuclear explosion develops. In 2004, the companion star of the White Dwarf was possibly found close to the center of the remnant.

The spectrum of Tycho's supernova contains a peculiarity not normally found with Type Ia supernovae: The Doppler shift of the strongly blue-shifted absorption line of the ionized calcium, labeled "HV Ca II" in Fig. II.1.7, corresponds to an expansion velocity of up to 30 000 km/s. This line has previously been only very rarely observed for Type Ia supernovae at this intensity and speed. This was the case with SN 2001el, for example. Here, it was possible to attribute it to an asymmetrical explosion of the star. The cause is nevertheless not clear: Either the companion star was responsible for this in some way, or the development of the explosion itself was not spherically symmetric.

The exact type of two of the three most recent supernovae in our Milky Way has now been unequivocally established. What is still completely unknown is whether the third eruption of the last 500 years, Kepler's supernova of 1604, was a Type I or Type II supernova. Oliver Krause and his team are now using the Eso/MPG 2.2 m telescope on La Silla to look for light echoes from this explosion as well, and hope to soon be able to solve this mystery.

Oliver Krause, Stephan Birkmann, Miwa Goto.
In collaboration with: University of Tokyo,
National Astronomical Observatory of Japan,
Steward Observatory, Tucson (USA)

Fig. II.1.6: Tycho's supernova, taken with the 3.5 m telescope at the Calar Alto Observatory in infrared (white stars) and with the Spitzer (red) and Chandra (green and yellow) Space Telescopes. The outer shock wave against the interstellar matter appears as a blue-glowing ring of synchrotron radiation from high-energy electrons.

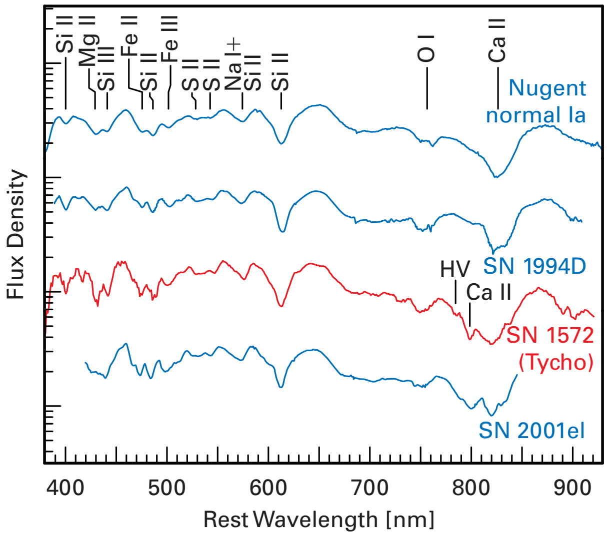


Fig. II.1.7: All important characteristic spectral lines of the light echo from Tycho's supernova (red) are consistent with the spectra of other classic Type Ia supernovae. The strong absorption of Si II is particularly clear. The calcium line labeled "HV Ca II" at a wavelength of 798.0 nanometers (HV stands for "high velocity") probably originated in matter ejected asymmetrically in the explosion.

II.2 A Spectroscopic Study of Binary Brown Dwarfs

In terms of their masses and other physical properties, Brown Dwarfs lie between stars and planets. This makes them particularly interesting objects to study for a number of reasons, especially since it is still not clear how Brown Dwarfs are formed. Some light can be shed on this topic by comparing their abundance in binary systems to the abundance of stars in binary systems. Researchers at MPIA have now carried out the first spectroscopic study of Brown Dwarfs in close binary systems in the Chamaeleon I star-forming region. The result: The low number of such binary systems follows a trend observed for low-mass stars and supports the hypothesis that Brown Dwarfs are formed in the same way as stars, namely by the gravitational collapse of interstellar clouds.

Brown dwarfs have masses of between 0.013 and 0.07 solar masses (between 13 and 75 Jupiter masses). As they form, the temperature and the pressure in their core do not increase sufficiently to ignite the fusion of hydrogen. Deuterium "burns" to form tritium for only a brief period – this fusion reaction is short-lived. The Brown Dwarfs then slowly cool down. And at masses below around 13 Jupiter masses, deuterium can no longer burn to tritium. This is the mass range of the planets, asteroids and moons.

Since the first Brown Dwarf was discovered in 1995, several hundred others have been added; however, there is still no universally accepted scenario for the formation of Brown Dwarfs, and current discussions focus on a number of possibilities.

One obvious speculation is that Brown Dwarfs are formed like stars, from the collapse of interstellar cloud cores, but on a smaller scale. However, numerical simulations have problems creating bodies with such low mass in this way. Therefore, other scenarios are being discussed where the growth takes place in larger cloud cores but is cut short prematurely. This can happen, for example, if neighboring hot stars with their intense UV radiation cause the protostellar matter to vaporize before it can completely accrete onto the growing star. Another possibility is that, as the forming stars interact with one another, those that have the lowest mass are ejected from the cloud before they can achieve the minimum mass required for a star. This event is also called embryo ejection. Finally, it is also possible that Brown Dwarfs are formed in circumstellar disks, like planets, and then ejected from their original system by a star passing by in very close proximity in a densely populated star-forming region, for example.

These different scenarios affect the abundance and the properties of Brown Dwarfs in binary systems in different ways. If embryo ejection is the predominant formation path, only a few Brown Dwarfs should exist in binary systems covering the whole separation range (0 – 3 AU) that is not accessible by current direct imaging surveys and only with close binary separations. However, if they form in the same way as stars, the properties of binary Brown Dwarfs should follow those of low-mass binary stars.

The low luminosity of Brown Dwarfs makes it difficult to identify the binary systems among them and the search is only possible with the aid of the largest and most advanced optical telescopes. Most samplings of this kind are based on direct images with high spatial resolution and they have found that only between 10 and 30 percent of the Brown Dwarfs and low-mass stars (with less than 0.1 solar masses) exist in binary systems – a significantly lower percentage than is the case with stars of higher mass. Most systems found in this way have orbital separations of between 3 and 10 astronomical units (AU). Both components of the systems have similar masses: Three-quarters of all pairs have a mass ratio between 0.8 and 1. Astronomers from the MPIA also came to this conclusion in 2002 (see Annual Report 2002, Chap. II.1).

These results must be cautiously considered, however. With current direct imaging surveys, it is not possible to detect close binary systems where the two components are separated by less than 2 to 3 AU nor those where the mass ratio is less than about 0.6. It therefore remains unclear whether the detected abundance maximum at separations close to 3 AU is real, or whether most binary Brown Dwarfs have a separation of less than 3 AU and thus lie in a separation range that has not yet been investigated.

Brown Dwarfs in the Chamaeleon I Star-forming Region

The only way to currently answer this question is to use high-resolution spectroscopy; however, this requires a lot of effort. It is therefore not surprising that only four close spectroscopic binary Brown Dwarfs have thus far been discovered where it has been possible to determine the orbital elements. One of them, Chamaeleon Hα 8, was discovered in the Chamaeleon I star-forming region (Fig. II.2.1 and II.2.2) in 2007 by the two MPIA astronomers Viki Joergens and André Müller. The secondary component of Cha Hα 8 is probably the Brown Dwarf with the lowest mass ever discovered in a close

Fig II.2.1: This image of the Chamaeleon I star-forming region was taken in 1999 at VLT with the Fors 1 camera. It is a superposition of images in the spectral regions V, R and I. (Image: Eso)

binary system. It could even be a planet. Both bodies orbit each other on a strongly elliptical path with a semi-major axis of one astronomical unit and a period of 4.4 years. Moreover, as early as 2006 Joergens discovered that the star CHXR 74, which has a mass of less than 0.25 solar masses, has a companion with an orbital period of more than twelve years.

These discoveries were made with the Uves echelle spectrograph at the Eso Very Large Telescope (VLT). Several objects must be investigated over a long period of time in order to determine the abundance of close binary Brown Dwarfs. Until now, too short a time base or insufficient measuring accuracy have meant that such

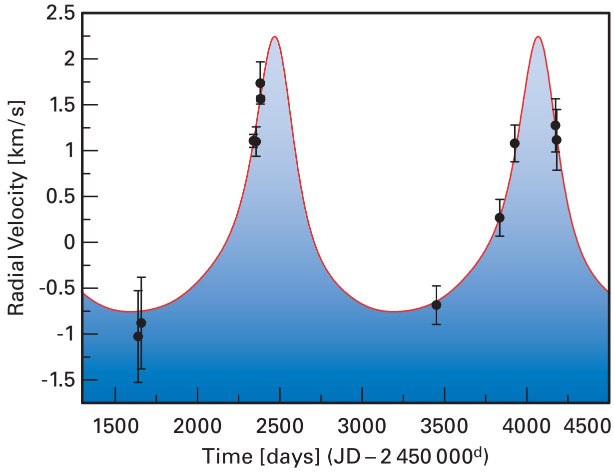


Fig. II.2.2: The periodic change in the radial velocity of Cha Hα 8 reveals its invisible companion.

spectroscopic studies of Brown Dwarfs have only covered separations of less than 0.6 AU.

With precise follow-up observations of ten Brown Dwarfs and the CHXR 74 star at the VLT, Joergens was able to extend the time base to almost six years in 2008 and thus determine the abundance of close pairs of Brown Dwarfs with separations of up to 3 AU.

However, apart from the previously known binaries Cha Hα 8 and CHXR 74, no additional binary systems were found within the measurement accuracy. An initial analysis thus shows that two out of eleven Brown

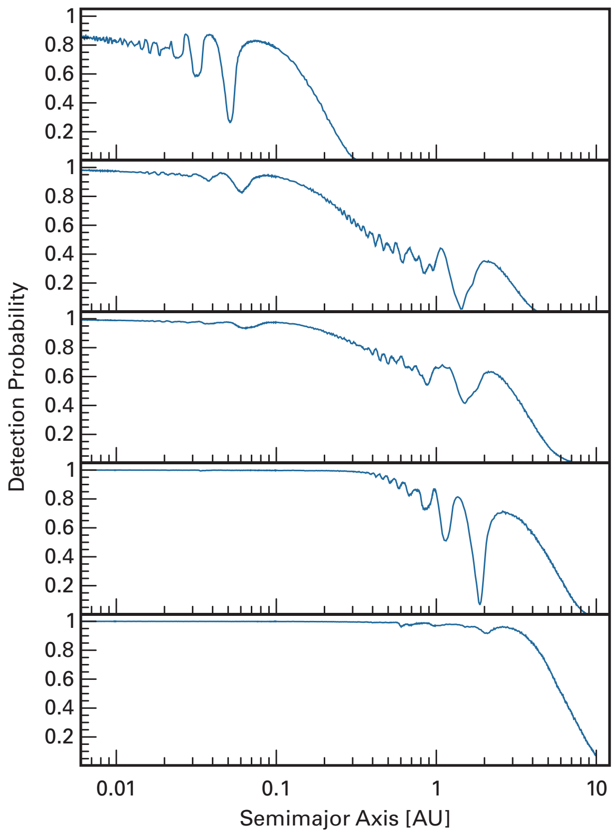
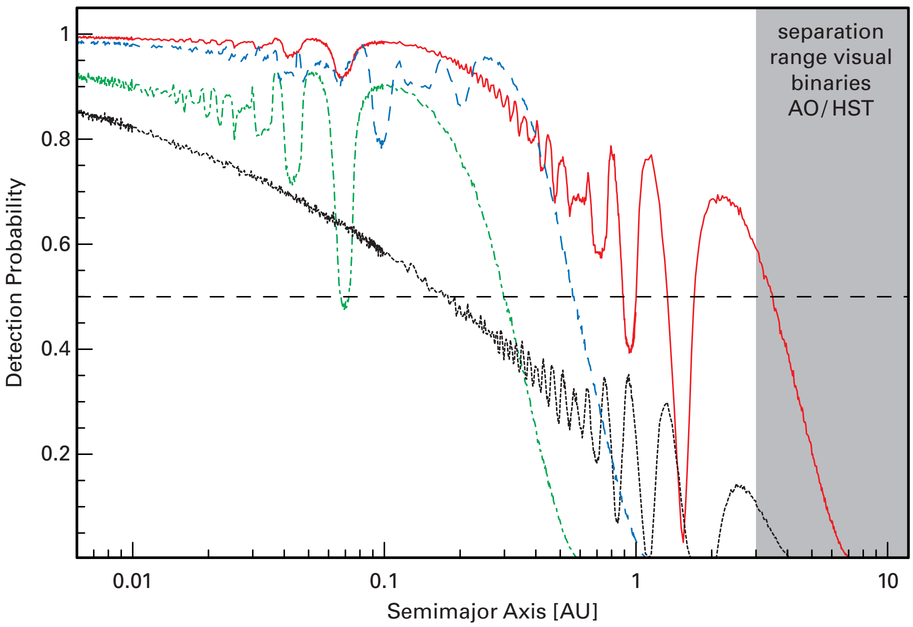


Fig. II.2.3: Detection probability of companions as a function of the mutual separation. The curves have been individually calculated for groups of Brown Dwarfs with similar observing time patterns using Monte-Carlo simulations.

Fig. II.2.4: Detection probability of binary systems in several spectroscopic studies. The investigation conducted at the MPIA and described above (red) is the most sensitive one, especially at low separations. The gray region shows the sensitivity of current direct imaging with adaptive optics and the Hubble Space Telescope.



Dwarfs investigated in Chamaeleon I, around 20 percent, are in binary systems. If CHXR 74 is not included as a low-mass star, the fraction decreases by half.

A further crucial question relates to the separation range over which the investigation was sensitive. This depends on the total duration of the survey, on how often the observations are repeated, and on the sensitivity and accuracy of the measured values. The average measurement error for the radial velocity was ± 0.3 km/s, and the interval as well as the frequency of the observations differed in each individual case. Six of those cases were observed at intervals of 20 days, repeated again after 5.8 years, the other objects were observed more frequently and over a period of two to seven years.

These data were entered into a Monte-Carlo analysis, which simulated 100 000 binary Brown Dwarfs orbiting each other on circular orbits with radii of between 0.006 and 10 AU. The mass ratio was varied between 0.2 and 1.0, and different angles of inclination of the orbits with respect to the line of sight were tried.

The analysis was applied to each of the eleven objects observed. The result (Fig. II.2.3) shows that, on average, the observations cover the complete separation range below 3 AU with a detection probability of 50 percent. This was therefore the first time the abundance of binary Brown Dwarfs and low-mass stars had been investigated over the complete separation range with such a high sensitivity, as a comparison with other spectroscopic surveys shows (Fig. II.2.4).

This new study accordingly rules out the existence of a high percentage of as yet undiscovered, very close pairs of Brown Dwarfs. Not one candidate was found with an orbital period of less than four years or a semimajor axis of less than 1 AU. The 10 percent abundance of binary systems also fits well with the results obtained by direct images.

Brown Dwarfs therefore continue a trend that is also observed for stars: The proportion of objects in binary systems decreases with decreasing mass. This result supports the hypothesis that Brown Dwarfs form in the same way as stars.

Viki Joergens, André Müller

II.3 The Dynamics of Star Formation in NGC 346

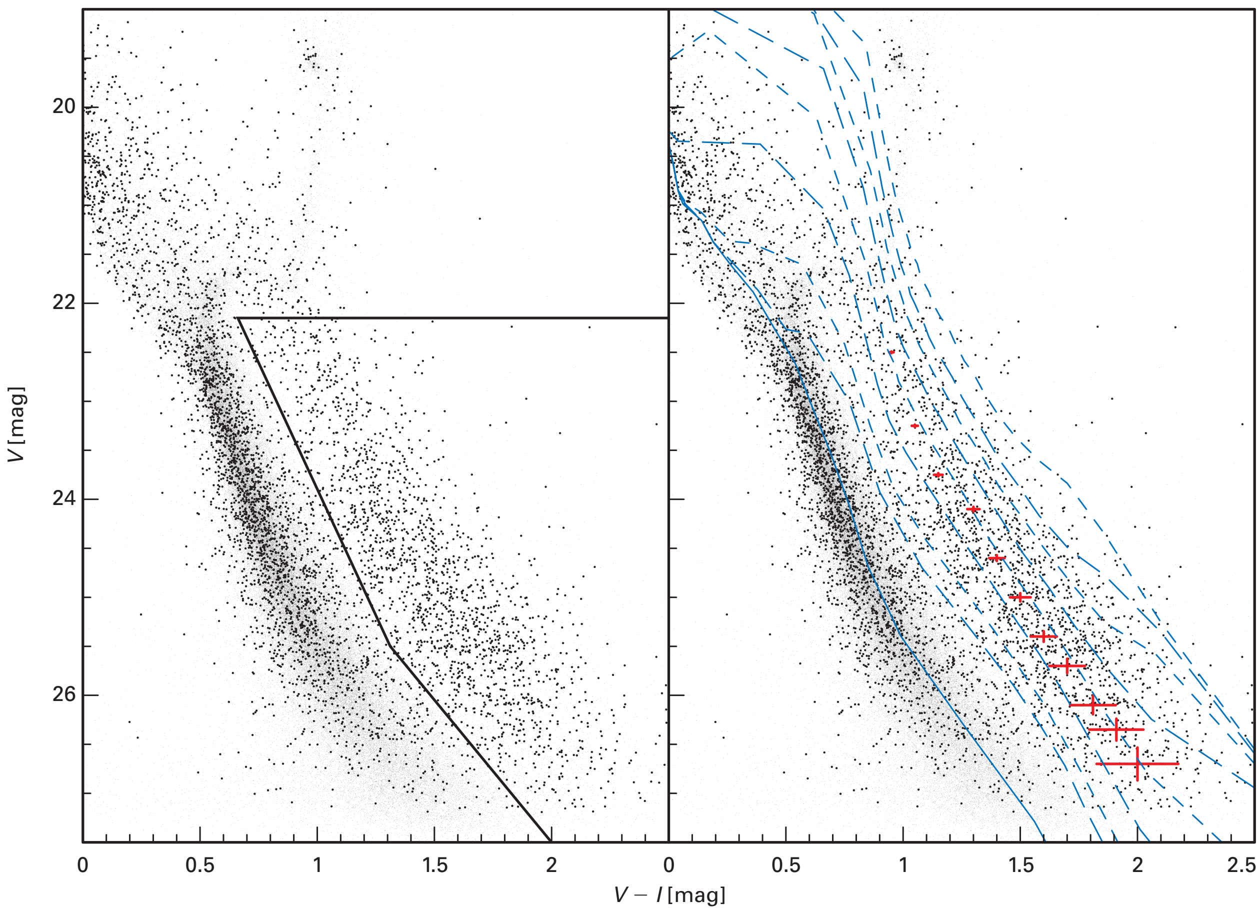
Star formation in large molecular clouds has an effect on its environment and can thus trigger the formation of further stars: The UV radiation of the newly formed high-mass stars creates HII regions, and their particle winds sweep out large bubbles on whose shock fronts interstellar gas and dust is compressed. The example of NGC 346 in the Small Magellanic Cloud shows how such feedback is able to trigger an entire star-forming region. The complex history of this region has now been reconstructed by astronomers at the MPIA in collaboration with colleagues in the United States.

Fig. II.3.1: Astronomers at the MPIA used the image in Fig. II.3.2 to derive a color-luminosity diagram in which the low-mass pre-main sequence stars could easily be identified (points at the bottom right of the diagram on the left). With the aid of the diagram, the age of the pre-main sequence stars can be compared with theoretical isochrones (broken lines in the diagram on the right) to narrow down the age to between 5 and 10 million years.

NGC 346 is the brightest star-forming region in the Small Magellanic Cloud (SMC), which is 210 000 light years away from Earth. It is connected with the brightest HII region called LHA 115-N 66, or N 66 for short, whose luminosity in the Hα emission line is almost 60 times that of the Orion Nebula. Moreover, the star cluster in the center of the nebula contains 33 detected O-type and B-type stars, the highest known concentration of hot, high-mass stars in the SMC.

The star cluster is located in the center of an elongated region, also known as a "bar", which stretches from southeast to northwest. Earlier studies found molecular hydrogen and carbon monoxide emission in the region. Further observations in the near infrared led researchers to speculate that the young stars in this bar did not all form at the same time, but in several episodes, and that

Fig. II.3.2 (right): The NGC346 star-forming region, taken with the ACS camera of the Hubble Space Telescope at wavelengths of 555 nm (shown in blue) and 814 nm (red). (Nota et al., Nasa/ Esa).



the star-forming activity had spread outwards from the center of the bar to the southeast and northwest.

The team of Dimitrios Gouliermis, Thomas Henning, Wolfgang Brandner, Eva Hennekemper and Felix Hormuth then made a great leap forward when they evaluated archived images taken by the HUBBLE Space Telescope (Fig. II.3.2). These images were the first to show a large number of low-mass pre-main sequence stars with a typical age of a mere 5 million years (Fig. II.3.1).

The astronomers used statistical methods to prove that these stars are not uniformly distributed in space but instead form several groups. A photometric analysis of all young stars did not confirm the previous assertion that the stars had been formed sequentially, however. On the contrary, the astronomers came to the conclusion that the stars in the bar of NGC 346 have all been formed within the last ten million years. The data would also be consistent with two different periods of star formation – five and ten million years ago.

High-mass Stars Triggered Star Formation

Gouliermis and his colleagues, on the other hand, discovered three compact, significantly younger star clusters only 2.5 million years old (Fig. II.3.3 and II.3.4) to the north of the bar. This result cannot be fit into the scenario already mentioned whereby the star formation propagated outwards from the center of the bar. A detailed investigation of these young star clusters to the north produced a much more complex history of this star-forming region than had previously been assumed.

Furthermore, an Hα image (Fig. II.3.5) clearly shows two compact clusters to the north of the bar and also a cluster of young stars in a bow-shaped region stretching from the southwest to the northeast, in addition to the stars in the bar. All stars in this northern region are much younger than those in the bar.

The crucial hint concerning the formation history of these young stars was brought to light by superimposing three images from the archives with very different wavelength ranges (Fig. II.3.6): An X-ray image from the XMM Newton Space Telescope (shown in blue), an image in the light of the doubly ionized oxygen [OIII] at 501 nm (green) which was taken with the ESO NTT telescope, and an infrared image taken with the SPITZER Space Telescope at 8 μm wavelength (red).

The first thing one recognizes in Fig. II.3.6 is a bow-shaped dust filament in the south (shown orange in Fig.

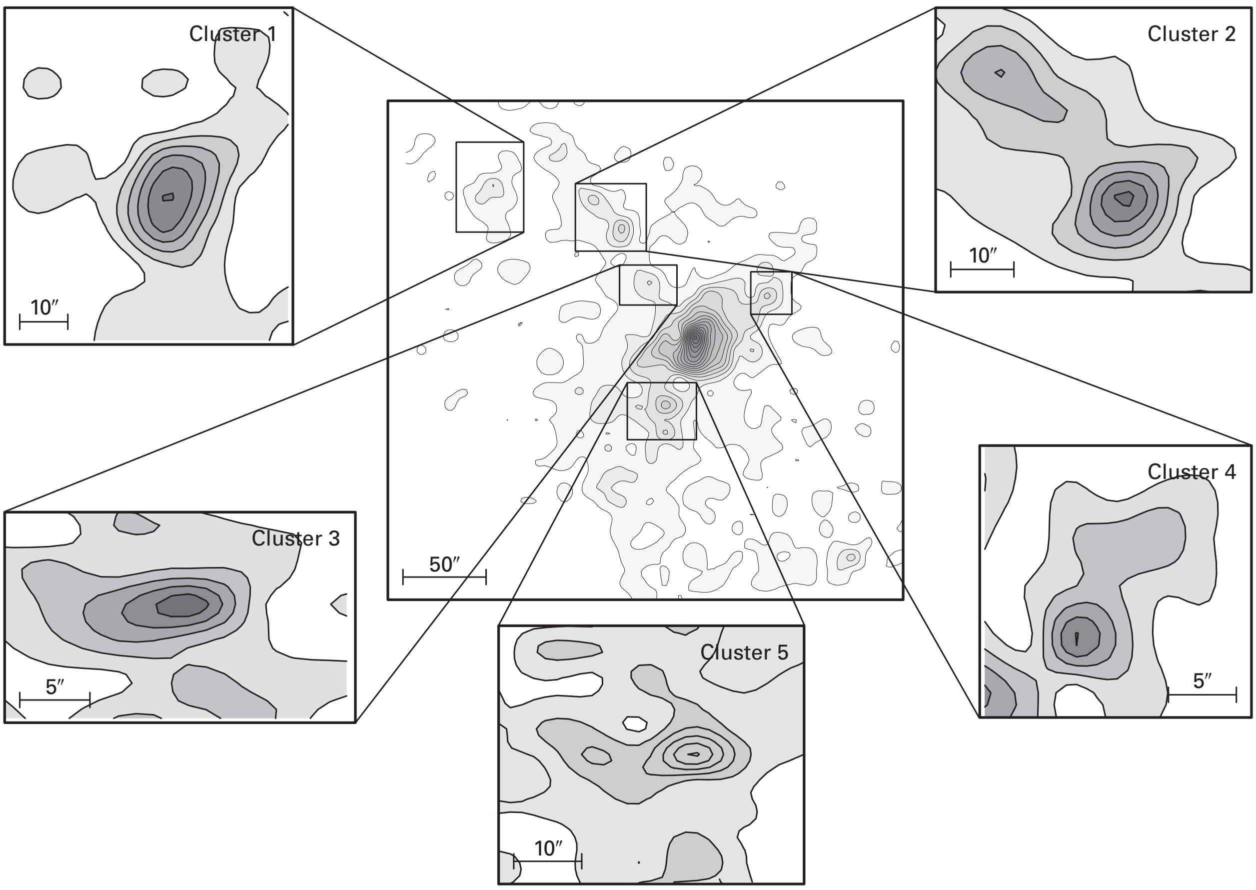


Fig. II.3.3: Map of the young stars in the whole NGC 346/N 66 region, described by a contour diagram of the stellar density.

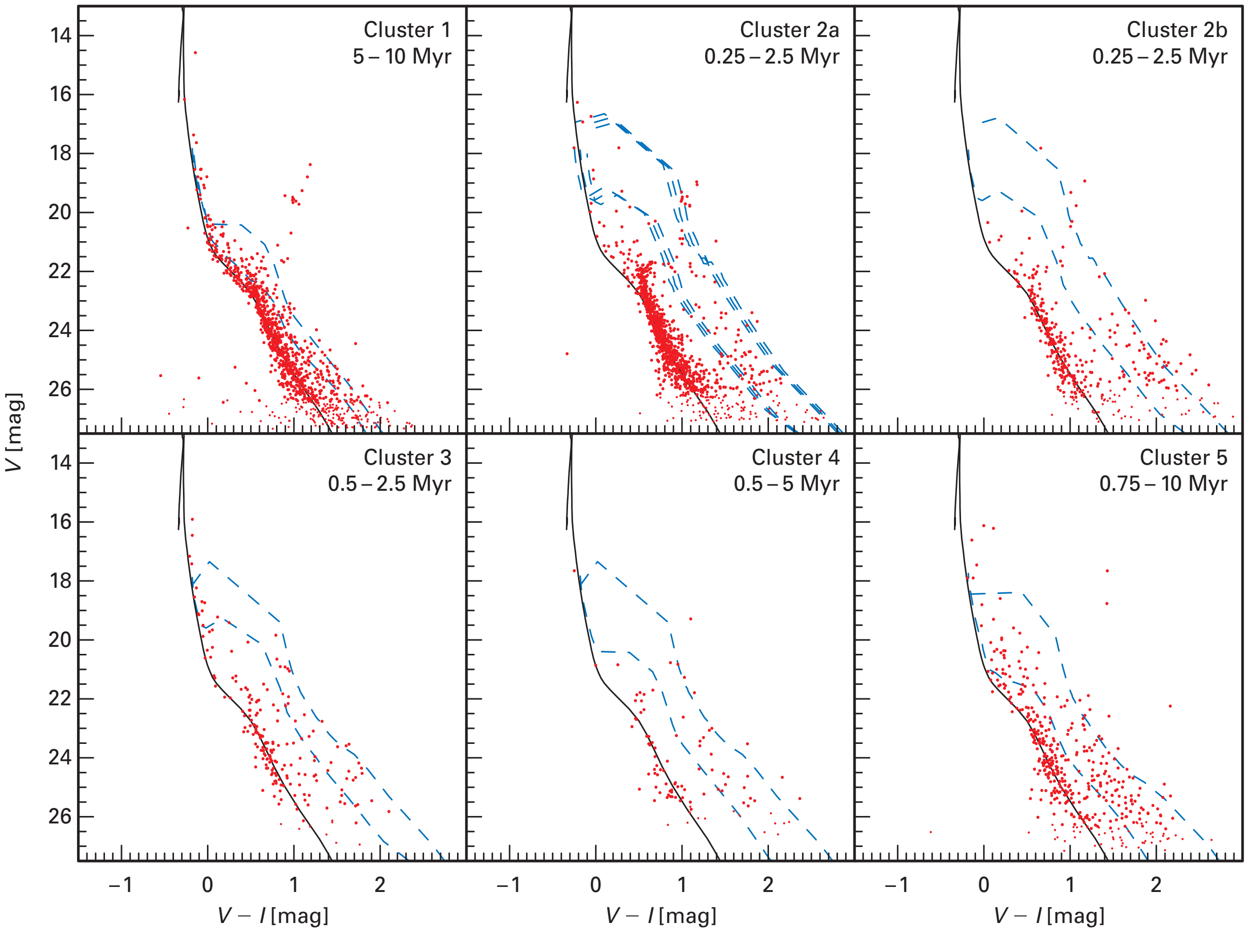


Fig. II.3.4: Color-luminosity diagram of the stars in different clusters. The clusters 2 and 3, which lie in the northeast of NGC 346, are significantly younger than cluster 5 in the bar.

II.3.7). It marks the ionization front created by the intense UV radiation and particle winds of the familiar OB-stars in the center of NGC 346. The strongly curved bow to the north cannot be causally connected with these stars, however. Along it lie the star clusters 2a, 2b and 3, which are a mere 2.5 million years old. So what did cause it?

The objects HD 5980 and B0057-724, which are particularly bright in the X-ray spectrum, are located more or less in the focus of this bow, some 60 light years away from the cluster of young stars: These two objects are the key to the star-forming history of the northern part of NGC 346/N 66.

HD 5980 is a triple system comprising two Wolf-Rayet stars with 50 and 28 solar masses and a high-mass O-type star. In 1994, this object, also known as Sanduleak 78 (Sk 78), had an eruption of the type familiar from luminous blue variables (LBV). The not so distant object B0057-724 is a supernova remnant, a fact indicated in particular by its non-thermal emission.

Some astronomers had already suspected that the pressure wave of the supernova explosion could have been the trigger for the star formation north of the bar, but this is not possible. The supernova remnant is currently expanding at a rate of 175 km/s and would have reached the 2.5 million year old star cluster after 40 000 years. Consequently, the supernova would have to have exploded more than 2.5 million years ago for it to have been able to trigger the formation of these stars. However, supernova remnants can only be detected until they are about 100 000 years old, then they disappear. The progenitor star of the supernova could well have triggered the star-forming activity though.

A high-mass star influences its environment in two ways: On the one hand, its UV radiation ionizes its environment and creates an HII region, whose ionization front propagates at a speed of about 10 km/s. Its particle wind, on the other hand, sweeps out a bubble that expands at between 10 and 100 km/s. At the shock front of this bubble the interstellar matter becomes denser and can then collapse to form new stars. In this phase, the star evolves away from the main sequence and initially becomes a blue supergiant, then an LBV, and then a Wolf-Rayet star. When the latter finally explodes as a supernova, the supernova remnant expands into the existing bubble. If the north eastern bow where the youngest star clusters are located is the shock front of this remnant, the supernova which produced B0057-

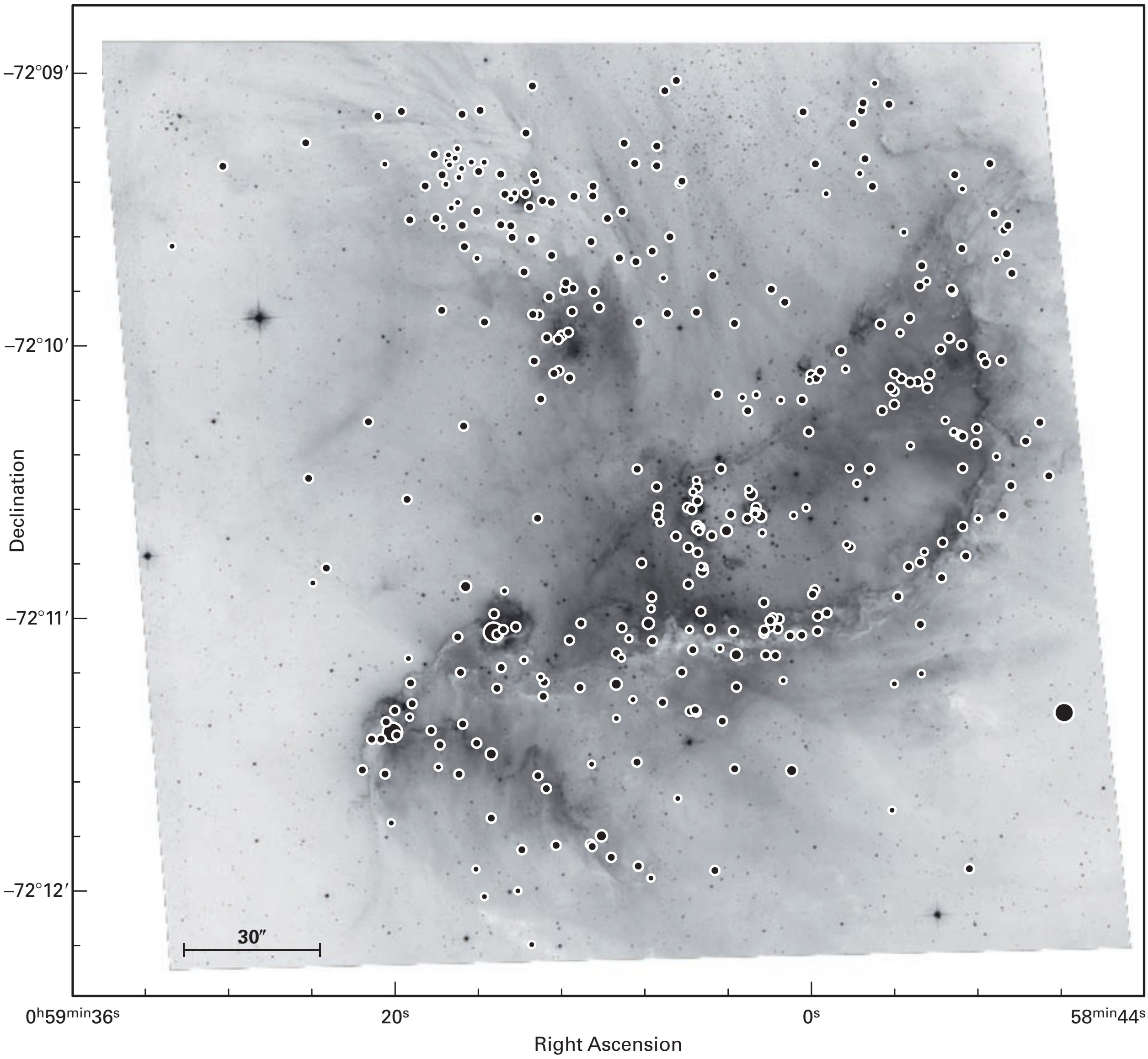


Fig. II.3.5: Hα image of NGC 346 taken with the ACS and WFC cameras of the HUBBLE Space Telescope. Stars with Hα excess are circled in white.

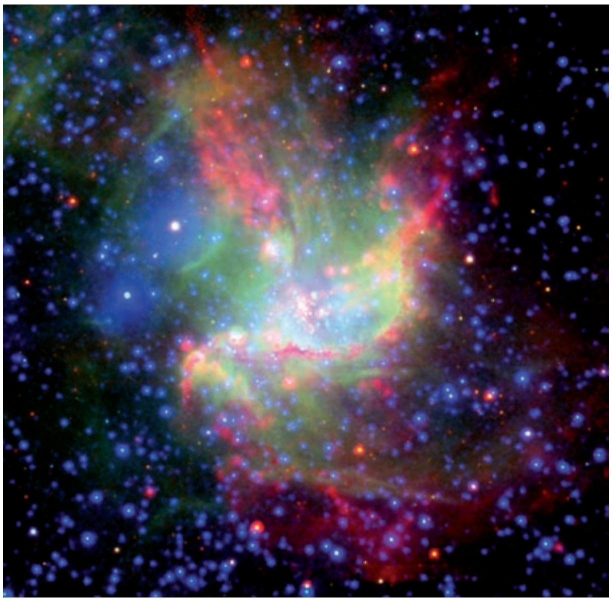


Fig. II.3.6: Superposition of images taken with the SPITZER Space Telescope in the infrared (shown red), XMM Newton in the X-ray spectrum (blue) and the ESO New Technology Telescope in the light of the [OIII] emission (green). The cool dust glows in the infrared, the more or less hot interstellar gas radiates in the visible and in the X-ray spectral range. Normal stars appear blue with a white center. (ESO / ESA / JPL-Caltech/ NASA / MPIA)

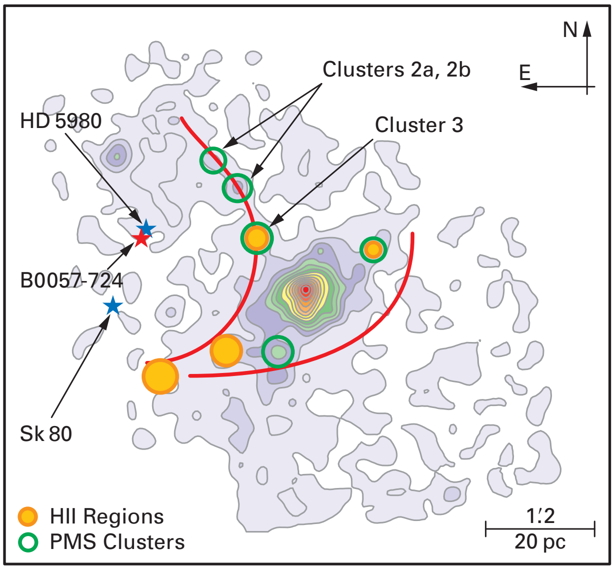


Fig. II.3.7: Sketch of the relevant objects in this region. The contours show the density distribution of all the stars.

724 must have exploded 40 000 years ago. Was the progenitor of this supernova the sole trigger of this star formation?

A close examination of the star field around NGC 346 reveals only two further potential candidates: The previously described triple star HD 5980 (Sk 78) and the O7 supergiant Sk 80 further to the south. An estimate of the mechanical luminosity produces a figure of about 2.6×10^{38} erg/s for Sk 78, and 3×10^{36} erg/s for Sk 80, which is only about one per cent of the first value. Nothing is known about the progenitor star of B0057-724. However, it probably never attained more than one tenth of the luminosity of the HD 5980 triple system. It alone could nevertheless have triggered the formation of the young stars, namely if it had ejected 20 to 30 solar masses of matter in extreme eruptions within a short time period. Such behavior is typical of LBVs such as Eta Carinae.

The study presented here has led to a more complex picture of the star-forming history in NGC 346/N 66 than has been assumed so far. It indicates that the star formation had a dual origin: Initially, a large star cluster formed in the center of the nebula some ten million years ago. It is possible there were two star-forming episodes five million years apart. While the new stars were forming in the bar, the high-mass star Sk 78 and the progenitor of HD 5980 lit up in the north eastern region. Then, 2.5 million years ago, their particle winds compressed the surrounding matter and triggered the formation of further stars.

The astronomers at the MPIA are now working together with theoretical astrophysicists from the University of Heidelberg in an attempt to improve their understanding of the structure of individual star clusters and the complete structure of the NGC 346 star-forming region. Moreover, it is hoped that the evaluation of data recorded in the near infrared with the ESO New Technology Telescope will complete the understanding of the star-forming history in NGC 346.

Dimitrios Gouliermis, Thomas Henning,
Wolfgang Brandner,
Eva Hennekemper, Felix Hormuth.
In collaboration with:
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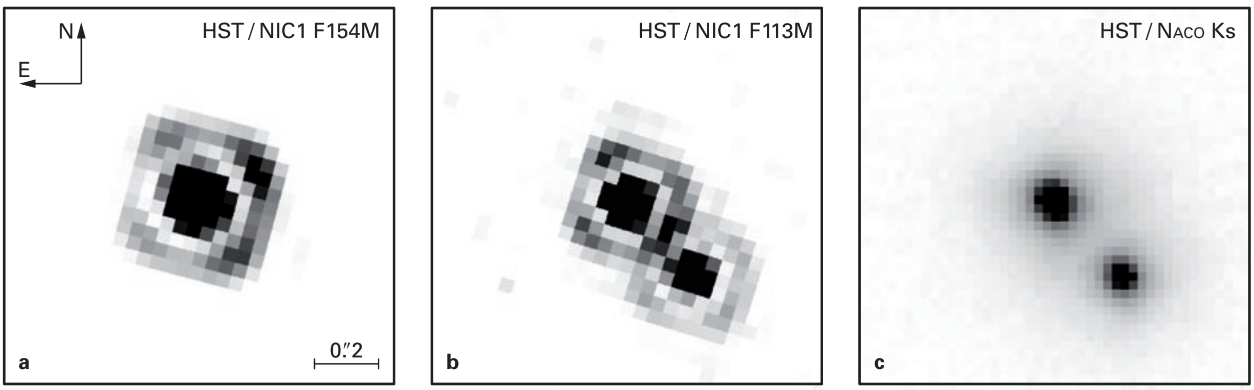
II.4 Kelu-1 – a Binary or Triple System of Brown Dwarfs

Several hundred Brown Dwarfs have been identified in the solar neighborhood and presumably they are as numerous as main sequence stars. But the models for the structure and evolution of these objects are nowhere near as reliable as the models for stars. Spatially resolved binary systems of Brown Dwarfs offer researchers a unique opportunity to determine the masses of the individual components without using models, but such cases are rare. A group at the MPIA has now succeeded in determining the orbital parameters and the masses of the Brown Dwarfs Kelu-1A and B. The results of these measurements show yet again that the existing models systematically yield mass values which are too low. The spectra observed also suggest the presence of an invisible third Brown Dwarf in Kelu-1.

The mass of a star is the most important parameter for its evolution: It determines its luminosity, temperature and lifespan, among other things. Consequently, one of the fundamental tasks of stellar astronomy is to determine a star's mass. The usual procedure is to measure the luminosity of the star and to determine its mass indirectly by means of a mass-luminosity relationship. This relationship is well established for evolved high-mass stars, but scientists have not yet been able to calibrate it with independent observations for Brown Dwarfs, and so here they have to rely completely on comparing the measurements with numerical models of the evolution of Brown Dwarfs.

Unlike stars, Brown Dwarfs never reach the stage of hydrostatic equilibrium. At the formation stage they are hot and then – after a short phase of burning deuterium – they slowly cool down. Therefore, photometric observations cannot be used to unambiguously derive their temperature, luminosity, mass and age. In other words, it is not possible to distinguish between a young low-mass Brown Dwarf and an old high-mass Brown Dwarf. The Kelu-1 system now offers researchers the opportunity to determine the masses of the two known components without using models.

Discovered in 1997, Kelu-1 is only 60 light years away and is one of the most extensively investigated Brown Dwarfs. Its age is very difficult to determine because it does not belong to a group of stars. Scientists had noticed at an early stage that its luminosity was significantly higher than would have been expected from its spectrum. This mystery was solved in 2005 when several groups of astronomers, including one at the MPIA, ascertained that it was a binary system. At that time, it



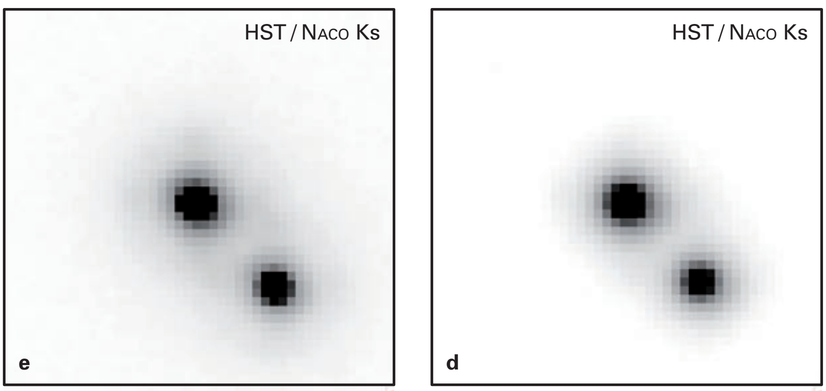


Fig II.4.1: Images of Kelu-1, taken with (from left to right) NICMOS at HST on Aug. 14, 1998 and Jul. 31, 2005 and also with NACO at VLT (Apr. 28, 2006, Feb. 22, 2007 and Mar. 18, 2008).

was determined that the Kelu-1A component was of the spectral type L1.5-L3 and the Kelu-1B component of the type L3-L4.5.

The two components have a separation of about 0.3 arcseconds, which means they can be separated with high-resolution imaging techniques, enabling this system to open up the possibility of measuring the orbital parameters and using the dynamics to determine the total mass of both components. The MPIA researchers began a long-term photometric and spectroscopic observation program. For the analysis now completed they used the data they obtained in 2005 with the Hubble Space Telescope. They also observed Kelu-1 at the Very Large Telescope with the Conica infrared camera with adaptive optics that was designed and built at the MPIA. This was the first time it had been possible to record separate spectra of the two components Kelu-1A and B in the wavelength ranges between 1.37 µm and 1.72 µm and also between 2.02 µm and 2.53 µm. These data covered the period between 2005 and 2008. It was also possible to evaluate a Hubble image from 1998 (Fig. II.4.1).

Orbits, Masses, and Spectral Types

The MPIA team was able to add nine new data points to the previous orbital determinations. The data could best be described by a highly elliptical orbit with an eccentricity of 0.82, which is tilted at an angle of 85 degrees to the celestial plane, i.e. we look almost exactly onto the edge of the orbital plane (Fig. II.4.2). The orbiting period and semi-major axis were determined as 38 years and 6.4 astronomical units. These data were used to calculate the total mass as 177 (+ 113, –55) Jupiter masses. This is the first mass determination of this system that is based purely on dynamics and carried out without the aid of an evolution model for Brown Dwarfs. It is significantly higher than previous results, which were based on fewer data points and produced a maximum value of 120 Jupiter masses. This creates a problem.

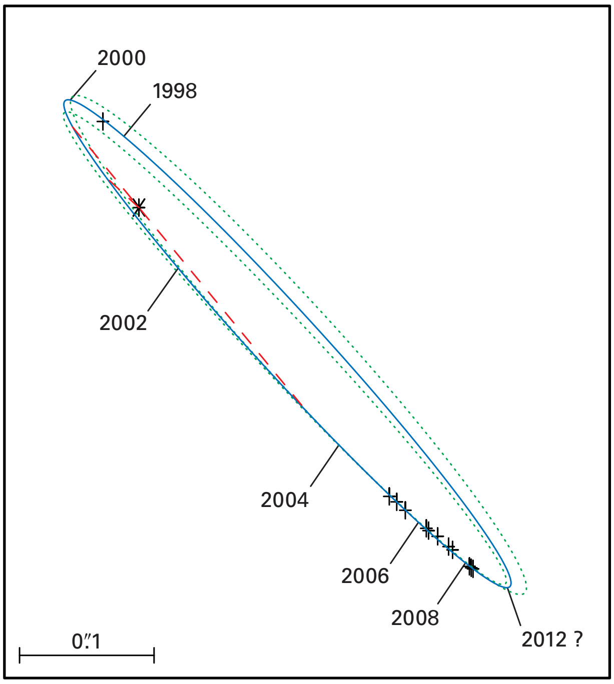
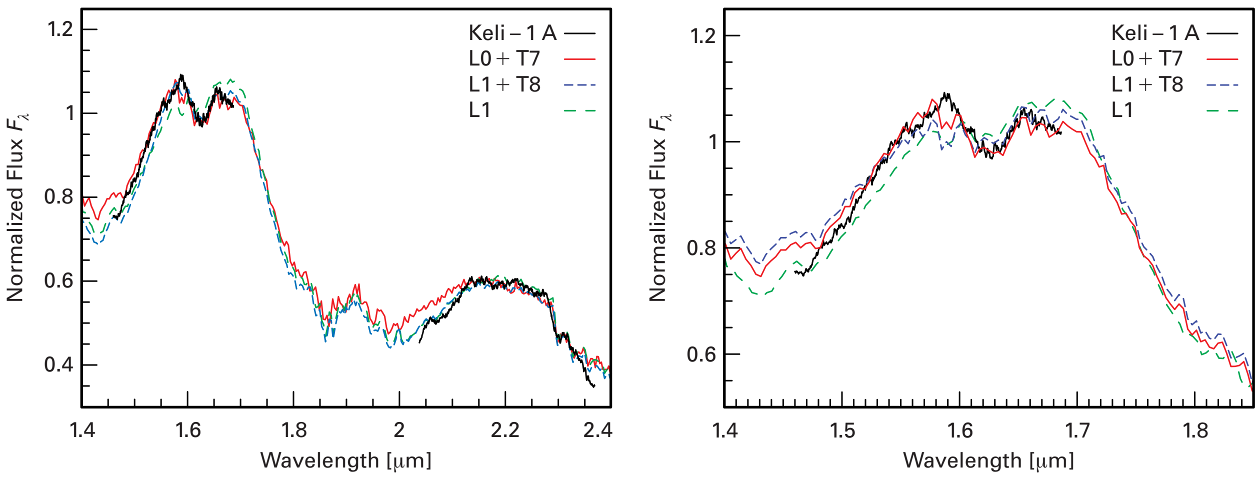


Fig. II.4.2: Orbit of Kelu-1A and B (blue). The range determined with 90 % confidence is shown by a green dotted line, the line of nodes is a red broken line.

A lithium absorption line was discovered in the joint spectrum of Kelu-1A and B as early as 1997. It can only be explained by present-day models if one of the two components has a maximum mass of 65 Jupiter masses. This means the other component would have 110 Jupiter masses and would be an M8V main sequence star, be-

Fig. II.4.3: *On the left*, the infrared spectrum of Kelu-1A in the *H* band and the *K* band; *on the right*, the section around the absorption at 1.62 µm. The best fits with two spectra of different types are also shown.



cause the upper mass limit for Brown Dwarfs is about 75 Jupiter masses. But the spectrum precludes the existence of such a star.

The MPIA researchers think the problem could be solved by assuming that Kelu-1A is really an unresolved binary Brown Dwarf. Kelu-1 would then be a system of three Brown Dwarfs. The following analysis of the spectra supports this hypothesis.

The spectrum of Kelu-1A in the near infrared obtained with NACO (Fig. II.4.3) is quite a good match for a Brown Dwarf of the spectral type L0 to L1. Atypical for L0, however, is a marked absorption at the 1.62 μm wavelength. Such a feature is usually only found with T-dwarfs, where it is caused by CH_4. The astronomers therefore tried to explain the spectrum as the sum of two different spectra. They combined one spectrum from objects in the spectral class M8 to L4 with one spectrum from T2 to T8. The best match was obtained by superimposing the spectra of an L0.5 dwarf and a T7.5 dwarf. In this case, the more luminous component would be some three to five classes of magnitude more luminous than the less luminous companion, depending on the wavelength.

The spectrum of the second component Kelu-1B presents even more problems because it has a »hump« at 1.6 μm which is atypical of Brown Dwarfs. At present, only two other Brown Dwarfs of type L0 and L6 are known to have this peculiarity. The cause of this structure is unknown, but an unusually high abundance of heavy elements ("metals") and the presence of dust clouds in the atmosphere or a low gravity seem to be possible causes. The MPIA astronomers classified Kelu-1B as a peculiar Brown Dwarf of type L3 pec. In any case, further research is necessary to explain these mysterious spectral features.

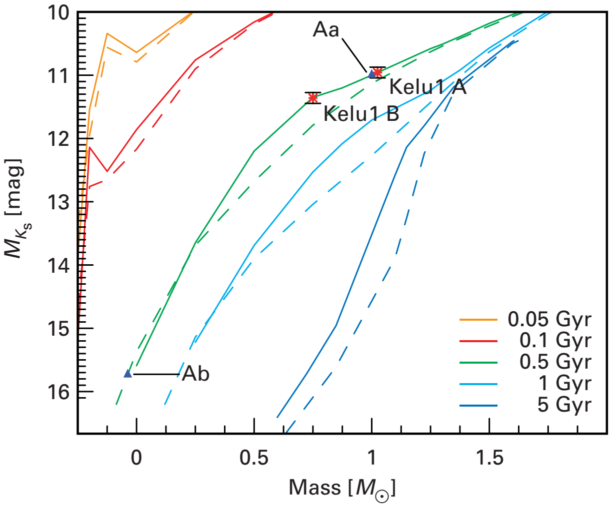
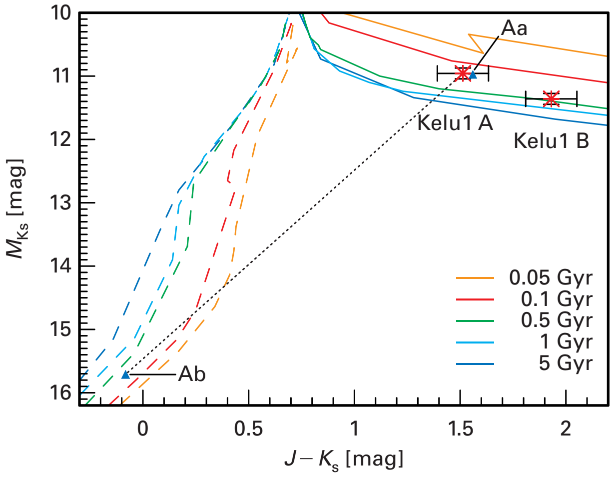


Fig. II.4.5: Evaluation of the masses by comparing the measured absolute luminosities with model calculations for Brown Dwarfs of different ages. Kelu-1Ab has very little significance here either.

Fig. II.4.4: Color-magnitude diagram with evolution paths (isochrones). The values for Kelu-1A and Kelu-1B have been added. If Kelu-1A is separated into two components, the lower mass companion Kelu-1Ab makes hardly any contribution at all to the total value.



Age and Mass Values – Test of Evolution Models

The results described so far could then be used to test evolution models for Brown Dwarfs. As was mentioned at the beginning, the age of the system is an important parameter. In the absence of any further clues, such as the affiliation with a star cluster of known age, researchers have to rely on theoretical evolutioary paths (isochrones) in a color-magnitude diagram, for example. Earlier models predicted Kelu-1 was between 100 million and one billion years old. Entering the newly obtained values into such a diagram produces a somewhat narrower range of between 300 and 500 million years (Fig. II.4.4).

It was very interesting to then compare the mass values obtained by dynamic methods with the masses derived from models. As Fig. II.4.5 shows, with the magnitude measured in the K_S band (at 2.15 μm) and a maximum age of 500 million years, the model suggests a mass of about 61 Jupiter masses for Kelu-1A and 50 Jupiter masses for Kelu-1B. Even if 18.5 Jupiter masses are added for the third component Kelu-1Aa corresponding to its luminosity, the result is a total mass of only 130 Jupiter masses – significantly less than the dynamically obtained value of 177 Jupiter masses.

Kelu-1 is not the only case in which the models give too low a mass. In 2005, MPIA astronomers derived a dynamical mass of 93 Jupiter masses for the low-mass object AB Doradus C, while the models produced a mass only half this value (Annual Report 2005, Chap. II.2). A similar discrepancy also seems to exist for the two Brown Dwarfs Epsilon Indi Ba and Bb.

It is therefore quite apparent that the numerical models for Brown Dwarfs need to be significantly improved. It is suspected that atmospheric processes such as the formation of dust clouds play an important role here. Kelu-1 is extremely well suited to the investigation of these issues. Further observations are required. The researchers at the MPIA want to try to test their suspicion that a third component exists. This can be accomplished with high-resolution infrared spectra of Kelu-1A. It should then be possible to use the Doppler effect to detect the orbital movement of the invisible companion. Additionally, the orbit of the two main components must be tracked further because it is still not known with sufficient accuracy.

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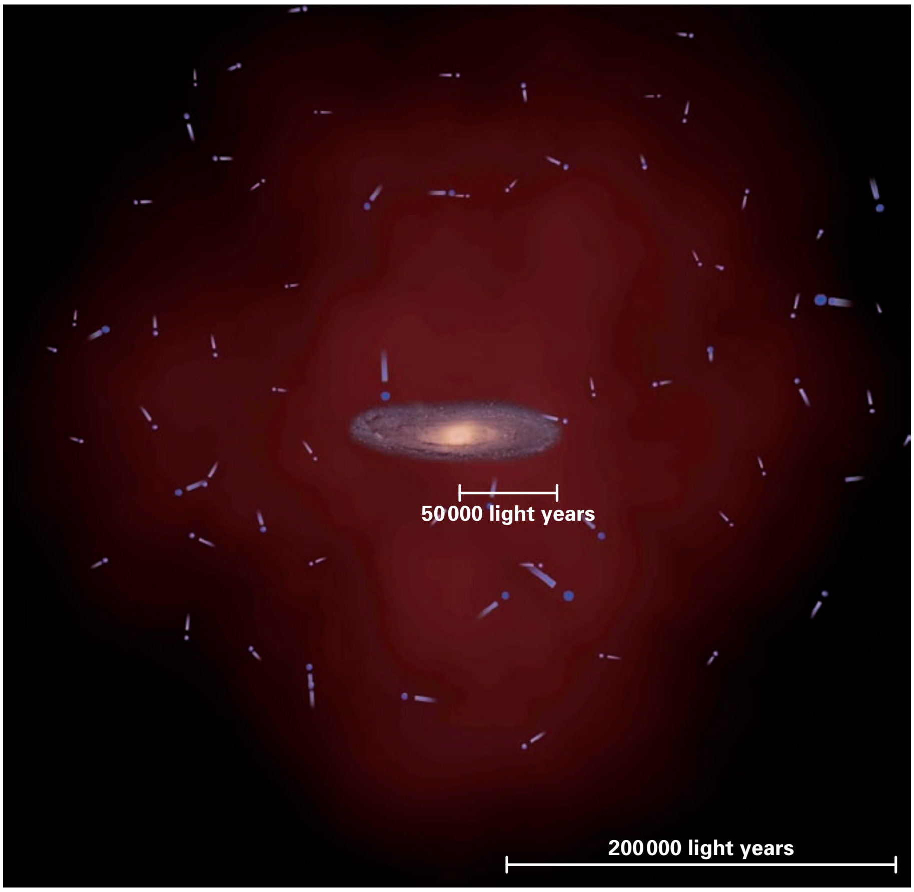
II.5 The Milky Way – a Lightweight After All

Gravitation is the dominant long-range force in the universe, making the mass of a celestial body is one of its fundamental astrophysical characteristics. This applies to planets and stars as well as galaxies. A number of difficulties are encountered when trying to determine the mass of our own Galaxy, however. It is comprised mainly of dark matter, which cannot be observed directly. A group of astronomers headed by the MPIA has measured the velocity of the stars in the galactic halo and thereby derived the most accurate value to date for the total mass of the galaxy: The region within a radius of 200 000 light years contains 4×10^{11} solar masses. An extrapolation to 800 000 light years leads to 10^{12} solar masses. This result shows that the mass of the Milky Way has previously been significantly over-estimated. It also proves that our Milky Way has been extraordinarily efficient at forming stars.

According to current ideas on how galaxies form, condensations of the cold, dark matter initially increase in size before acting as “gravitational traps” for the normal baryonic matter. This means that the visible parts of the galaxies formed in the centers of large haloes of dark matter that still surround them. The Milky Way halo is 10 to 20 times larger than the distribution of stars at its center.

It is difficult to determine the mass of the Milky Way and its halo of dark matter as we ourselves are inside this system. In 1999, astronomers derived a total mass of 1.9×10^{12} solar masses from observations of 27 satellite galaxies and globular clusters. Four years later, a different group arrived at a mass of about 2×10^{12} solar masses after analyzing eleven satellite galaxies, 137 globular clusters and 413 stars in the solar neighborhood. In 2007, the analysis of a group of high velocity stars produced a mass of 1.4×10^{12} solar masses. The uncertainty of all these mass determinations is a factor of 2 to 3, however.

Fig. II.5.1: The Milky Way of normal, visible matter is embedded in a large, high-mass halo of dark matter (shown here in red). The stars on the blue horizontal branch (BHB) which were investigated as part of the SDSS study presented here orbit the visible galaxy at large distances.



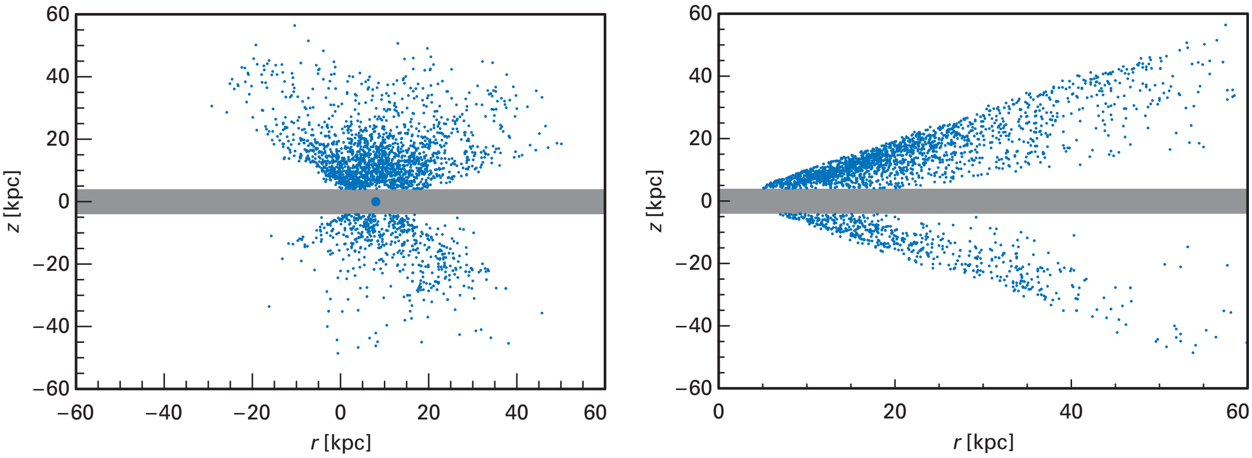


Fig. II.5.2: *Left* – Distribution of the BHB stars investigated in the x-z plane of the Milky Way, whose motions are used to estimate the Milky Way mass. *Right* – Distances of the BHB stars from the galactic center. The strange spatial distribution reflects the survey volume of the SDSS.

The team headed by Xiang-Xiang Xue, a researcher from the National Astronomical Observatory of China, who was studying for her doctorate at the MPIA, used stars in the halo of the Milky Way, which are on the blue horizontal branch (BHB) of the Hertzsprung-Russell diagram, for their new study. These high-mass, luminous stars are at a late stage of their evolution, they are burning helium in th eir core, and their absolute luminosity is known. Their distance can therefore be determined quite accurately from the measurement of their apparent luminosity. The astronomers identified these stars in the archive of the SEGUE survey (Sloan Extension for Galactic Understanding and Exploration) which is part of the second Sloan Digital Sky Survey (SDSS-II).

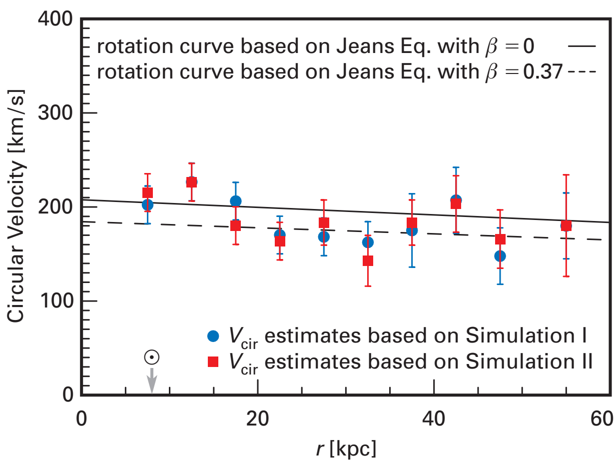
In order to identify the BHB stars, the astronomers evaluated the spectra of some 10 000 possible candidates and identified them by means of a detailed analysis of their absorption lines. A total of 2401 stars ultimately remained at a distance of up to 200 000 light years from the galactic disc, and their radial velocity could be determined from the SDSS spectra with an accuracy of at least 30 km/s (Figs. II.5.1 and II.5.2). The distances were obtained from the color and the spectral information. This is by far the largest homogeneous sample of stars in the outer regions of the galaxy that has ever been used to determine the mass of the Milky Way.

The task ultimately consisted of determining the mass profile of the Milky Way halo and the virial mass of the halo from these distances and velocities. The astronomers solved this problem by combining their measured data with two numerical simulations that simulated the formation of the Milky Way inside the halo of dark matter. Effects such as gas dynamics and star formation were also included.

The astronomers used these two simulations to produce kinematic "pseudo-observations" of simulated halo stars, as it were, and then posed the following question: For which mass profile of the haloes of dark matter in the simulations are the radial velocities of the simulated halo stars in agreement with the actual observations? By comparing the simulation and the measured data the astronomers were able to determine the most likely mass distribution in the Milky Way halo which is traditionally described by the circular velocity of its stars.

The result of both cosmological simulations over a range of distances between 30 000 and 200 000 light years (corresponding to 10 and 60 kiloparsecs) is shown in Fig. II.5.3. This is therefore the first time the rotation curve of the Galaxy has been determined at such large distances from the galactic center and with such high accuracy. A striking feature is a slight decrease in velocity from 220 km/s to about 175 km/s from the locus of the

Fig. II.5.3: Estimate of the Milky Way's mass profile, expressed by the circular velocity derived from the data using the two simulations (solid circles and squares). The graph shows the calculated values for two models with isotropic (= 0) and anisotropic (≠ 0) velocity distribution of the stars. The sun is located at $r = 8$ kpc.



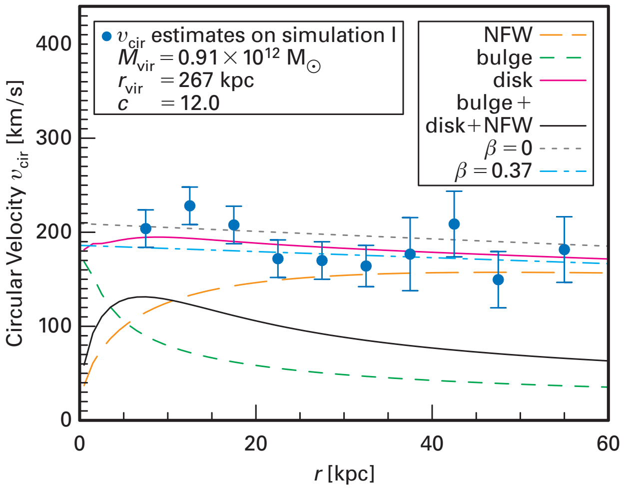


Fig. II.5.4: Circular velocities obtained (example for one of the two simulations) compared to models for the stellar disk (disk), the stellar bulge (bulge) and a dark matter model (NFW, after Navarro, Frenk and White).

A comparison of the total mass determined with the stellar mass measured independently shows that almost half the baryons in the Galaxy have been used in the formation of stars. This is twice as many as in other comparable galaxies. Our Milky Way has thus been especially efficient at forming stars.

If confirmed, this result would have far-reaching consequences for the dynamics of the satellite galaxies. A particular question that arises is whether the Magellanic Clouds, for example, have always been bound to the Milky Way. Moreover, the new mass value also has implications for cosmological models which are concerned with the motion of the Milky Way relative to the Andromeda galaxy. In contrast to the general recession of the galaxies as a result of cosmic expansion, these two galaxies are approaching each other.

sun to the greatest distance. Fig. II.5.3 shows how the result is derived for the mass of the Milky Way inside a radius of 200 000 light years. (This is the maximum distance at which velocities have been measured.) The astronomers obtained a value of 4.0×10^{11} solar masses with an accuracy of about 20 %.

The region contributing to the virial mass extends much further than the 60 kiloparsecs, which is the limit of the observational results. The astronomers were able to mathematically determine a virial mass from their data by entering the value obtained within 60 kpc into the cosmological simulations and using the models to extrapolate to a distance of up to 290 kpc. This method led to a virial mass of 1.0×10^{12} solar masses with an accuracy of between 20 % and 30 % (Fig. II.5.4). This result is considerably more accurate than earlier mass determinations and is at or below the lower limit of the bandwidth of all earlier estimates.

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II.6 The Unusual Progenitor Star of the Supernova 2008S

Since the explosion of the supernova 1987A in the Large Magellanic Cloud, whose progenitor star was the first that could be determined, astronomers all over the world have succeeded in identifying the progenitor stars of ten or so other supernovae. Such identifications remain difficult but are very important for the theory of star formation and supernova theory, especially since, in some cases, unexpected types of progenitor stars emerge. This was again the case with the core collapse supernova 2008S in the spiral galaxy NGC 6946. An international team of astronomers, including several from the MPIA, discovered a progenitor star with a mass of only around ten solar masses on images recorded with the Spitzer Space Telescope. This raises the question as to whether SN 2008S is a »real« supernova at all, or only the very strong eruption of a luminous blue variable star (LBV).

Fig. II.6.1: The galaxy NGC 6946 in the visual spectral range, recorded in May 2007 (before the supernova explosion) with the Large Binocular Telescope (LBT).

Most progenitor stars of core-collapse supernovae have been found in archive images recorded with the Hubble Space Telescope. It turned out that red supergiants with masses between 8 and 20 solar masses explode as Type II-P supernovae. Most core collapse supernovae are of this type. There are, however, some completely different, unexpected cases. The progenitor star of SN 1987A in the Large Magellanic Cloud was shown to be a blue supergiant with 20 solar masses, and in the case of SN 1993J of Type IIb in M 81, a red supergiant in a binary star system exploded.

The rarest group is the Type IIn group. The spectra of these supernovae exhibit strong Balmer lines, while their slowly diminishing light curve provides clear indications of an interaction between the shell they have shed and hydrogen-rich circumstellar matter. Archive images have been used to classify the progenitors of supernovae SN 2005gl and SN 2006jc, both of Type IIn, as luminous blue variables (LBV). One of them had a luminosity eruption which resembled Eta Carinae two years previously. It was therefore assumed that high-mass stars in particular end as Type IIn supernovae.

On February 1, 2008 the American amateur astronomer Ron Arbour discovered the supernova SN 2008S in the spiral galaxy NGC 6946, which is only 18.3 million

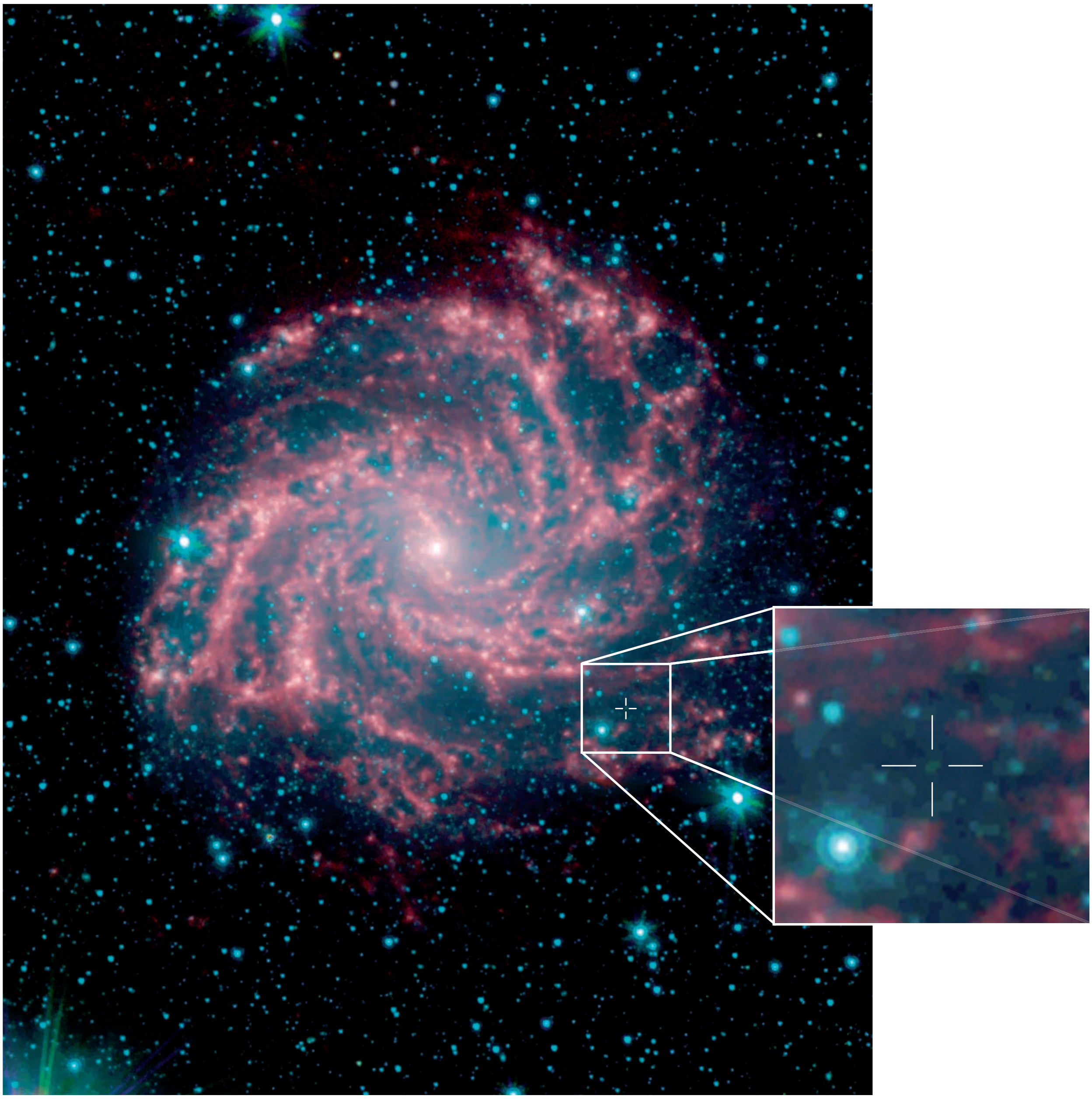

Fig. II.6.2: Infrared image of the galaxy NGC 6946 recorded before the supernova explosion with the Spitzer Space Telescope. The crosshair in the magnified image marks the suspected progenitor star of the supernova. (Image: Nasa, JPL-Caltech, R. Kennicutt/University of Arizona, Sings team) light years away, and this again presented an opportunity to track down the progenitor star of a Type IIn supernova. The observations revealed that the light of the supernova was strongly reddened, and in a later phase spectral lines such as the [CaII] emission appeared.

The relative proximity of NGC 6946 opened up the possibility of finding the progenitor star in archive images if it was a high-mass supergiant, as assumed. Anna Pasquali of the MPIA had carried out a thorough study of the spiral galaxy with the Large Binocular Telescope (LBT) on Mount Graham in Arizona in the course of her research into star formation activity. Her images in the blue spectral range taken in May 2007 (225 days before the supernova explosion) thus offered a unique opportunity to find the progenitor of SN 2008S. However, at the supernova location no star could be detected within the 0.2 by 0.5 arcseconds large error ellipse (Fig. II.6.1 and Fig. II.6.3 top left). From this negative result the astronomers were able to derive the maximum absolute luminosities $M_U > -4.8$, $M_B > -4.3$ and $M_V > -3.8$.

Archived data from the Spitzer Space Telescope offered another chance to identify the exploded star. And this time the astronomers were indeed successful: Several images recorded between June 2004 and January 2007 showed a star at the location of the supernova (Fig. II.6.2). It could only be detected in the near infrared at 4.5, 5.8 and 8.0 μm (Fig. II.6.3) and over the obser-ving period there were no luminosity fluctuations which were greater than 10 %. It could not be detected at shorter or longer wavelengths, so it was only possible to derive upper limits for the luminosity. The source could not be identified on images recorded with the Chandra X-ray telescope, thus eliminating a bright X-ray binary star as the progenitor.

The three measured values and the upper limits from Fig. II.6.3 provide a spectral energy distribution that cannot be represented with one single black body spectrum. The infrared radiation can, however, be explained by a black body with a temperature of 440 K and a luminosity of 3.5×10^4 solar luminosities. These values suggest a spherical dust shell with a radius of about 500 light years which is heated by a star of 10 solar masses to $T = 440$ K (Fig. II.6.4).

The obvious strong decrease in luminosity in the wavelength region between 4.5 and 3.6 μm, where the source could no longer be detected, could be caused by relatively large dust particles. By making several further assumptions about the dust, and with the aid of a numerical model, the astronomers were able to estimate that the shell contains gas and dust with a mass of about one thousandth of a solar mass and that the star must have suffered an annual mass loss of at least 10^{-5} solar masses in order to form the dust shell.

In the Milky Way and the Large Magellanic Cloud, the values obtained for the progenitor star of SN 2008S are typically found for AGB stars and red supergiants, which are surrounded by dense dust clouds. If such a star had been the progenitor, it would have had an unusually low mass of only ten solar masses or so. The observational data available also indicate that the supernova itself had a relatively low absolute luminosity of $M_V \sim -14$ mag (after taking the extinction into account). Researchers therefore cannot exclude the possibility that SN 2008S was not a supernova but an extremely strong eruption of a luminous blue variable. Such an event can be mistaken for a supernova. It is then called a supernova impostor.

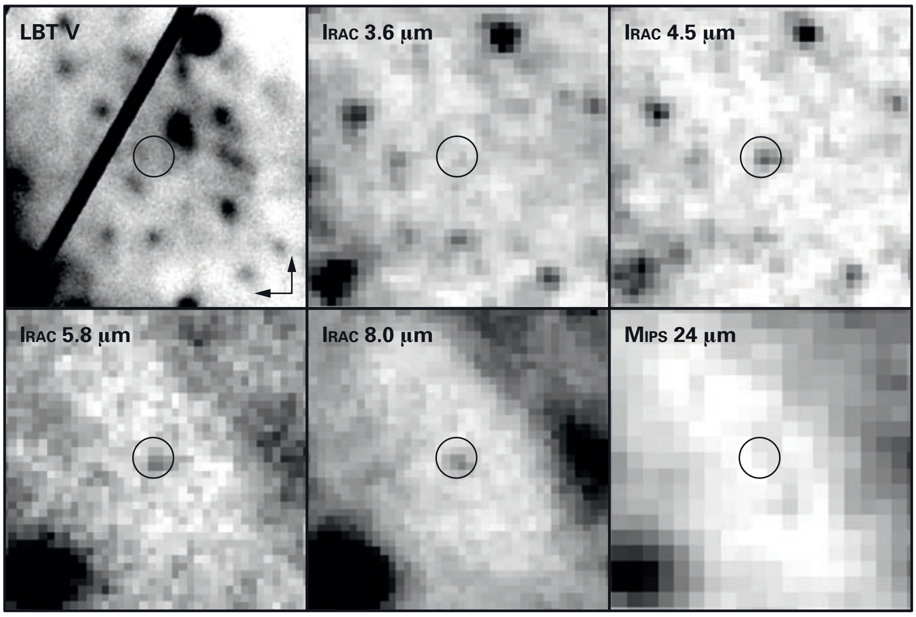

Fig. II.6.3: Images of the vicinity of SN 2008S before it exploded. The image top left was recorded with the Large Binocular Telescope in the visual range; all others were recorded with Spitzer at the wavelengths indicated.

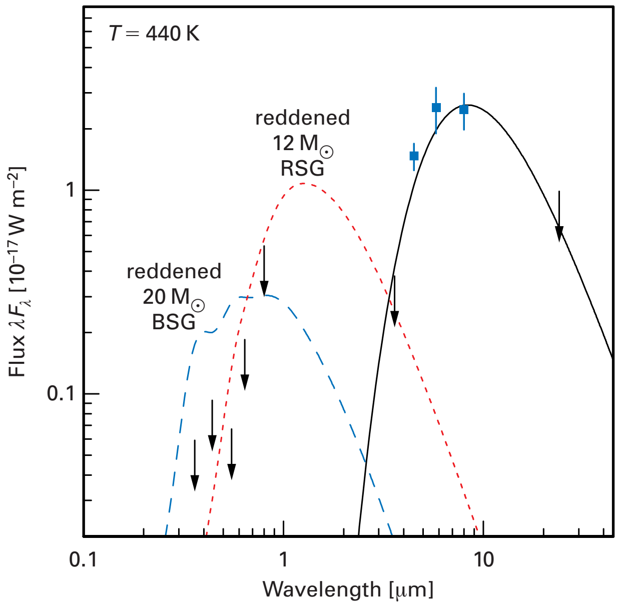

Fig II.6.4: Spectral energy distribution of SN 2008S's progenitor star. The infrared emission (blue squares) can be represented by the thermal emission of a black body at a temperature of 440 K. The dotted curve shows the black-body emission of a red supergiant of 12 solar masses, a luminosity of 3.5×10^4 solar luminosities and a temperature of 3000 K. The broken curve corresponds to the black-body emission of a blue supergiant with 10^5 solar luminosities and a temperature of 16 000 K. These were the values for the progenitor star of SN 1987A, which is one of the LBVs with the lowest known luminosity. The measured values of SN 2008S are all still below this curve. All values were calculated with a visual extinction of $A_V = 2.5$ mag.

In order to further investigate the nature of the exploded star, the object will be observed in as many wavelength ranges as possible because, in the near future, the first signs of an interaction between the stellar wind and the surrounding matter could appear.

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II.7 A Hyper-starburst 870 Million Years After the Big Bang

A large number of stars must have been created while the first galaxies were forming in the infant universe. Observations of this phase are still very rare, however, because of the great distances involved. It is thus all the more remarkable that an international team of astronomers headed by MPIA has succeeded in observing a spatially resolved region in the center of the most distant known quasar called J1148+5251, in which stars with a total mass of more than 1000 solar masses are formed every year. What we are presumably seeing here is the creation of the spherical star component that we observe in today's galaxies, and which we call the »bulge«.

The quasar J1148 + 5251 first came to the attention of astronomers working on the Sloan Digital Sky Survey (SDSS) because of its red color. (The MPIA is one of the survey's participanting institutions.) Follow-up observations with the Keck telescope on Hawaii, which yielded both sharper images and spectroscopic data, confirmed the suspicion that the object is a very distant quasar (Fig. II.7.1). In fact, with a redshift of $z = 6.42$, J1148+5251 is the current record holder – the most distant quasar yet observed. Its light takes more than 13 billion years to reach Earth; in consequence, observations show this quasar as it looked when the universe was a mere 870 million years old. For astronomers, this is a particularly interesting time: the transitional period between the "dark", neutral era and the era of re-ionization, and J1148 + 5251 is one of the few known quasars observed at this stage of cosmic evolution. As for all quasars, the object's high optical luminosity originates from a disk of hot gas (accretion disk), which surrounds a central black hole. In this case, the black hole has a mass of between 1 and 5 billion solar masses.

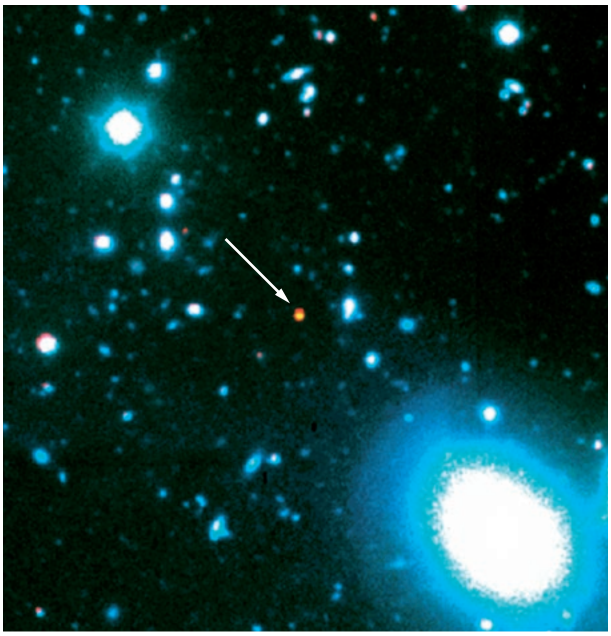
MPIA astronomers and their colleagues already observed this record quasar back in 2004, using the Very Large Array in Socorro, New Mexico. Using the spectral lines of CO gas as a tracer, they found at its core a large cloud measuring 4500 × 12 000 light years, with a total mass (predominantly in the form of molecular hydrogen) of 2×10^{10} solar masses (see Annual Report 2004, Chap. II.5). Another extraordinary thing about J1148 + 5251 is its high infrared luminosity of 2.2×10^{13} solar luminosities. In the past, this was at least partially attributed to intensive star-forming activity.

In order to measure the size of the star-forming region, and to deduce the star formation rate, the astronomers observed the quasar in the light of the 158 micron line produced by singly ionized carbon [CII] – an important indicator for ongoing star formation; due to the extremely high redshift of J1148 + 5251, this line is shifted to a wavelength of 1.17 mm. Therefore, the most powerful radio-telescope currently available for observations at and near this wavelength could be used: the IRAM interferometer on the Plateau de Bure in the French Alps. The angular resolution achieved, 0.23 × 0.31 arc seconds, corresponds to an area of 4000 × 5000 light years at the location of the quasar.

After a total integration time of 20 hours, the quasar could not only be clearly detected in the [CII] line, but also spatially resolved (Fig. II.7.2, center). The emission region has a diameter of 4900 light years and is located inside the larger CO- and H_2-cloud detected earlier. Its center is some 2000 light years north of the quasar's location (observed in the visible light). This offset is significant within the framework of measurement accuracy. While this offset remains unexplained, it provides a clear indication that the emission is not directly related to the central black hole.

With data of such high quality, the astronomers were even able to differentiate between the red- and blue-shifted parts of the [CII] region (Fig. II.7 right). With this information about the motion of the gas, it is possible to estimate the cloud's overall mass. The result agrees with the mass value calculated from the spectral line width in 2004.

Fig. II.7.1: In this image taken with the Keck telescope, the quasar J1148+5251 (arrow) is identifiable by virtue of its red color. (S. Djorgovski/Keck)



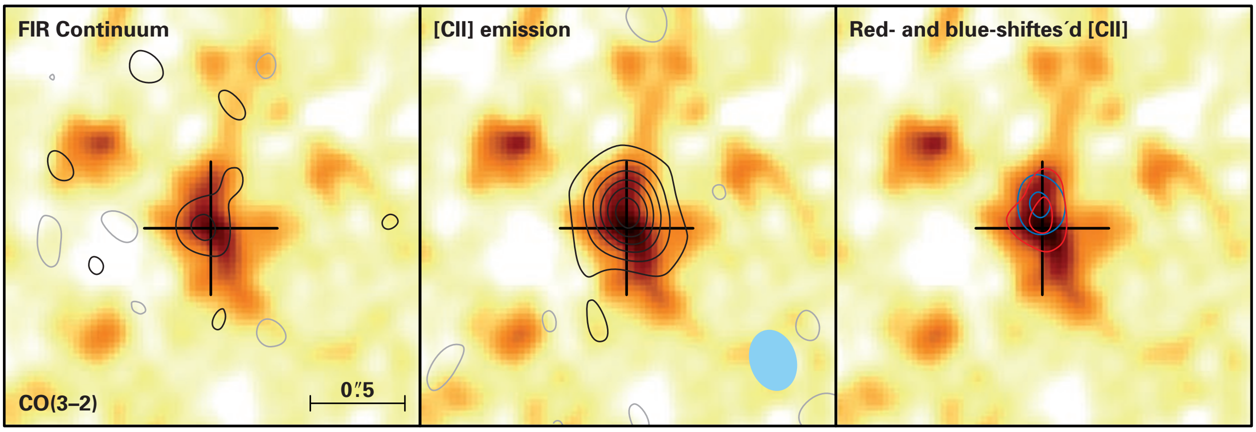


Fig II.7.2: Observations of the quasar J1148+5251 with the IRAM interferometer. *Left:* the continuum emission in the far infrared, in the *center* the [CII] line emission. *Right:* the red- and blue-shifted parts of the [CII] line, obtained by integrating velocity offset ranges from 75 to 175 km/s.

The cloud is also visible in the far infrared continuum around the [CII] line (Fig. II.7.2 left and II.7.3). At these wavelengths, it is centered around the position of the quasar. Still, if all of the infrared continuum radiation were caused by the black hole, one should be able to trace it to the spatially unresolved central region of the optical quasar. In reality, this is the case for only about half the continuum radiation. Very probably, the larger part of the radiation is indicative of ongoing star formation. If this is the case for half the observed luminosity, 1.1×10^{13} solar luminosities, this corresponds to stars being formed at a rate of 1700 solar masses per year.

The intensity of the continuum radiation is too low to be of use for measuring the star-forming region's size. The [CII] line, on the other hand, provides suitably high spatial resolution. With this additional information, one obtains a surface density of the star formation rate of 1000 solar masses per year and square kiloparsec, averaged over a region with a radius of 2500 light years.

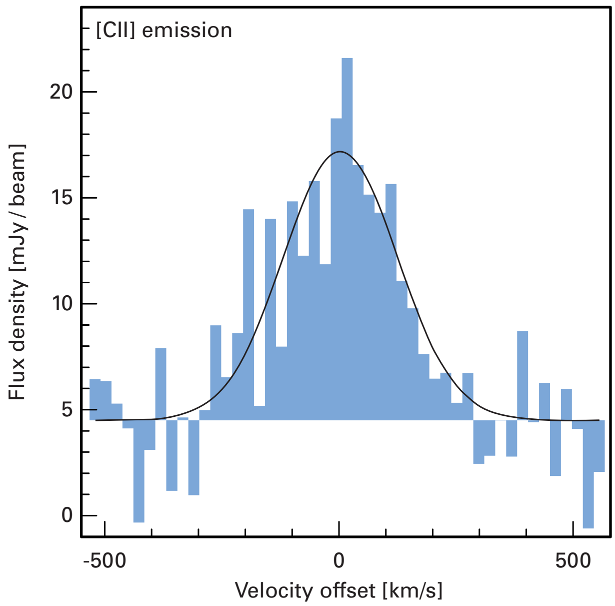
Star formation at the physical limit

Such an extraordinarily high rate of star formation is quite surprising. While similar values are found in objects that are much closer to us than distant quasars, notably in ultraluminous infrared galaxies (ULIRG) such as Arp 220, the star-forming regions in question are two orders of magnitude smaller. Within our own galaxy, extremely dense regions of star formation such as Orion KL reach comparable values; however, in those cases, the area is smaller still: eight orders of magnitude smaller than the star-forming region observed in J1148 + 5251.

Compared to these smaller star-forming regions, what is going on in J1148 + 5251 can justifiably be described as a hyper-starburst. In fact, the surface density value that was measured is very close to a fundamental limit imposed by the laws of physics. As new stars form, intense radiation is emitted which, in turn, drives the surrounding clouds of gas and dust apart. This makes it more difficult for further collapse to occur, and for additional stars to form. The result is an upper limit on the number of stars that can possibly be formed in a given volume of space in a given time, known as Eddington-limited star formation. The star formation density in J1148 + 5251 is very near to this limit.

Models which trace the processes of star formation provide an additional limit: a maximum value for the

Fig. II.7.3: Spatially integrated spectrum around the [CII] line. The line has a width (FWHM) of 287 km/s and a luminosity of 4.2×10^9 solar luminosities. The continuum at 4.5 mJy is also clearly detectable.



rate of star formation as a function of the efficiency with which the interstellar gas is transformed into new stars. Applied to J1148+5251, this formula yields an impressively high efficiency of 40 percent. A value of this order of magnitude is expected when two galaxies merge – a process that is known to trigger significant star formation activity.

The new observations indicate that this quasar galaxy's star-filled regions have grown from within: Initially, star formation is restricted to a core region; star formation rates are high. Over time, the star-filled central region grows in size – mainly by collisions and mergers with other galaxies – until it reaches the much greater size typical for older galaxies, such as the Milky Way or elliptical galaxies. This result is of great importance for the theoretical modeling of galaxy evolution.

As far as the [CII] line is concerned, this research has probably reached the technical limit; J1148 + 5251 cannot be observed with the Atacama Large Millimeter/Submillimeter Array (ALMA), as it is in the Northern sky. The next task for the astronomers is to try to detect emissions of C^+ in other quasars with a very high red shift.

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II.8 CO Gas in Highly Redshifted Quasars: Star Formation and the Effect of Black Holes

Carbon monoxide is the most important indicator of star forming regions. CO observations also offer the best opportunity to study the evolution of star formation in the course of cosmic evolution if one is successful in observing this gas in distant galaxies. An international group of astronomers headed by the MPIA investigated CO in two highly red-shifted (i.e. very distant) quasars. The results provide insight into the intense star forming activity in these young galaxies and also allow far-reaching conclusions on the effect of extremely high-mass black holes at their centers.

Molecular gas in the form of CO has so far been detected in more than 30 galaxies with redshifts greater than $z = 2$. This is where we see the universe at a time when it was 3.5 billion years old, about one quarter of its age today. Molecular gas in distant galaxies is usually found in the shape of a disk around their centers or, where two galaxies are merging, in the central regions and in the overlapping regions where the interstellar gas of both galaxies mixes. It is an important component of the matter from which new stars are formed. CO observations offer the opportunity to study the formation and evolution of stars and galaxies even in those early epochs.

Reconstruction of the gravitational lens image of a quasar

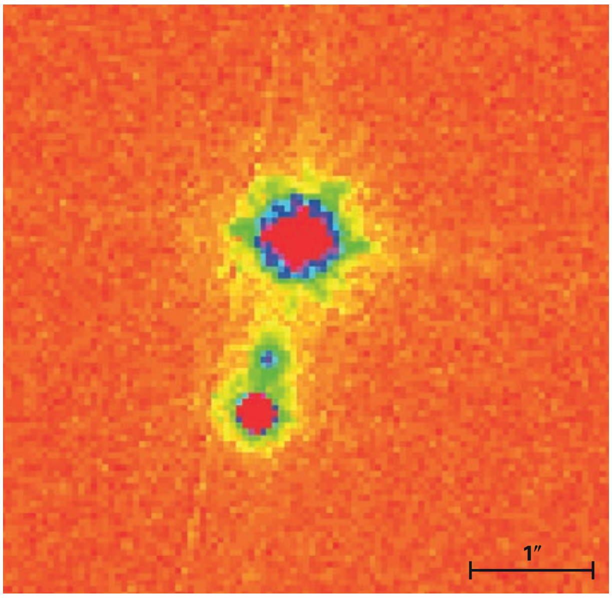
A group headed by Dominik Riechers, who is continuing the studies he started in Heidelberg as a Hubble Fellow at the California Institute of Technology in Pasadena, and Fabian Walter of the MPIA, used the Very Large Array (VLA) in New Mexico to observe a quasar at a redshift of $z = 4.12$ with an as yet unsurpassed spatial resolution and sensitivity. There is a very interesting story about how the object with the designation PSS J2322 + 1944 was discovered.

In 2002, astronomers discovered that this quasar appears at visible wavelengths in the form of a double image with a separation of 1.5 arcseconds (Fig. II.8.1). X-ray and infrared radiation was subsequently detected from it, suggesting not only a bright, active galactic nucleus but intense star forming activity as well. Things became particularly interesting in 2003 when Christopher Carilli from the National Radio Astronomy Observatory in New Mexico discovered that the image of the CO gas in the quasar galaxy appears as a complete ring. This is caused by the strong gravitational lens effect that is generated by a foreground galaxy located exactly in the line of sight from Earth to the quasar: The space curvature caused by this galaxy produces an annular image of the quasar, a so-called Einstein ring. Moreover, the gravitational lens effect increases the observed luminosity. It was this effect that made it possible to study the CO gas in detail.

In the visible and infrared spectral range, the bright core region hopelessly outshines the surrounding galaxy. In the radio frequency region, the rotational transition $J = 2 - 1$ produces a strong emission line of the CO molecule at a wavelength of 1.3 mm, but in the case of PSS J2322 + 1944 the large redshift causes this line to appear at 6.66 mm. It is very difficult to obtain sufficient spatial resolution at this long wavelength. Riechers and his colleagues achieved this by using the 27 antennae of the Very Large Array (VLA) in New Mexico.

A total of 70 hours of observation time under the best weather conditions were required to obtain what is currently the best resolved sky radio chart of PSS J2322 + 1944. It shows the structured Einstein ring with two intensity maxima close to the two visual images of the quasar (Fig. II.8.2). The task now consisted in reconstructing the spatial distribution of the CO gas from the observed Einstein ring, although the distance and mass of the foreground galaxy were not known exactly.

Fig. II.8.1: False-color representation of the two images of the quasar PSS J2322 + 1944 and the galaxy in between them, which acts as a gravitational lens. The image was recorded with the Hubble Space Telescope. (Photo: NASA/ESA)



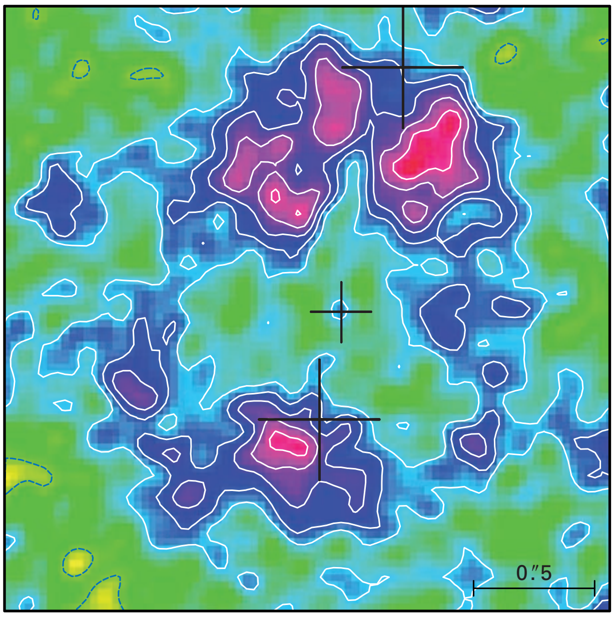


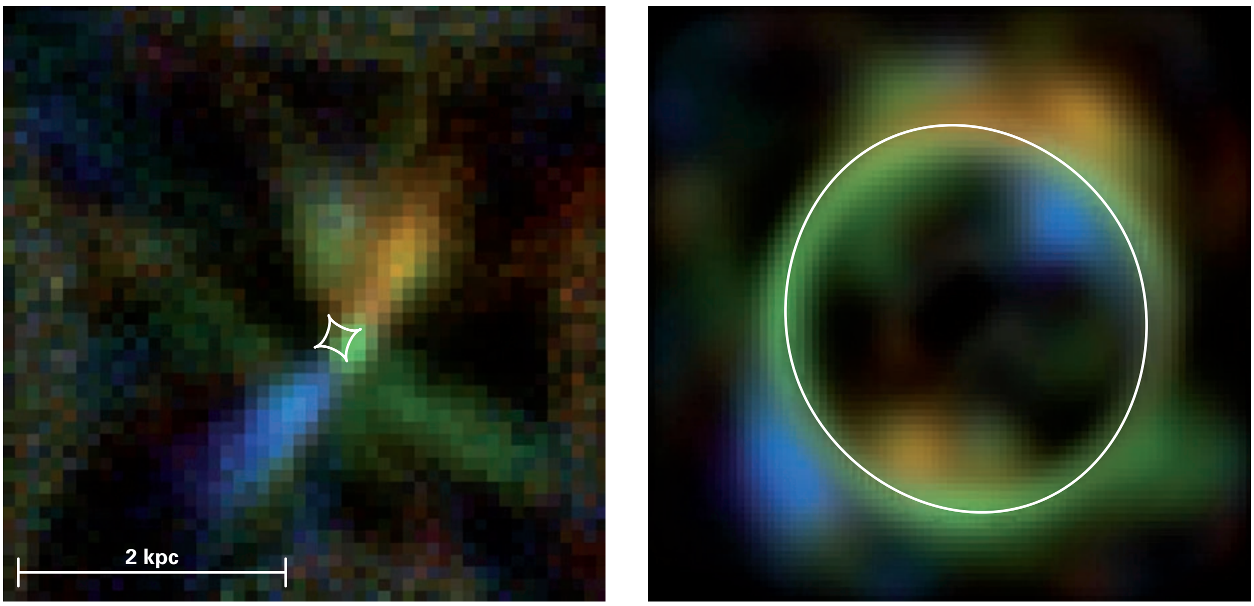
Fig. II.8.2: This sky radio chart of the quasar PSS J2322 + 1944 was obtained with the VLA by observing at a wavelength of 6.66 mm. The two large crosses mark the positions of the quasar images obtained from the image recorded by the Hubble Space Telescope; the small cross indicates where the foreground galaxy is acting as a gravitational lens.

These two values had to be obtained from model calculations. The astronomers were also able to observe the quasar at severalwavelengths within the broad CO emission line. The motion of the gas, which leads to a Doppler shift of the emitted wavelength, could thus be used as an additional criterion for the reconstruction. According to the model used, the lens-induced amplification factor for the luminosity varied between 3.9 and 6.4, depending on the Doppler velocity observed.

All of these data were entered into a computer model that Riechers and his colleagues used to produce the first reconstruction of the spatial distribution of the gas within such a distant quasar galaxy; they also used the Doppler effect to reconstruct the dynamics of the gas (Fig. II.8.3 left). One can recognize an elongated structure whose lower part is blueshifted while the upper part is redshifted. The astronomers interpret this as an extended structure with a length of 16 000 light years within the host galaxy of the quasar. The lower part is approaching us, the upper part is receding.

The velocity data, which reflect the gravitational potential of the galaxy, can be used to derive a dynamic total mass of at least 4.4×10^{10} solar masses. This contains the gas and also the dust, the black hole, the total stellar mass and any dark matter that may be present. The total mass of the gas (predominantly molecular hydrogen H_2) can be derived from the intensity of the CO emission and is found to be 1.7×10^{10} solar masses. This means about 40 % of the total available matter is present in gaseous form. This is a very high percentage: In normal spi-

Fig. II.8.3: False-color representation of the CO distribution. On the left, the true appearance reconstructed in the computer simulation is shown, on the right the Einstein ring as it appears in the sky. The three colors orange, green and blue mark the radial velocity of the gas receding, at rest and approaching us. The diamond in the image on the left marks the position of the gravitational lens If the assumption that here we see two merging galaxies is correct, the quasar with the black hole is in the node on the right above the diamond, and the center of the second galaxy is in the green node on the left. The elongated tails are the deformed galaxies as they can be observed in a similar shape in the Antennae Galaxies. .



ral galaxies, such as our Milky Way, it is less than one per cent, as they have by now converted most of the gas into stars. We see the Einstein ring galaxy as it was 1.5 billion years after the Big Bang, however. It is presumed that it didn't have sufficient time to convert much gas into stars.

The high luminosity of the CO emission and the large extension of the gas reservoir led the astronomers to conclude that the gas is strongly heated on a large scale. This is probably due to the presence of a large number of young stars. This would also explain the high infrared luminosity of the quasar mentioned above, which implies strongly heated dust on similar scales. Both pieces of evidence point to a very high star formation rate of 680 solar masses per year. The galaxy was thus able to convert a large part of its gas reservoir into stars within a mere 30 to 100 million years or so.

This outburst of star formation is probably triggered by the quasar galaxy colliding with another large and gas-rich galaxy. That galaxy can be seen in Fig. II.8.3 as a greenish gas component that appears slightly curved and is crossing the quasar galaxy. It is known from nearby interacting galaxies that during such collisions star formation is triggered and the central, high-mass black holes of the galaxies involved are "fed" with matter, glowing brightly as a consequence. This would explain the high luminosity of the quasar.

Quick growth of the black hole

In the end, PSS J2322 + 1944 offers the fascinating chance to test a correlation discovered several years ago between the mass of the central black holes in the galaxies and the mass of the surrounding stellar bulges. According to this correlation, the bulge mass is about 700 times the mass of the black hole. This is valid for different types of galaxies and covers many orders of magnitude of the mass range. The correlation is seen as a sign that there must be a causal connection between the evolution of the central black holes and the stars in their surrounding galaxies.

Was this correlation also valid in the young universe when the galaxies were just coming into being? There are as of yet no definite answers to this question because the mass determination becomes more and more difficult with increasing distance.

From the luminosity of the quasar, the astronomers determined the mass of the black hole to be 1.5×10^9 solar masses. For the stellar bulge they derived an upper limit of 4.4×10^{10} solar masses from the dynamic mass, as described, so that the mass of the bulge in this case only amounts to at most 30 times the mass of the black hole. The black hole in PSS J2322 + 1944 therefore has more than one order of magnitude more mass than the relationship in today's universe would lead us to believe. It appears that the black holes in high-mass galaxies initially grow faster than their surrounding stellar component in the bulge.

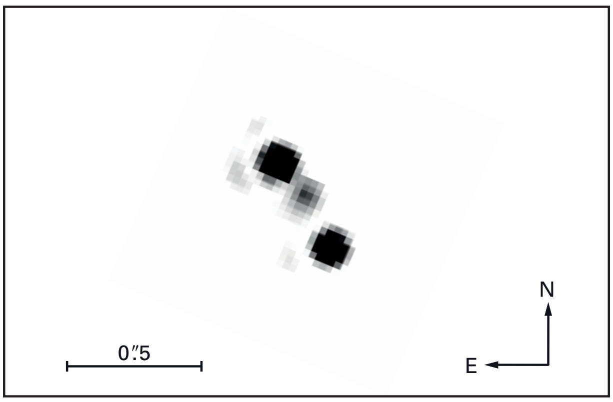
These conclusions have far-reaching consequences for models of galaxy formation and for cosmology in general. They are still the subject of controversy. The results obtained, however, are (within the framework of remaining uncertainties) in agreement with observations of other distant quasars.

Similar conditions in the quasar APM 08279+5255

The second set of observations were of the quasar APM 08279 + 5255 with a redshift of $z = 3.9$. It emitted the light we are now receiving 1.6 billion years after the Big Bang. An extremely high bolometric luminosity of 7×10^{15} solar luminosities was determined for this object, but it soon emerged that this value was produced by the amplification of a gravitational lens. Highly-resolved images show APM 08279 + 5255 as a triple image (Fig. II.8.4), where the galaxy in the foreground, which acts as a gravitational lens, has a very low luminosity, and thus has still not been identified. This also explains why the light amplification factor is not precisely known. The fact that about 20 % of the luminosity is emitted in the infrared is remarkable, and indicates thermal emission of dust and a very high star formation rate.

APM 08279 + 5255 is one of the best investigated objects in the young universe. In addition to the molecules HCN and HCO^+, strong CO emission was also detected from this source, although it was not possible to spatially resolve the emission region. This is where the group working with Riechers and Walter were again successful with the VLA, where the observation wavelength of the CO line $J = 1-0$ (rest wavelength 2.6 mm) was at 12.77 mm. At the same time, they observed the radio continuum emission of the quasar close to this line.

Fig. II.8.4: This picture, which was obtained with the Hubble Space Telescope, shows the three images of quasar APM 08279+5255. (R. A. Ibata et al., 1999).



After a total integration time of 55 hours it was possible to assign the line emission to two distinct regions separated by 0.31 arcseconds. They correspond to the two bright gravitational lens images of the gas emission in the central region of the quasar (Fig. II.8.5), which can also be seen in other wavelength ranges, such as the X-ray spectrum and in the far infrared. The continuum emission could also be spatially resolved, but appeared as an extended region with a maximum between the two CO emission regions.

From these new data and other known observations the astronomers constructed a consistent model with which they were able to describe the quasar. This produced a factor of 4 for the most probable light amplification factor by the gravitational lens. This result is in strong contrast to the value of 100, which had been used until then (derived from near infrared observations of the active galactic core). According to this model, the CO line emission comes from a central gas disk with a radius of 1800 light years which surrounds the active black hole. The total gas mass present in this disk (predominantly H_2) has been determined from the CO luminosity with an empirical conversion factor as 1.3×10^{11} solar masses. The mass of the black hole can be determined in different ways, with various methods pointing to a value of 2.3×10^{10} solar masses.

The new observations also enabled the researchers to derive a dynamic mass M_{dyn} of the disk from the radius of the disk – 1600 light years – and the CO line width of 556 km/s measured by Riechers and his colleagues. It turned out to be $M_{dyn} \sin 2i = 4.0 \times 10^{10}$ solar masses – where i is the unknown angle of inclination of the disk with respect to the line of sight. M_{dyn} comprises the sum of all components: Black hole, gas, dust, stars and any dark matter present in the central region of the galaxy. Since the dynamic mass cannot be less than the sum of the measured mass of the gas and the black hole, the angle of inclination i can be a maximum of 30 degrees. The astronomers used 25 degrees, which is a value in agreement with other observations of the quasar and also with a statistical analysis of galaxies at similarly high redshifts.

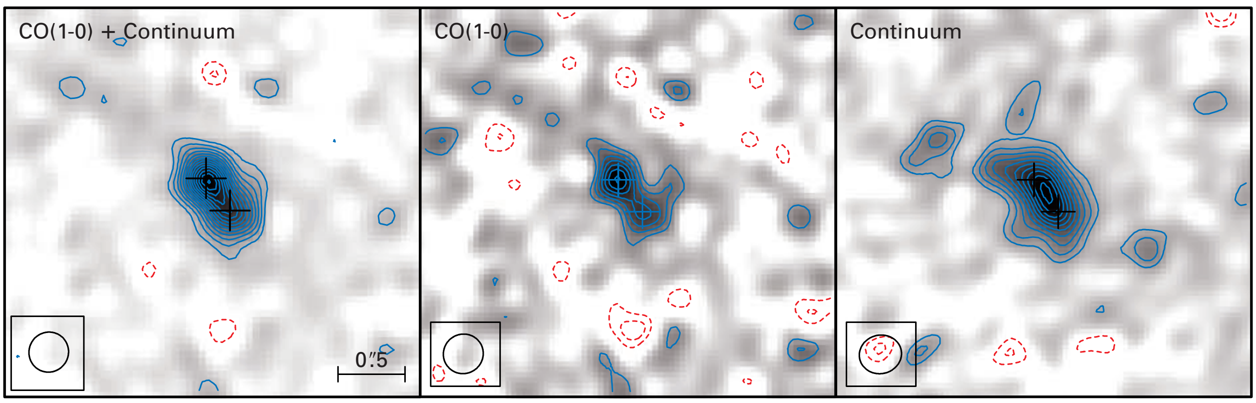
The mass of the central stellar bulge cannot be derived explicitly from the observations, but indirectly results from the dynamic mass after subtraction of the mass of the gas, the dust and the black hole. The astronomers thus obtained a value of 7.5×10^{10} solar masses for the bulge.

These values result in a value of only 3.4 for the mass ratio of the bulge to the central black hole. Although this value is strongly dependent on the light amplification factor used, even using the old value of 100 results in a mass ratio of a mere 50. In both cases, the stellar component (relative to the mass of the black hole) thus has a mass which is one or two orders of magnitude less than the relationship determined in today's universe would suggest. This result thus points in the same direction as the quasar PSS J2322 + 1944 described above: One has to conclude that the central black holes initially grew faster than the stellar bulges surrounding them.

These two results, which are supported by two further studies on highly redshifted quasars carried out by this team, therefore indicate that the mass correlation observed in our cosmic neighborhood is not a universal law, but is the end result of a long cosmic evolution.

The team wants to study the interesting quasars even more thoroughly in the future to gain a better understanding of their characteristics. It is also important to observe further galaxies at less extreme redshifts to obtain a more accurate determination of how the mass correlation evolves with the age of the universe. The results of this study need to be integrated into large cosmological computer models in order to more accurately determine their significance for the evolution of galaxies in the early universe.

Fig. II.8.5: Radio images using the VLA. *Left:* Superposition of the CO line and the continuum emission. *Center:* Pure CO line emission, showing the two separate images; the third, weak image (see Fig. II.8.4) is unrecognizable. *Right:* An extended source appears in the continuum.



The observations presented here prepare the way for future studies with the Atacama Large Millimeter/Submillimeter Array (ALMA) which, in the next decade, will provide the opportunity to observe these quasars and similar objects with higher sensitivity and spatial resolution.

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III. Selected Research Areas

III.1 Rotation and Accretion Disks in Massive Star Formation

Researchers at MPIA are deeply involved in studying massive star formation with observational and theoretical studies of the formation, evolution and properties of massive rotating circumstellar envelopes and disks. This chapter outlines several observational and theoretical studies we are conducting in this field.

High-mass stars play a crucial role in determing the energy budget and molecular/atomic content of the interstellar medium (ISM). Throughout their whole life-time they inject energy into their environment starting with molecular outflows during their formation, continuing with copious UV photons during their entire main sequence phase, and ending with the final supernovae events. Furthermore, they are the cradle of all heavy elements, and their formation is the only star formation mode observable in distant galaxies. The high-redshift submillimeter galaxies can only be understood through violent high-mass star formation events already in the early universe. In spite of their importance, it remains an observational and theoretical challenge to understand the actual physical processes leading to the formation of massive stars.

Fig. III.1.1: The Submillimeter Array (SMA) on Mauna Kea, Hawaii.

The main theoretical obstacle lies in the fast evolutionary time-scale because massive stars begin burning hydrogen before they finish accretion. In a simple spherical accretion model, the strong UV radiation from the ignited protostar should stop further accretion because of its strong radiation pressure, and hence very massive stars could not form at all. Obviously, this scenario has to be wrong because stars as massive as 100 solar masses are known to exist. The most likely way out of this problem is abandoning the spherical accretion and forming the massive stars via accretion through circumstellar accretion disks where simultaneously most of the angular momentum gets shed away via perpendicular energetic jets and outflows.

From an observational point of view, high-mass star formation is difficult to access because the target regions are on average far away (several kpc). Furthermore, massive stars form solely in a clustered mode making the spatial differentiation of several objects within a single forming cluster challenging. On top of that, massive stars form deeply embedded in their natal cold dust and gas cloud, prohibiting classical observational approaches at optical and near-infrared wavelength. These physical properties direct the observational approach: We have to use (sub-)millimeter interferometers which give on the one hand the required spatial resolution to resolve the important structures, and which on the other hand

are sensitive to the cold dust and gas of the regions. Fig. III.1.1 shows the Submillimeter Array on Mauna Kea as an example observatory.

The MPIA organized in 2007 a large international conference in Heidelberg dedicated solely to the formation of high-mass stars. The corresponding proceedings were published in 2008 in the ASP Conference Series (Volume 387, eds. Beuther, Linz & Henning). Studying rotation and massive accretion disks is one of the central topics within this field.

Properties of rotational structures – from Infrared Dark Clouds to High-Mass Protostellar Objects

To investigate the evolutionary changes of rotating structures and accretion disks in high-mass star formation, we selected several target regions as representative examples of their evolutionary class: one Infrared Dark Cloud (IRDC) for the earliest evolutionary stages, one High-mass Protostellar Object (HMPO) for the main evolutionary phase, and one hot core for chemically more evolved regions. This project is part of Cassandra Fallscheer's PhD thesis, and here we outline some results obtained for the IRDC and HMPO evolutionary stage.

The Infrared Dark Cloud IRDC 18223-3: The larger-scale environment of this region has previously been the object of several studies. However, we now resolved for the first time its small-scale structure with the Submillimeter Array in the light of 1.1 mm dust continuum emission and of several spectral lines. While the large-scale molecular outflow emanates from the region in the northwest-southeast direction, we have found a flattened structure perpendicular to that in the dust continuum emission, and a velocity gradient accross it in the spectral lines of CH_3OH and N_2H^+ (Fig. III.1.2). The overall size of this disk-like feature with an extent of approximately 25 000 AU is surpisingly large, much larger than expected sizes of a few 1000 AU or less. In contrast to this, the velocity spread across the structure is relatively small, of the order 3 km/s (Δ_v at center ~ 1.7 km/s). With these dimensions and a mass of about 120 $M_\odot$ this structure cannot be a stable Keplerian accretion disk: it rather reflects the rotating and infalling envelope that is flattened by the angular momentum conservation during infall. To test this scenario, we employed a simple infall model conserving angular momentum (Ulrich 1976, ApJ 210, 377). This model reproduces our observed structures well. These observations outline the rotational properties of massive infalling envelopes at the onset of high-mass star formation. We find large flattened structures, however with our spatial resolution on the order of 5000 AU (1.3 arcseconds at 3.7 kpc) we do not resolve a central Keplerian accretion disk. Since at larger spatial scales we observe a typical molecular outflow, and such outflows are only explainable via magneto-hydrodynamic accelaration from accretion disks, it is likely that

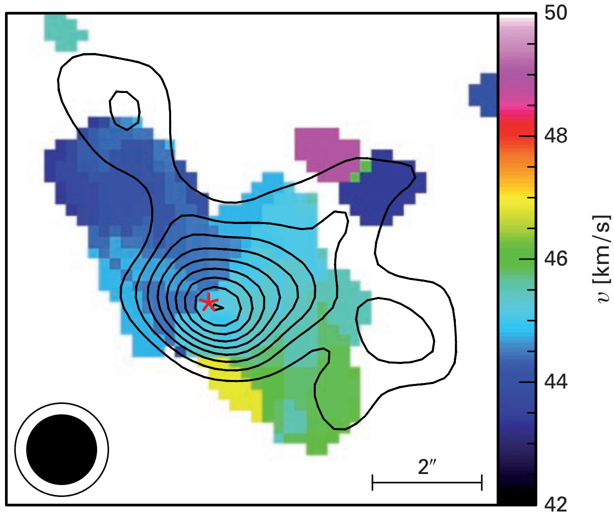
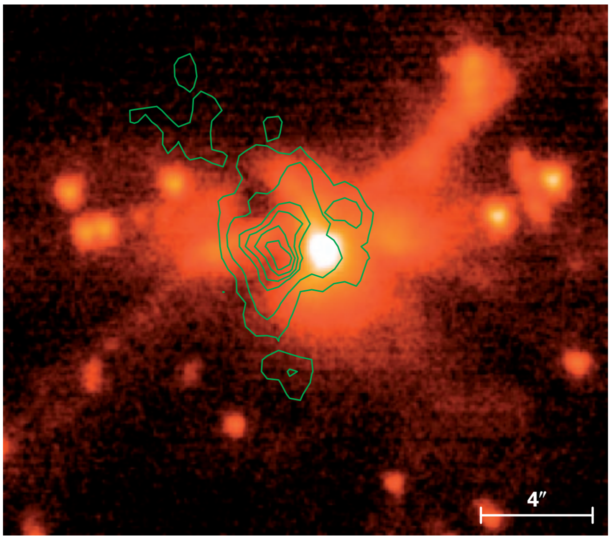


Fig. III.1.2: The color scale presents the intensity weighted velocity structure (1st moment) toward IRDC 18223-3 observed in CH_3OH. The contours show the 1.1 mm dust continuum emission. The corresponding molecular outflow is oriented perpendicular in the northwest-southeast direction.

a more typical Keplerian disk structure will be found at even smaller angular scales in future observations, e.g., with the Atacama Large Millimeter Array (ALMA).

The High-Mass Protostellar Object IRAS 18151-1208: The study of the small-scale structure around this HMPO – representing likely the main accretion phase for high-mass stars – again revealed an elongated structure in the 1.3 mm dust continuum emission perpendicular to the molecular outflow (Fig. III.1.3). Interestingly, we have not identified a molecule yet that traces the kinematics of the region well. The spatial extent of this structure is about 6000 AU, and the measured line width toward the center is on the order of 3 km/s, more typical numbers for an expected accretion disks. In this case, we now model the disk structure via Monte Carlo radiative transfer calculations. Input parameters are the disk density structure, the disk flaring, the disk mass, the disk size and several more parameters. The code (MC3D, Wolf 2003, CoPhC 150, 99) then self-consistently calculates the temperature structure and resulting radiation from optical to mm wavelengths. While quantitative parameters like the disk size or mass are orders of magnitude larger than those of typical low-mass disks, it is interesting that we find that the scaling properties from low- to high-mass disks apparently do not vary that strongly. The derived density and flaring structure for the disk structure in IRAS 18151–1208 is consistent with the corresponding structures from low-mass TTauri disks (e.g., the Butterfly star, Wolf et al. 2003, ApJ 588, 373). Although better statistics are needed to confirm this assessment, the current data and modeling indicates that while the quantitative parameters change considerably from low- to high-mass stars, their qualitative structure apparently remains remarkably similar.



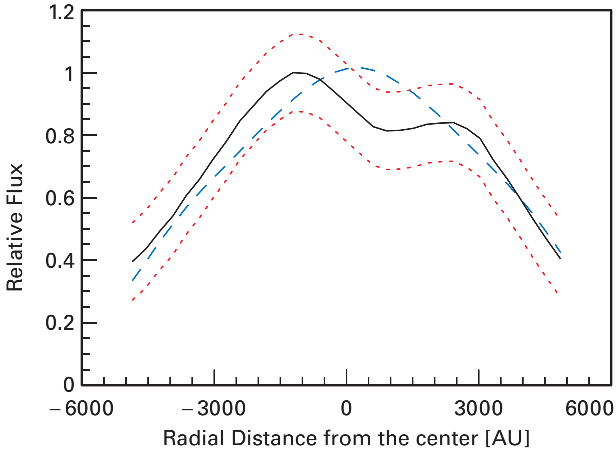


Fig. III.1.3: IRAS 18151-1208. The left panel presents in colour-scale the near-infrared shocked H_2 emission (from Davis et al. 2004), and in green contours the elongated 1.3 mm dust continuum emission elongated perpendicular to the outflow. The right panel shows as solid line a cut along the disk axis (northeast-southwest with dotted lines the 1σ uncertainties) and as dashed line our corresponding Monte Carlo radiative transfer model. We are mainly interested in the disk structure of the outer region.

A survey for rotation of southern hemisphere hot molecular cores

Although case studies like those described above are important for a detailed understanding of representative sources, for a more general understanding of rotational and disk properties a larger statistical base is required. Following this approach, we conducted a large program at the Australia Telescope Compact Array (approximately 60 hours at this interferometer) to investigate a sample of 12 high-mass disk candidates in highly excited ammonia lines (NH_3(4,4) and (5,5)). The rationale for the source and line selection is slightly different to the above. Since the disk rotational tracers strongly depend on the evolutionary stage, density and temperature structure of the sources, for a uniform study, sources at similar evolutionary stages need to be selected. Furthermore, we wanted to have a spectral line tracer that filters out the cold envelope and mainly traces the inner rotating structures. Since optical depth is an additional constraint we selected the highly excited NH_3 lines at cm wavelength (where the emission certainly is optically thin) that have excitation temperatures between 200 and 300 K. These are likely tracing only the innermost warm regions of the target sources. However, IRDCs and HMPOs like those discussed in the previous sections are not evolved enough to heat significant amounts of gas to the respective temperatures, and other sources need to be selected. Based on previous studies, we hence selected a sample of 12 hot molecular cores for this more statistical study (Beuther et al. in preparation).

Except for one, all other sources were detected in both NH_3 transitions (Fig. III.1.4 shows one example). From the eleven mapped sources, six show clear signatures of rotation and/or infall motions. These signatures vary from typical velocity gradients perpendicular to the outflows, to infall signatures in absorption against ultracompact HII regions, to more spherical infall signatures in emission. Although our spatial resolution is about 1000 AU, we do not find clear Keplerian signatures in any of the sources. Furthermore, we also do not find flattened structures. In contrast to this, in several of

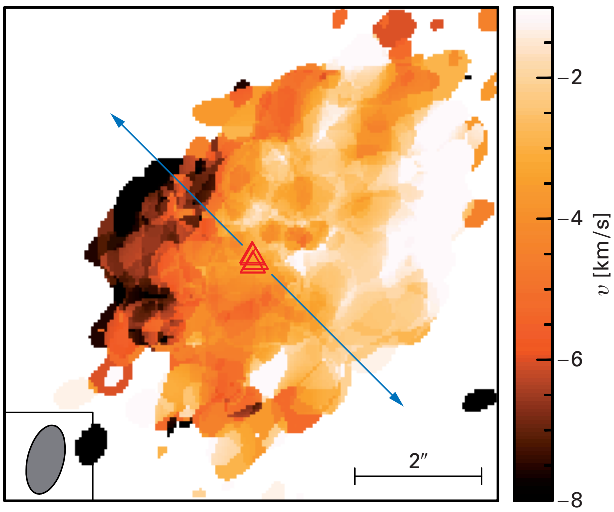


Fig. III.1.4: The colour-scale presents the intensity weighted velocity structure (1st moment map) toward the hot molecular core G351.77-0.54 measured in NH_3(4,4). The arrows show the orientation of the molecular outflow, the triangles mark the CH_3OH maser positions, and the synthesized beam is shown at the bottom-left.

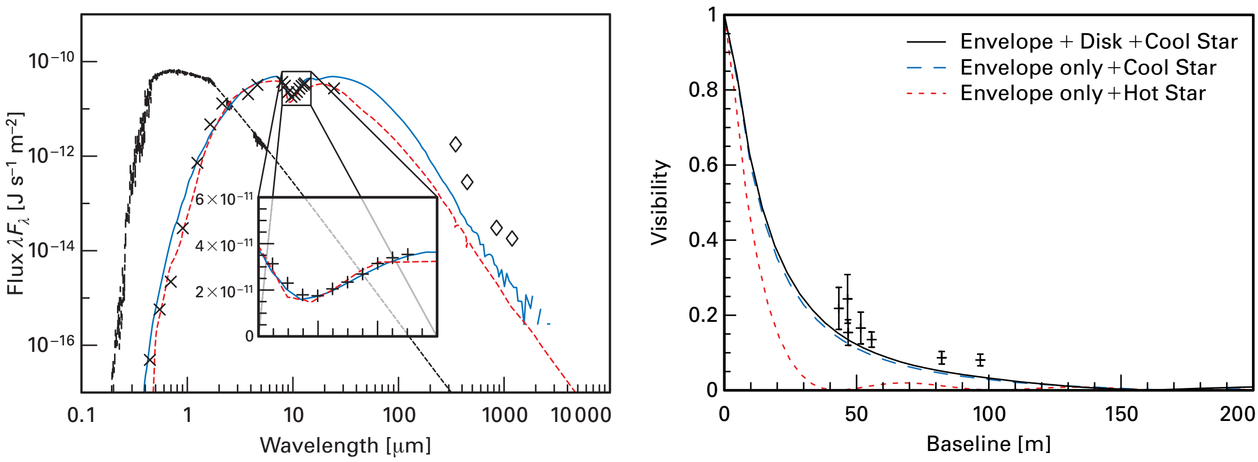
the sources with rotational signatures, the spatial structure is approximately spherical with sizes exceeding 10^4 AU, showing considerable clumpy sub-structure at even smaller scales. This implies that on average typical Keplerian accretion disks – if they exist as expected – should be confined to regions usually smaller than 1000 AU. It is likely that these disks are fed by the larger-scale rotating envelope structure we observe here. Furthermore, we do detect 1.25 cm continuum emission in most fields of view. While in some cases weak cm continuum emission is associated with our targets, more typically larger-scale HII regions are seen offset more than 10 arcseconds from our sources. While these HII regions are unlikely to be directly related to the target regions, this spatial association nevertheless additionally stresses that massive star formation rarely proceeds in an isolated fashion but rather in a clustered mode.

Towards the center of massive disks: MIR interferometry

While the studies presented so far investigate the rotating structures on scales of the order 1000 AU, corresponding to arcsecond resolution of the currently available (sub) mm and cm interferometers, we are still lacking information about the very small-scale structure on scales below 100 AU. To address the physical processes on these scales, we have set up a program to utilize the mid-infrared interferometer Midi at the VLTI to access the structure of the warm circumstellar dust around massive YSOs down to scales of 20 milli-arcseconds. Thirteen massive YSOs have been observed to date. Since Midi as a two-element interferometer does not allow to deduce images directly, but only visibilities (spectrally dispersed fringe contrast measurements), subsequent modelling is necessary for interpretation. We first use the SED fitting tool of Robitaille et al. (2007, ApJS 169, 328) to identify parameter setups from a large grid of models where the resulting continuum emission well fits the known SED of the observed YSO. Then, the underlying Monte Carlo radiative transfer code of Whitney et al. (2003, ApJ 591, 1049) is used to produce high-resolution mid-infrared maps for those model setups. Comparing the resulting synthetic visibilities with the observed ones indicates which models can simultaneously account for the observed SED and visibilities.

For the object M8E-IR our investigations are most advanced and lead to some interesting conclusions (Fig. III.1.5, Linz et al., submitted). M8E-IR is a prominent high-mass YSO well investigated at lower angular resolution since the 1980's. According to our best SED fit, the source comprises a very compact circumstellar disk (< 50 AU), a larger envelope with small bipolar cavities, and a cool central object ($T_{eff} \sim 4500$ K). We mention explicitly, that among the well-fitting models there are also configurations without a disk (axisymmetric flattened envelope plus outflow cavities only), but also including a cool bloated central star. This suggests that in the case of M8E-IR, the choice of the central object might actually govern the resulting visibility levels. The best-fitting models for M8E-IR in the Robitaille model grid feature central stars of 10 – 15 $M_\odot$ which are strongly bloated (120 – 150 R_{sun}) and, therefore, have relatively low effective temperatures. As demonstrated already by Kippenhahn and Meyer-Hofmeister (1977, A&A 54,

Fig. III.1.5: *Left:* The SED of M8E-IR, shown as crosses (measured fluxes) and diamonds (upper limits). The solid blue curve denotes the SED of the best-fitting radiative transfer model (disk + envelope + cool star). The dashed black line marks the unreddened SED of the bloated central star for this particular model. The red dashed line is the traditional model (envelope only + hot star). The inset is a zoom into the 8 – 13 μm region that underlines the quality of the fit. *Right:* Comparison of the well-models with bloated cool central star (black solid line and blue dashed line) and a standard configuration including a spherically symmetric shell and a hot central star (red dashed line). Obviously, the latter one is not compatible with the observed visibility data, shown here as plus signs including error bars.

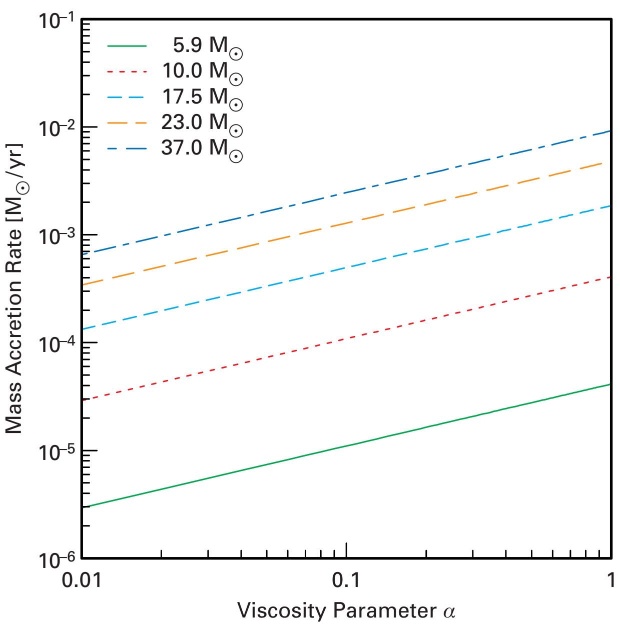


539), accretion with high rates onto main sequence stars can temporarily puff up such stars. Recent simulations confirm this assessment (Hosokawa and Omukai 2009, ApJ 691, 823; Yorke and Bodenheimer 2008, ASP Conf. Ser. 387, 189). These groups find that for accretion rates of the order 10^{-3} $M_\odot$/yr, the protostellar radius can temporarily increase to over 100 R_{sun}, in accordance with our findings. Interestingly, Mitchell et al. (1988, ApJL 327, L17) had revealed high-velocity molecular outflows from M8E-IR based on *M*-band CO absorption spectra and speculated on recent (< 120 yr) FU Ori-type outbursts for this object. If these multiple outflow components really trace recent strong accretion events, the central star certainly can have been affected.

The structure of massive accretion disks based on analytic modeling

After these observational characterisations of massive rotating structures, we now move to their theoretical investigations. The PhD thesis of Bhargav Vaidya is devoted in principle to study the driving and acceleration of jets and molecular outflows in high-mass star formation. However, to understand the boundary constraints of the outflows, we have to understand the accretion disks as well because the outflows are driven from their surface magneto-hydrodynamically. One difficulty arises from the fact that the outflows are launched from approximately the inner one AU of the accretion disk whereas we have observationally more or less no access to those scales, even with near- and mid-infrared interferometry as outlined in the previous section. Therefore, it is important to construct global disk models that on the one hand we can relate to observations of disks at hundreds to thousands of AU, and that on the other hand reveal the required boundary conditions within the inner few AU. In a relatively simple and straightforward approach, we employed the well-known disk model by Shakura and Sunyayev (1973, A&A 24, 337), that has already been extensively used for low-mass disks as well as disks around black holes, and adapted it to high-mass star formation. In addition to larger disk sizes and masses, as well as higher luminosities of the central protostars compared to low-mass disks, also the viscosity parameter α is higher – it has to be set to values between 0.1 and 1 to account for the large accretion rates required to form massive stars within their short time-scale of about 10^5 years. A few interesting characteristics of the corresponding disks can be deduced.

Fig. III.1.6: This plot shows the variation of the mass accretion rate with the viscosity parameter α. Due to viscous heating, the dust sublimation temperature is reached at radii around three times larger than for heating by the central star. The various lines are for different spectral types of stars.



While the necessary high accretion rates between 10^{-4} and 10^{-3} $M_\odot$/year are achieved, we find that the disk is gravitationally stable within the inner 100 AU whereas it is gravitationally unstable at larger scales. This is consistent with recent 3D hydrodynamic simulations that find fragmentation and the formation of multiple systems within the forming accretion disks (Krumholz et al. 2009), as well as with the stability of the disk associated with IRAS 18151-1208 (see above). Additionally, the temperature structure of the inner accretion disk is very important. As outlined in the introduction, radiation pressure on dust is a severe problem to form massive stars, independent of the geometry. Since the optical depth of the dust exceeds that of the gas by orders of magnitude, the sublimation radius of the dust is an important parameter to constrain whether radiation pressure is problematic. Because of the high viscosity parameter α and the high accretion rates, the temperature in the inner disk region is less dominated by the radiation of the central star, but the viscous disk heating itself dominates within the inner few ten AU. The model deduces that the dust sublimation radii based on this disk heating exceed exceed the dust sublimation radii due to the radiation of the central star by approximately a factor 3 – 4. This diminishes the radiation pressure problem strongly and hence allows continuous accretion in spite of the radiation pressure of the central star.

3D Radiation Hydrodynamic Simulations of Collapsing Cores and Disk Formation

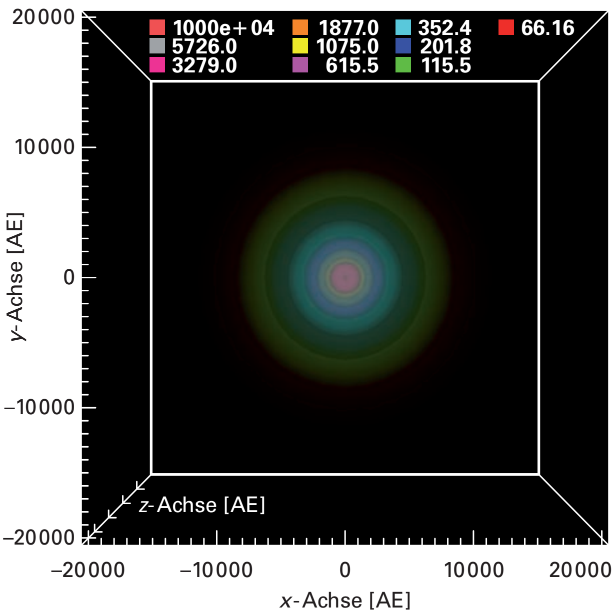
We are conducting 3D simulations of the formation of massive stars and the related phenomena like the formation of disks and outflows. Here we aim for a twofold goal. On the one hand we want to determine the star formation efficiency for a given cloud mass with the best physics possible. On the other hand we want to compare our observational findings with simulated intensity maps based on high-resolution 3D simulations, which will help to understand the physical processes of forming massive stars.

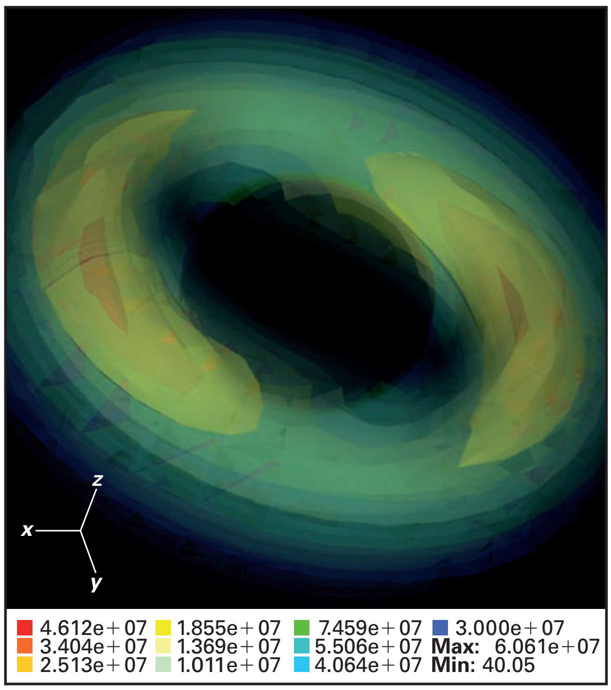
For the code development we have chosen the modern Magneto-Hydrodynamic (MHD) code Pluto that was originally developed in the jet community. It contains a variety of hydro and MHD solvers, all of a Godunov/Riemann solver type and it includes the possibility for using a spherical grid which we think is most suited for simulations that involve rotating material, e.g. collapsing clouds and forming disks. On spherical grids the angular momentum is easily conserved and using a logarithmic spacing in the radial direction concentrates the resolution automatically to the places of interest, e.g. the center of the grid, around the forming central object. Thus we have a much faster and simpler algorithm than using adaptive mesh refinement (AMR) on Cartesian grids. Where the latter is superior in the initial stages of collapsing turbulent clouds, when multiple centers will fragment, it is less suited at later stages, to treat the formation and evolution of disks.

Rolf Kuiper introduced radiation transport and self-gravity into the Pluto code as part of his PhD thesis. Especially the radiation transport has to be accurate and fast. Many published results suffered from too long computation times and thus only 2D simulations and small grids were possible. Or the radiation transport was too oversimplified and one had to use rather course grids even in AMR simulations. For that purpose Rolf Kuiper implemented our hybrid radiation scheme into Pluto. In this scheme first the radiation from the central region of the grid, e.g. the newly formed star is treated via frequency dependent ray tracing to get the proper radiation pressure and gas temperature especially around the dust destruction zone. The absorbed and reemitted radiation is then treated via flux-limited diffusion in the optical thick parts in the forming disk around the star. One important ingredient for the formation of massive stars, the radiation pressure that limits ultimately the mass of the forming objects, is also treated precisely enough as we showed in a comparison with the Monte Carlo radiation transport code by Cornelis Dullemond.

The diffusion part in our radiation algorithm includes the inversion of a matrix, which has to be done implicitly, usually a tough problem within parallel codes with distributed memory. Therefore, we added the PETSC library to the Pluto code, which are both parallelized and can use parallel clusters like the 256 processor PIA cluster of the MPIA theory groups. We tested the parallel performance of the generalized minimal residual method (GMRES) implemented in the PETSC code and showed its stability, scalability and reliability. The Poisson equation for the self-gravity of the gas is numerically related to the diffusion equation in radiation transport. Therefore we use the very same GMRES as mentioned above also for the gravity solver within Pluto.

Fig. III.1.7: *Left:* A snapshot (density) of our 3D radiation hydromagnetic simulation of a collapsing cloud. On the large scales (out to 20 000 AU) the collapsing structure is still merely spherical. *Right:* here we zoom into the center of the box. The plotted structure extends roughly from 150 to 300 AU. Parameters are like in the 2D simulation presented above, yet we show an earlier stage at about 20 000 years into the collapse.





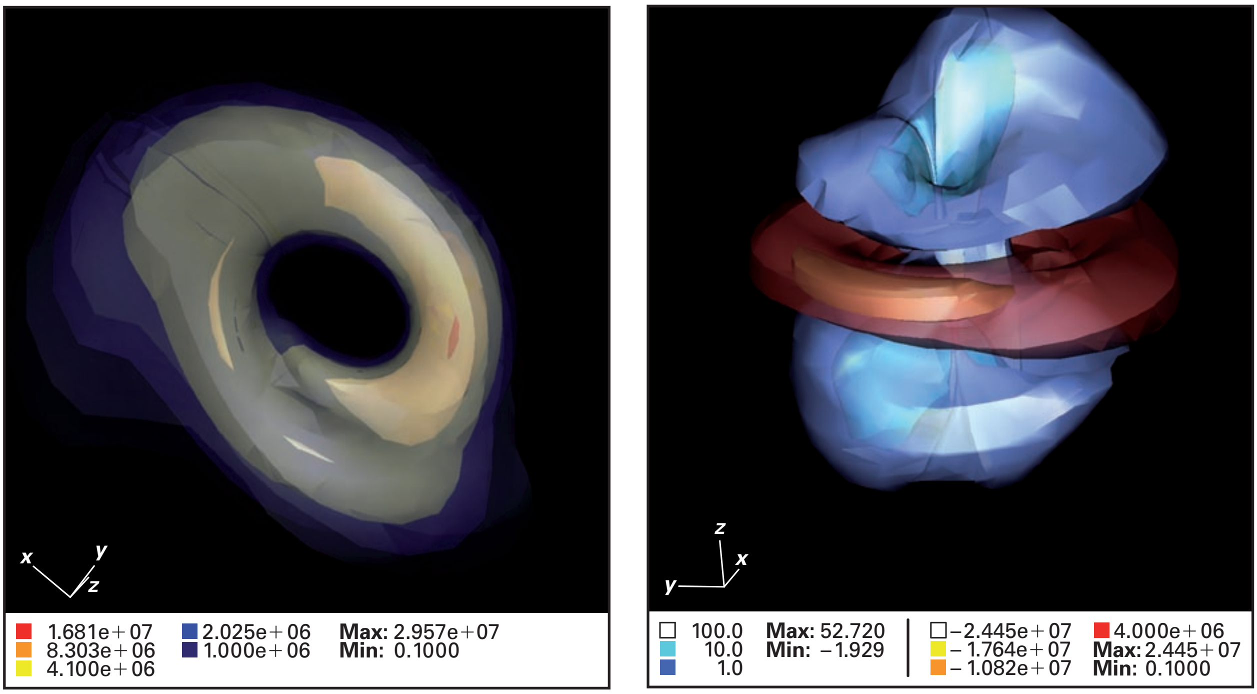
Meanwhile we also have performed 2D and 3D test runs of massive star formation. As a first step we compared our results to the published 2D work by Yorke and Sonnhalter (2002) where the collapse for various cloud masses was calculated on a staggered set of cylindrical grids. Radiation was treated without ray tracing yet with a multi-frequency diffusion Ansatz. The non-parallel code suffered greatly from the slow convergence of the solver, thus high-resolution simulations or even 3D attempts forbade themselves.

Similar to their standard setup we simulate the collapse of a rotating cloud of 40 000 AU in diameter. In contrast to Yorke and Sonnhalter we use a single centrally condensed spherical grid, which gave us a resolution of 40 AU per grid cell down to 80 AU from the star. Even more is possible, yet not needed for a comparison to the work in the literature, where the resolution was still a little worse, due to the linearly spaced cylindrical grid applied there. The mass and luminosity development of the star is followed with a dedicated evolution code for the star using the mass accretion as determined in the hydro simulation. We find an overall good agreement between both simulations in 2D, but a much better numerical performance, due to the improved radiation transport and the parallel modern matrix solver GMRES. We also find a very fast, radiation pressure driven outflow of hundreds of kilometers per second, blowing a cavity in the circumstellar still collapsing material.

Ongoing work will now push the resolution way beyond what was possible in Yorke and Sonnhalter and also move the grid closer to the star to search for a convergence of the models. Nevertheless 2D models will always suffer from the need that viscosity, e.g., angular momentum transport has to be parameterized and can not be studied per se. Also the evolution of non-axis-symmetric pattern due to self-gravity and radiation pressure is excluded, yet will play a role for the final mass of the central object and the possibility to form a stellar companion via fragmentation of the disk. Therefore we also have to go 3D. There we will also be able to study the role of the magnetic fields during the collapse phase, the turbulent phase of the disk and the generation and collimation of jets. The physics is already included now, yet to test the ingredients carefully, we first do 3D simulations of a non-magnetic cloud, like in the 2D cases, yet do not use any explicit viscosity to allow for the development of a self gravitating pattern in the disk and angular momentum transport via gravoturbulence.

We start with the same set up as for the 2D simulations, yet slightly perturbed from axis symmetry (Fig. III.1.7). Our grid has now a maximum resolution of 15AU per grid cell down at 80 AU from the star, yet still extends out to 20 000 AU. Also this simulation treats the full thermodynamics plus radiation transport and needed only a few hundred CPU hours for the studied low-

Fig. III.1.8: At a later stage, e.g., after 33 000 years an m = 1 mode has formed from the m = 2 mode and more mass has been accreted onto the star in the center. This m = 1 mode could potentially be the onset of a companion that fragments from the disk. On the right side, we show in red the iso-surfaces of the disk and in blue colors iso-surfaces of the outflow velocity. One sees nicely how the two bubbles are developing their non axisymmetric pattern as well, which is here an effect of the radiation transport and radiation pressure.



resolution cases. Yet even at the low resolution we find very interesting effects. The massive disk whose formation we already observed in the 2D run is now prone to self gravity and the related spiral arm forming instabilities, as can be seen if we zoom down to the center of the simulation box (Fig. III.1.7). Here the disk of roughly 150 – 300 AU extent shows a m = 2 mode developing after only 20 000 years into the collapse.

As the collapse proceeds (e.g., after 33 000 years) the two-peaked structure merges into a one armed spiral and one can see a single condensed clump in the density maximum (Fig. III.1.8). At the same time the radiation pressure begins to push the gas up along the rotation axis creating an outflow and a cavity, yet still not as evolved as in the 2D case, which was after 50 000 years.

Future work will analyze the numerical resolution effects, the physical parameter space for cloud masses, and the angular momentum content in the cloud, of course using refined dust and gas opacities and stellar evolution models. As mentioned above we will eventually also switch on the MHD module in the PLUTO code for our 3D simulations to study both the effects of the B-field not only the collapse phase but also the MRI driven evolution of the disk around the star and the possible formation of magneto centrifugally driven and magnetically collimated winds, all in combination with self gravity and radiation transport on our spherical grid. Starting from fall of 2009 we will also generate our own boundary and initial conditions with a new Post Doc working with a Radiation magneto hydro version of the adaptive mesh refinement code RAMSES. Thus we will be able to study large-scale star formation processes, bind them vice versa to the formation of disks and jets on small scales and test them against observations that we seek to understand.

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III.2 Quo Vadis Jupiter? – Planets on the Run

Planets not only wander around their host star, as their Greek name already implies, but they also significantly change their semi-major axis during their formation and evolution. They can either interact with the disk gas via tidal forces that can lead to both migration towards the star and away from it, or they can gravitationally scatter with each other if the system contains more than one planet. In both cases the location where we find a planet today is not necessarily the location where it was formed. This dislocation is a major effect for so called "population synthesis models" where we try to predict typical masses and semi-major axes for planets as a function of the stellar mass and metallicity.

Two objects attracting each other via gravity and moving freely in space will follow Kepler's laws in their orbit around each other. Already a third body added to the system makes the system chaotic, which means that small variations in the initial condition can have a severe impact on its dynamic evolution. It is really tricky to predict stability or instability of a three or more body system, and one has to rely on numerical simulations to test the system for given initial conditions. Stability means in this context that at least for a finite time the bodies stay gravitationaly bound to each other, whereas instability means the ejection of one or more objects from the multiple system. The community of planetary dynamics thus only speaks about guaranteed stability for a minimum time, e.g. it can happen that a planetary system will fall apart after billions of orbits of its individual members.

The reason for the change of the semi-major axis is angular momentum transfer from one body to the other. Angular momentum transfer needs a torque, which again is a force, which acts tangentially with respect to the orbit. Since in a strict two-body problem there are no torques, angular momentum is strictly conserved for each of the two bodies.

In a newborn planetary system, there are not only a number of planets interacting with each other via gravity, there is also a significant amount of gas left over from the planet formation process. At least during the first couple of million years we even expect the gas to exceed the combined mass of the planets by a large amount. For instance the nebula our solar system formed from had initially something like 10 percent of a solar mass in dust and gas. But in the end, only 0.2 percent of this material ended up in planets. Jupiter alone constitutes 0.1 percent of this mass. As a consequence there was a lot of gas mass in the disk the planets could interact with.

According to the standard planet formation model (see Fig. III.2.1), planetary growth starts with micron size

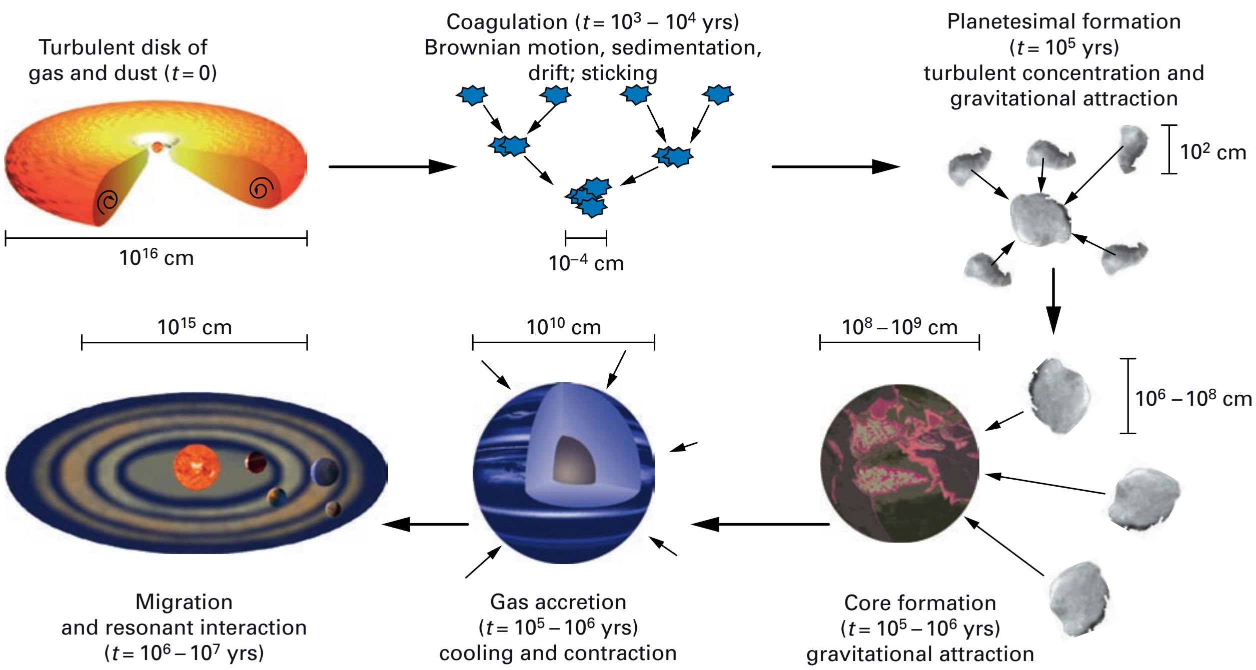
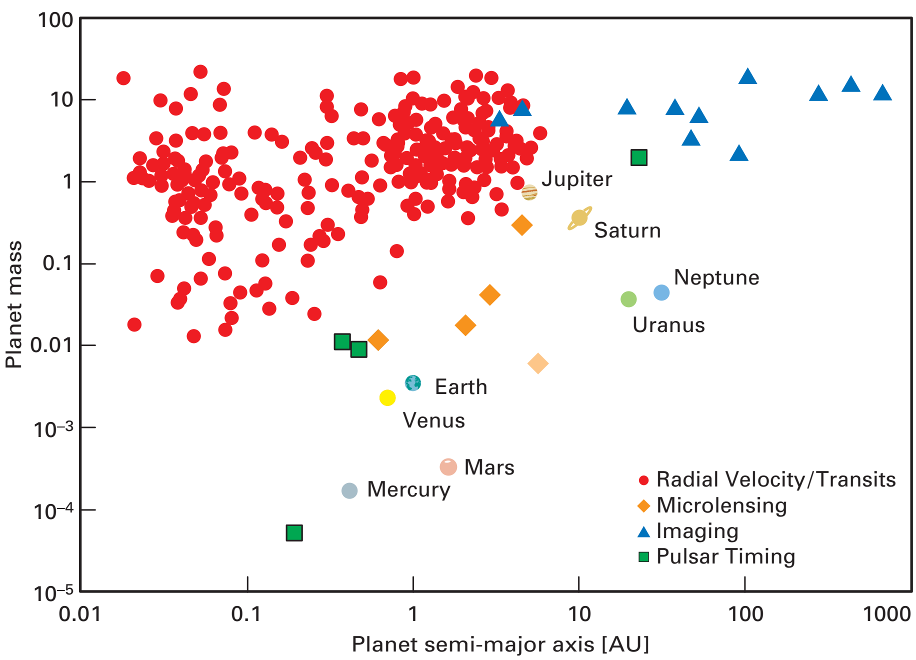


Fig. III.2.1: The standard picture of planet formation from dust grains in circumstellar disks to gas accreting cores. The currently observed position of a planet is ultimately determined in the final migration step within the disk and the gravitational interaction with the other planets. (Credit: H. Klahr) dust grains that accumulate to larger and larger bodies via simple "hit and stick" until gravity takes over to form and bind many kilometer sized planetesimals. From the planetesimals, gravitational attraction leads to the formation of terrestrial planets, and in case they become more massive than about 5 Earth masses, they start to accrete gas to become gas giants of up to several hundred Earth masses. Jupiter, for instance, is 300 Earth masses, yet it is not the most massive planet ever detected. An upper threshold is difficult to claim, as by convention a body of more than 13 Jupiter masses is called a Brown Dwarf rather than a planet. But physically, there is no reason per se that a planet may not grow beyond that mass limit via the accretion of more and more gas. And in fact, the mass distribution of most objects found in close orbit around our neighbor stars (see Fig. III.2.2) ranges more or less continuously from 4 Earth masses, which is about 1.3 percent of a Jupiter Mass, up to 25 Jupiter masses. The lower limit is, of course, an effect of detectability, as more massive objects are easier to find, yet this also tells us that the upper limit is significant. There is indeed a lack of objects in the Brown Dwarf realm above 20 Jupiter masses in close orbit around stars. This phenomenon is called the Brown Dwarf desert and may help us one day to better distinguish between planets and failed stars, *alias* Brown Dwarfs.

On the physical side, an upper mass limit for a planet formed via accretion of gas onto a rocky core is a non-trivial problem. The accretion rate depends on the thermal state of the planet, the locally available amount of gas and the distance from the central object. If the planet has eaten up all gas, which is locally available, it will starve and basically not grow any further. A possibility to escape from starvation is to move on to new feeding grounds. A planet that can migrate may move into regions, where there is still gas available. For ages, planet formation theorists were putting planetary cores of a few earth masses into their favorite model of the solar nebula with a fixed semi-major axis and determined the amount of gas that accreted over time on the planet. Many such models failed to produce Jupiter in a realistic lifetime for a circumstellar disk, e.g. a few million years. When the first hot Jupiters were discovered, the situation became even worse. The amount of material available for planet formation should be much lower close to the star, yet the planets discovered around our neighbor stars are close to their stars and, in some cases, significantly more massive than Jupiter. An *in situ* formation of those giants would need an extremely high concentration of gas and dust close to the star, which fits neither to observations nor to evolution models of accretion disks around stars. Suddenly one remembered models of planet migration derived a few decades back from the physics of the satellites in Saturn's ring system. But since our own solar system showed no evidence that migration had occurred, the theory of planet migration disappeared in the vaults of inapplicable theories. Only after the discovery of 51 Peg b, an almost Jupiter-sized planet with a 4 day orbit around its host star, migration suddenly was fashionable again.

The physics behind migration lies again in gravitational attraction and the resulting torques. These torques can change the angular momentum of a planet, which will that will react by adjusting its semi-major

Fig. III.2.2: Distribution of mass vs. semimajor axis of known exo-planets as of February 2009. A significant result is the upper cut off in planet masses and the large number of very massive planets close in to the star. (Credit: www.exoplanet.eu)



axis, depending on the sign of the torques either moving towards the star or away from it. Here, it is the gravitational attraction between the gas in the disk and the planet which has to be considered. In a perfectly rotational symmetric disk, there is, of course, also a mirror-symmetry between the gas distribution ahead of and behind the planet, with the symmetry axis being the connecting line between star and planet. This means that all gravitational attraction pulling the planet forward and pulling it backward with respect to its orbital velocity will cancel each other perfectly and the resulting net torque is zero – no migration occurs.

But as the planet itself pulls on the disk gas, it will perturb the density distribution in the gas. If the disk and the planet were not rotating, there would simply be another symmetric density perturbation around the planet, where the gas would be slightly compressed. Nevertheless, due to the symmetry, no net-torque will be acting. But the disk and planet are not simply rotating: the disk also has a roughly Keplerian velocity pattern. This means that gas closer to the star will have a higher velocity than the planet and drag the perturbation from the planet down-stream. The same happens for gas outside the planetary orbit. It rotates slower than the planet and as a result, the perturbation falls back with respect to the planet. In the equilibrium situation the perturbation is sheared out, producing a spiral structure that builds up in the disk (see Fig. III.2.3).

The net torque exerted by the spiral pattern on the planet is now slightly negative, which means that the planet loses angular momentum and drifts radialy inward. Theory was pretty proud in determining the resulting torques and, thus, the migration rate as a function of planetary mass versus the primary mass. The analytic predictions could be reproduced in numerical simulations treating the gas dynamics in great detail.

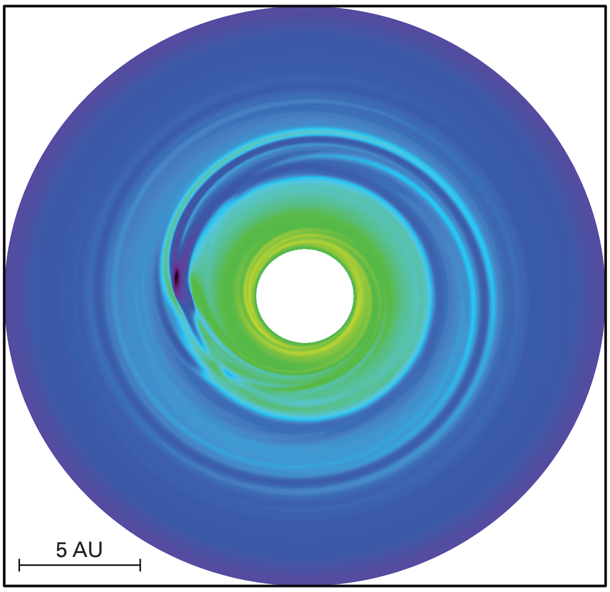


Fig. III.2.3: A 30 Earth mass planet is embedded in a circumstellar disk. Darker colors represent higher density. The gravitational pull by the planet, in combination with the Keplerian shear in the disk, leads to the formation of the stationary spiral pattern. The gas is treated as locally isothermal in this simulation.

The case shown above would be classified as Type 1 migration and is valid for planets up to about 100 Earth masses.

But as soon as the planet's Roche Lobe becomes larger than the disk thickness, e.g. the pressure scale height, it will open up a gap in the disk. In this case, there are no significant torques arising from the material close to the planet, and the planet simply positions itself at the center of the gap in a way, that there is no net torque. But if the disk is accreting, which means a continuous flow of gas through the disk, this flow is also pushing along the gas. As the planet wants to stay in the center of the gap, it is also migrating towards the star. This situation, where the mass accretion in the disk determines the migration rate ,is called Type 2 migration.

A third type of migration could occur if a planet at the borderline between Type 1 and Type 2 migration, e.g. almost opening the gap, gets a major kick from an unfriendly demon, or more precisely an unspecified external perturber. If the local disk mass is larger than the planet mass, a massive material overflow from either the outer disk to the inner or the other way around can occur, which leads to very fast runaway migration of the planet. The direction of the kick determines whether the gas will flow from the inner disk to the outer or vice versa. In the first case, the planet rushes in, whereas in the latter case, the planet quickly gains distance from the star. As long as the perturber is not identified in this so called Type 3 migration scenario, it is also difficult to say how important this migration type is and how many planets might be affected by it.

A typical migration rate, as derived from the analytic description of Type 2 migration, is 100 000 years for Jupiter to migrate inward from 5 to 4 AU. For planets smaller than Saturn the migration rate should drop proportional to the planetary mass. Now comes the problem: even if this migration rate sounds small, it is still faster than the growth speed of the small planets. In other words, they move inward and drop into the star before they can reach the comfortable size of 30 Earth masses, at which the quick runaway accretion of gas will set in. From there, it is only a few thousand years to reach Jupiter's mass. It became apparent that there must be something wrong with the analytic migration rates.

Our collaborator Willy Benz and his group study the predictive power of planet formation theory. They combined all our knowledge of planet formation from disk evolution through planetesimal physics to the gas accretion and migration of planets. These Population synthesis

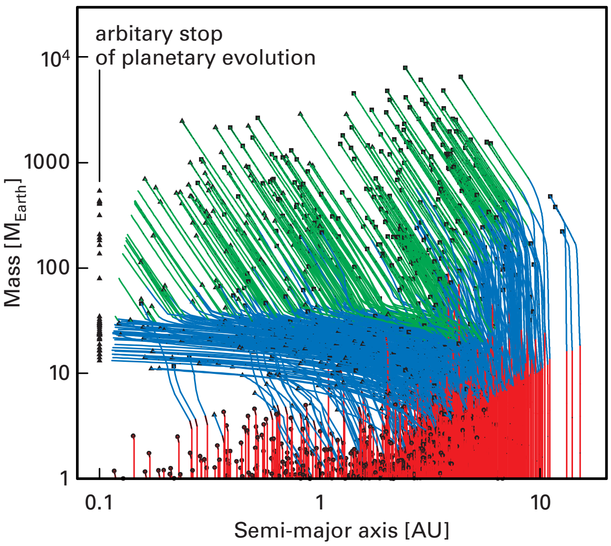


Fig. III.2.4: These model calculations show which planetary masses are expected at which distances from a solar like star. The numerical formation model contains our current knowledge about dust and gas disks around young stars as well as present-day theories about various planet formation processes, especially the migration of planets. (Mordasini, Alibert and Benz 2009)

models can then predict what typical planet masses should be found at a given semi-major axis (see Fig. III.2.4).

For each simulation of the formation of a planet, a small protoplanet is initially placed at some randomly chose initial distance from the young star inside a disk with some randomly chosen properties. In Fig. IV.2.4, each simulation run is represented by a solid, multi-colored line, the formation track in the mass-distance plane which shows how the protoplanet grows and migrates. Masses are measured in units of the Earth's mass and distances are in astronomical units. The randomly chosen disk properties are drawn from probability distributions that are derived from actual observed properties of protoplanetary disks. The planetary seeds start to grow at the lower boundary of the diagram by accreting the first planetesimals and, later, also gas. Due to this growth in mass, they move upwards along vertical tracks. Then, they start to migrate inwards at a speed set by the mass of the planet and of the gas disk. Depending on the particular type of this migration process, the formation tracks are plotted in red, blue or green. At the moment when the protoplanetary disk finally disappears, the planets reach their final position, indicated by a black symbol. Note that planets similar to our gas giants are formed. As the mechanism halting planetary migration close to the star is currently poorly understood, simulations are arbitrarily stopped once a planet migrates to about 0.1 AU from the host star.

When one is naively using the face value of migration, almost no gas giants form at all, but almost all drop into the star, as a result of the fast migration and slow growth. One is led to the idea that many Jupiters formed that all fell into the sun, but the last one, which was saved because the disk evaporated in time. This is a quite unsatisfying explanation and implies that the planet formation process is very inefficient, which is somehow in contradiction with the large number of planets around our stellar neighbors.

The suggestion that Willy Benz and his group came up with is that the planets must migrate significantly slower in the Type 1 phase than predicted in the analytic theory. The best value is about 1 percent of the analytic value. This has two effects: The planets still grow faster than in the no migration case, because they always enter new feeding zones in the disk (see above), and they grow before they drop into the star.

But why should the planets migrate slower than what theory and numerics had demonstrated? The answer is: thermodyna-mics! All migration up until our work in 2004 had been done for iso-thermal disks, which means they have a fixed temperature structure throughout the simulation. Whereas the precise treatment of heating and cooling including radiation transport changes little in the Type 2 migration case, it does a lot for Type 1 migration, as first put forward by Pardekooper and Mellema. They found that planets of 5 to 20 Earth masses should migrate outwards instead of inwards, if only the thermodynamics are non-isothermal but adiabatic.

In the last year, we extended the numerical simulations of Type 1 planet-disk interaction to the full 3D case. Fig. III.2.5 shows the resulting density and temperature structure of the same 30 Earth mass planet that did such a wonderful spiral in the isothermal case (see Fig. III.2.3). In such a more realistic yet complicated flow field, the torques from the material, especially in the region corotating with the planet, do not so easily cancel each other out anymore. The precise value of the net torque now depends also on the optical depth of the gas (surface density and opacity) and on the angular momentum transport via turbulence in the gas. Fig. III.2.6 shows a comparison between migration rates as a function of planet mass in the isothermal case, which is always directed inwards, and in the full radiation hydrodynamics case, which for a certain mass range is directed outwards. Currently, Christoph Mordasini implements this migration behavior into the Population synthesis model he developed while still in Bern, so we will see whether this fix in the migration behavior will be sufficient to eliminate the 1 percent “fudge factor” from the population synthesis model and still produce populations that agree with observation.

Outward migration was also suggested as an explanation for the planets at very large distance from the central object. The so-called direct imaging planets (see Fig. III.2.2) are found at distances of about 30 AU to several hundreds of AU from the star. But, as shown in Fig. III.2.4, there are almost no planets forming beyond 10 AU. The problem is the long time scale it

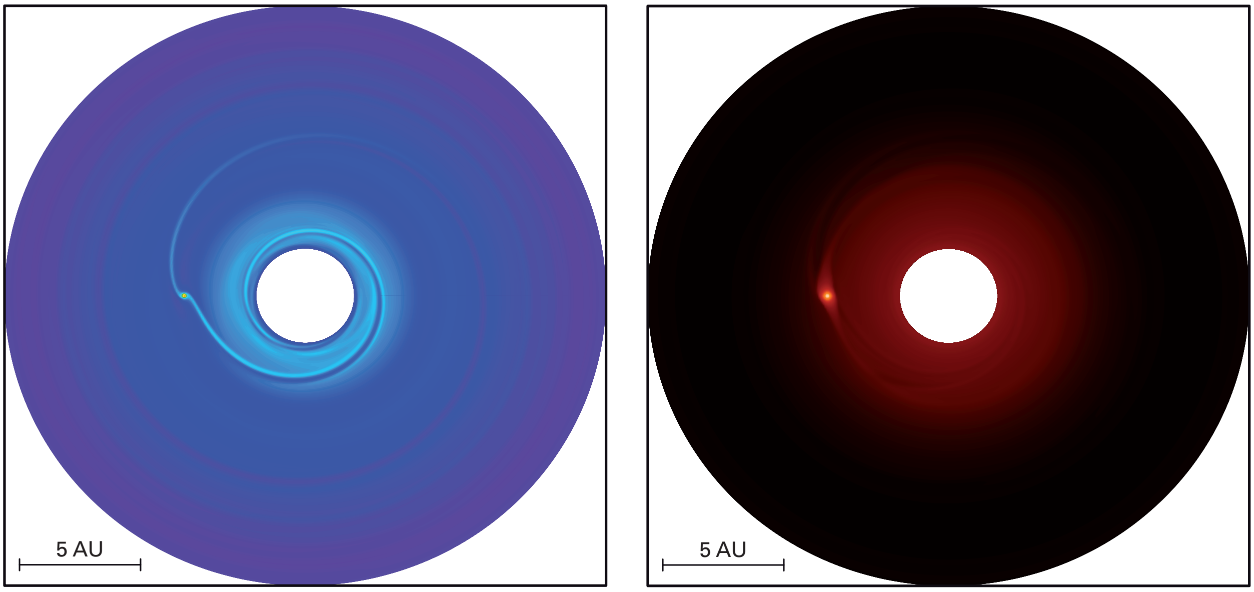
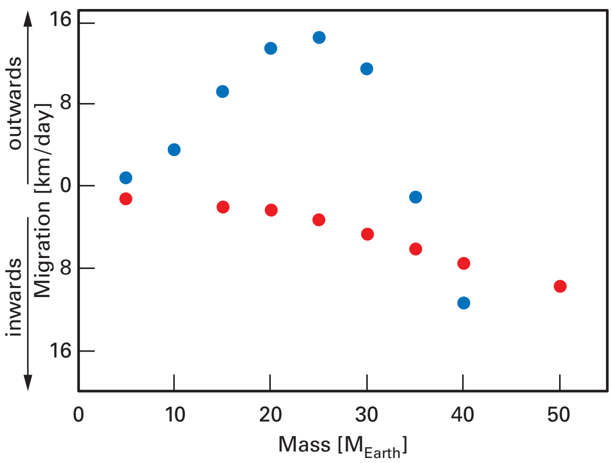


Fig. III.2.5: Density (left) and temperature distribution (right) for a 30 Earth mass planet interacting with a disk. This pattern is the result of a non-isothermal 3D viscous radiation hydrodynamical simulation.

would take to form a core for a planet at these distances. Neptune and Uranus probably came only alive because the young Jupiter bullied the baby Neptune and Uranus away by his gravitational torques. Indications are strong that this happened, and of course, Jupiter, with about 10 times the mass of the outer ice giants, clearly dominates the solar system in a dynamical sense. One could say: you shall not come too close to Jupiter, or he will kick you out. For many of the direct imaging planets, such a slingshot has been debated. Maybe these ~10 Jupiter mass planets also formed closer in and were later sent to their current location by an even more massive planet, still further in. Yet these objects, if they existed, would have been detected by now in many cases – but they were not, which rules out the sling-shot theory.

Another theory was that the viscously spreading disk was carrying the outward migrating planets along. In any case, the vast distances to be crossed render this idea as problematic. The reason why we could not form these planets at large distances from the stars lies in the formation theory from a core as mentioned above. So why not form a planet without a rocky core? We cannot really tell by looking at a planet whether it formed around a core or not. Even for Jupiter the existence of a core at its center is still under debate. The unknown properties of the equation of state for Jupiter material have a stronger influence on its size than the existence of this little additional potential of 5 – 10 Earth mass at its center. Such an alternative scenario, which works without a core, does exist. If the circumstellar disk at certain distances from the star was massive enough for self gravity to lead to a local gravitational collapse within the disk, and on the other hand, optically thin enough to cool on the collapse time scale, then, in principle, planets of several Jupiter masses could have formed from pure gas within a few hundred years. The conditions for this collapse are usually not given at the radii where we find most of the planets. Even if the disk was massive enough at 5 AU, where Jupiter could have formed, it would not fragment, as the cooling time, which determines the contraction of a fragment to a planet, is many orbital periods. In this time the initial fragment will be already pulled apart. Thus, instead of fragmentation, the disk would react with gravotur-

Fig. III.2.6: Migration rate as a function of planet mass: Red dots are the rate determined in analytic and numerical yet isothermal models. Blue dots are our new values for full 3D radiation hydro. (Kley, Bitsch and Klahr 2009)



bulence and quickly redistribute mass and angular momentum, until the disk is no longer self-gravitating.

Yet, at radii larger than 20-30 AU, depending on the stellar mass, metallicity and luminosity, one finds the conditions for disk fragmentation fulfilled, as we were able to show recently at the MPIA. As an example for our model, we use the beautiful system HR 8799, which hosts three planets, one of 7 and two of 10 Jupiter masses, at 24, 38 and 68 AU (see Fig. III.2.7).

In our model consisting of hydrostatic vertical disk atmosphere models, we can determine cooling times and Toomre parameters Q (fragmentation occurs for $Q \leq 1$). Based on a whole set of local models, we can determine what range of surface densities would lead to fragmentation by being high enough for self-gravity and low enough for fast cooling. These surface densities can be translated into probable masses of the fragments, which is shown in Fig. III.2.8.

Interestingly only the middle planet is in the allowed region. But if we assume that all planets formed originally with the same semi-major axis and calculate this location via the conservation of angular momentum, then the three planets end up right in the allowed region for disk fragmentation. So, it is conceivable that the planets in fact all formed at about 40 AU and then scattered out to their current locations. The remaining disk would then have damped the eccentricity of the relocated planets and circularized them in a short time. Migration within such a self gravitating disk is also possible, but has never been explored sufficiently.

In general, one has to say that the role of planet-planet scattering is too little considered when doing population synthesis models, since the effect of scattering can be quite dramatic. Still, due to the chaotic nature of N-body interactions, it will be difficult but not impossible to include these effects in future synthesis models. Conservatively, one can first improve the models for close-in planets, where most data are available against which the parameters of the models have to be checked. As we have seen, the proper migration rate is one way to do so.

But the slow-down and reversal of Type 1 migration is unfortunately not the only problem that we have with growing planets in disks. The next problem is to make the gas giants stop at the close-in radii where we find them today. Magnetic fields, tidal forces from the star, and disk truncation are all under discussion, yet no standard picture providing quantitative results has been established so far. This is currently the most burning question in planet formation and migration theory, and we, like many other groups around the world, are working to find the answer.

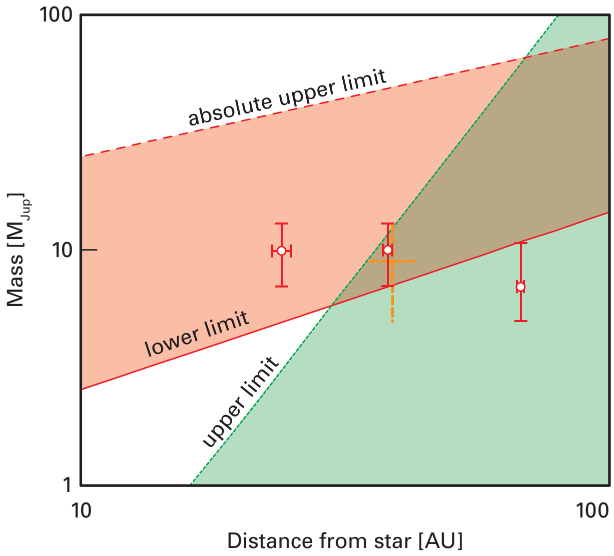
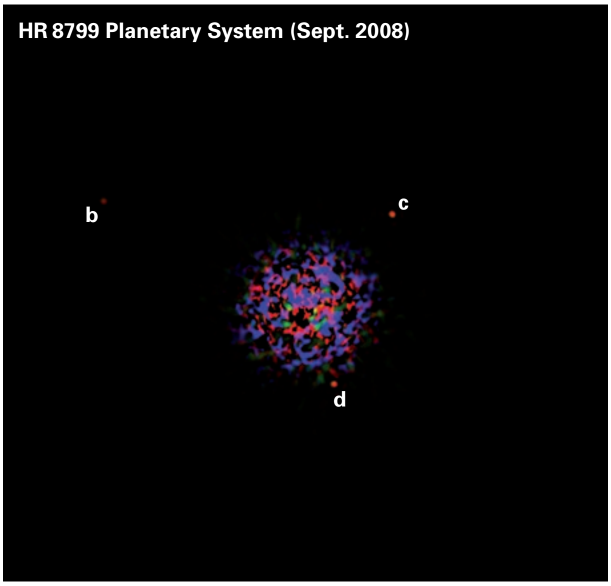


Fig. III.2.8: The actual masses and locations of the system HR 8799b, c, d and the allowed area given by the critical surface densities. Solid line = lower limit (i.e. self gravity), dotted line = upper limit (i.e. cooling rate) and dashed line = upper cut off (i.e. disk mass is half the stellar mass).

Fig. III.2.7: Direct image of the three planets orbiting the star HR 8799. (Ch. Marois/Keck/Gemini 2008)



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In collaboration with Willy Benz (Bern), Yann Alibert (Besançon), Willy Kley and Bertram Bitsch (Tübingen)

III.3 Dissecting the Centers of Nearby Active Galaxies

Active Galactic Nuclei (AGN) are powered by accretion onto a super-massive black hole. The unified scheme for strongly accreting AGN postulates that the central engine is enshrouded in a doughnut-shaped structure of gas and dust – the so-called torus. MPIA researchers have led observations with the Mid-infrared interferometric instrument (MIDI) at the VLT Interferometer, which resolve the tori in the nearest Seyfert 2 galaxies and suggest a complex structure, consisting of a compact inner disk embedded in a patchy or filamentary outer torus. Their findings can be understood with the help of hydrodynamical torus models and radiative transfer calculations. The prominent nearby radio galaxy Centaurus A, however, shows little sign of a torus. Instead, its mid-infrared emission is dominated by non-thermal radiation from the base of the radio jet. Thus, not all classes of AGN contain a thick torus.

The unified scheme for Active Galactic Nuclei (AGN) explains various types of AGN by a line-of-sight effect: it postulates that the central engine – an accreting super-massive black hole – is embedded in a doughnut-shaped torus of gas and dust. Thus, the hot accretion disk and the surrounding Broad Line Region (BLR) is only visible when looking along the torus axis. This is the case in Seyfert 1 galaxies, the optical spectra of which are characterised by a blue continuum and broad emission lines. In an edge-on case, however, the direct view onto the core is blocked by the dusty torus and only narrow emission lines from regions above and below the torus are visible. The object then appears as a Seyfert 2 galaxy. Spectro-polarimetric observations of Seyfert 2 galaxies, showing broad lines in polarized scattered light, support this idea (see review by Antonucci, 1993). The UV-optical light which is trapped by dust in the torus should heat the dust to a few hundred Kelvin, and the dust should re-radiate in the mid infrared. Indeed, the Spectral Energy Distributions (SEDs) of both Seyfert 1 and Seyfert 2 galaxies display signatures of AGN heated dust between $\lambda = 3$ and 30 µm. It is an open issue whether dust obscuration plays a similar role in radio galaxies.

Before the advent of the VLT Interferometer (VLTI), the size, shape and internal structure of the torus remained unknown, although mid-infrared spectra located the dust within a few parsec of the core. Single 8-m class telescopes cannot resolve mid-infrared structures of this size. Even in the *L*-band (3.6 µm) a diffraction-limited 8-m telescope is limited to 93 milliarcseconds resolution (FWHM). At the distance of nearby Seyfert galaxies, such as NGC 1068 (15 Mpc) and NGC 4151 (14 Mpc), this corresponds to 6.5 parsec. The situation changed dramatically in December 2002, when MIDI, the Mid-infrared interferometric instrument, became operational at the VLTI. MIDI observes in the *N*-band ($\lambda = 8 \ldots 13$ µm). Using the widest telescope separation (UT1–UT4) of 125 m, the width of the point-spread function ($\sim \lambda/2B$) at $\lambda = 8$ µm is only 7 mas or 0.5 parsec at the distance of NGC 1068. At the start of MIDI's operations two major questions remained: first, would MIDI be sensitive enough to reach extra-galactic targets? Second, would observations with a handful of baselines allow us to reconstruct the dust distribution in the torus and thus provide scientifically meaningful insights? This article demonstrates that today's answer to both questions can be unconditionally: yes!

Mid-infrared Interferometry with MIDI

MIDI operates as a classical stellar interferometer of the Michelson type. It combines the beams of two telescopes at a time (see also annual report 2003, p. 31). The sensitivity required for most AGN observations can only be reached by the combination of two of the 8 m Unit Telescopes (UTs) of the VLTI. The highest sensitivity for detecting and tracking the interferometric fringes is obtained by inserting a prism into the interferometric beams, thereby spectrally dispersing the *N*-band light. For brighter objects, a grism with higher resolution can be used. In both cases, MIDI delivers photons onto its detector containing spectral and interferometric information at the same time. A special analysis pipeline is needed to extract this information.

Observations of the scientific target have to be complemented by standard star measurements obtained with an identical instrumental setup, in order to compensate for the variable transmission of the atmosphere.

The essential result of the pipeline analysis is a spectrum of the (calibrated) correlated flux $F_{corr}(\lambda)$ in the range 8 to 13 µm (see Fig. III.3.1 b, c, d). Spatial information about the source structure can be obtained by comparing $F_{corr}(\lambda)$ at different telescope separations or baselines. A baseline is characterised by its length and position angle and is often described by its coordinates *u* and *v*, which form the so called *uv*-plane. In addition to the measured *uv*-points, the total flux $F_{tot}(\lambda)$ registered by a single telescope, is essentially equivalent to an observation with zero baseline (see Fig. III.3.1a). Different baselines can be realized either by using different telescope combinations or by watching the target during its movement across the sky with a fixed telescope combination.

As is evident from Fig. III.3.1, the AGN spectra between $\lambda = 8.5$ µm and $\lambda = 12.5$ µm are often dominated by a broad absorption trough, caused by silicate dust grains. The exact profile of this "silicate feature" depends on the chemical composition, size, and crystalline structure of the grains. Thus the *N*-band interferometry of an AGN not only resolves the spatial structure of the nuclear dust but also can give insight into the dust properties within the inner few parsecs.

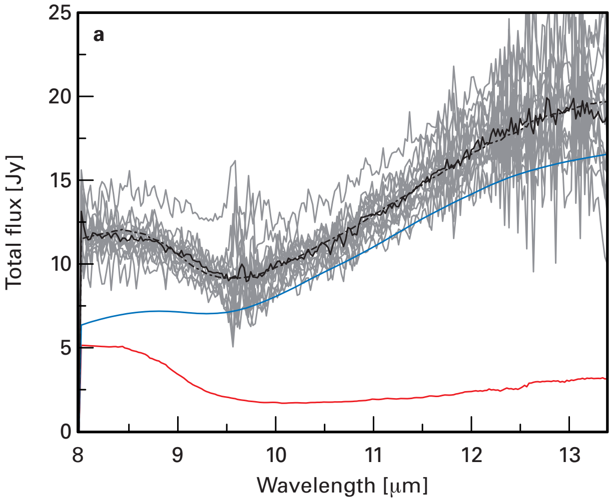
The Dust Torus in NGC 1068

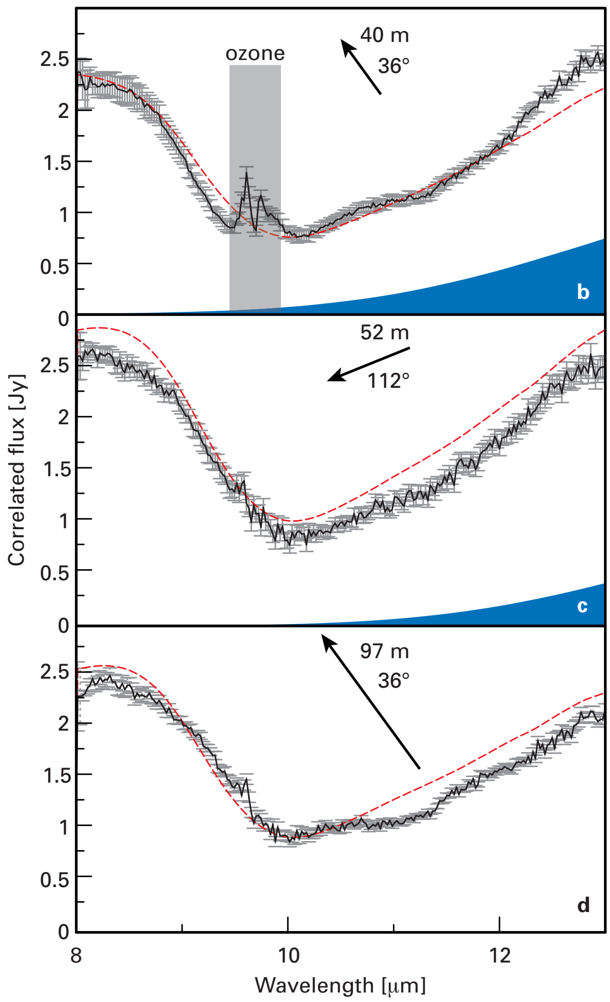
The first AGN observed with MIDI was the prototypical Seyfert 2 galaxy NGC 1068. It is the brightest extra-galactic *N*-band source in the southern sky. At its distance of 14.4 Mpc, one parsec corresponds to an angular scale of 14 mas, i.e. parsec-scale structures can just be resolved with MIDI at the VLTI. The earliest MIDI observations of NGC 1068 were obtained half a year after MIDI became operational, during VLTI Science Demonstration Time (SDT), but only two visibility points were observed at that time (see also annual report 2005, p. 32).

New observations with MIDI cover the uv plane much better: 15 visibility points were obtained with the telescope combinations UT1-UT3, UT1-UT4, and UT2-UT3. An additional measurement with the orthogonal baseline UT3-UT4 proved essential for the following results. To study the details of the silicate absorption profile, the higher resolution grism was used.

Even with this more complete uv-coverage, direct image reconstruction is not possible because MIDI can only use two telescopes at a time. With the combination of only two telescopes, it is not possible to use so-called phase closure techniques to recover the phase of the interferometric signal, which is required to reproduce an image of the source. Therefore, the measured $F_{corr}(\lambda)$ spectra for different baselines still have to be interpreted by simple models. Remarkably, a model of two components with Gaussian brightness distribution and black-body spectrum describes the correlated flux data reasonably well. With the inclusion of the longest VLTI baselines UT1-UT3 and UT1-UT4, the measurements perfectly constrain the size, shape and orientation of the hot, inner component of the dust torus: major axis 20 mas (1.4 pc FWHM), orientated along P.A. = 138°. It is rather elongated, $b/a = 0.25$, indicating a geometrically thin (disk-like?) structure. Only a lower limit, $T > 800$ K, can be set to its temperature. The lack of short baselines, < 50 m in the East-West direction makes the determination of the overall size and

Fig. III.3.1: Results of MIDI observations of NGC 1068. *a)* Total flux $F_{tot}(\lambda)$: the contribution of the hot component is shown in red, and that of the extended component in blue. *b)* Correlated flux $F_{corr}(\lambda)$ obtained with a 40 m baseline orientated along position angle *P.A.* = 36°. The red dotted line gives the model fit and the blue shaded area shows the contribution of the extended component. *c)* $F_{corr}(\lambda)$ for a 52 m baseline along *P.A.* = 112°. *d)* $F_{corr}(\lambda)$ for a 97 m baseline along *P.A.*= 36°. The comparison between *b)* and *c)* shows that the correlated flux of the hot component, that dominates the spectra shown here, is lower along *P.A.*= 112°, i.e. the hot component is better resolved (more extended) in that (SE-NW) direction.





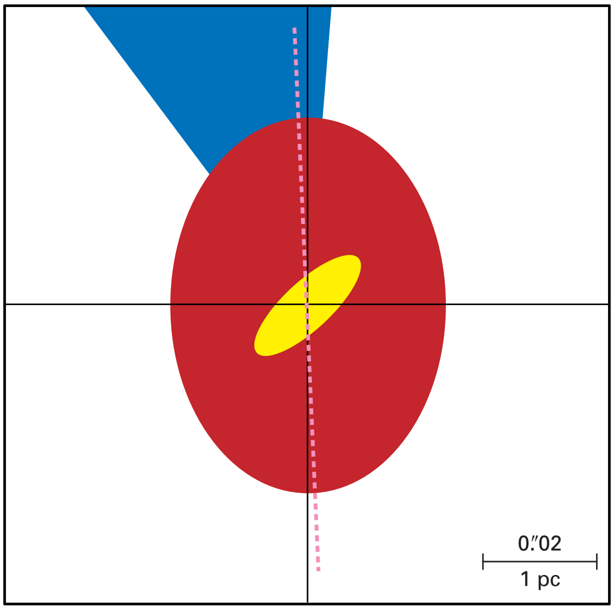


Fig. III.3.2: Observational model of the dust torus in NGC 1068. A hot component (yellow) is embedded in an extended cooler component (red). The orientation of the radio axis is indicated by a purple dotted line and the blue wedge gives the opening angle of the ionization cone, observed on 100 pc scales. North is up and East is left.

shape of the more extended "torus component" uncertain. Its diameter is about 3.5 pc, but its exact shape remains to be determined by shorter baselines along East-West. Such baselines are provided by the Auxiliary Telescopes (AT's). A MIDI observation program with AT's is under way and has already detected fringes from NGC 1068.

The major axis of the hot component is perfectly aligned with a spur of water masers extending about 20 mas NW from the (radio) core, although the relative IR-radio astrometric position cannot be determined. Surprisingly, the orientation of its minor axis (*P.A.* = 48°), which might mark the symmetry axis of an inclined disk, does not fit well to the source axis as determined by outflow phenomena: the inner radio jet points almost exactly to the North (*P.A.* = 2°), while the ionisation cone opens between *P.A.* = –5° and *P.A.* = 30°. For the standard torus scenario, this is a puzzle: the open funnel which allows the ionising UV photons to escape should be caused by the angular momentum barrier and thus be aligned with the rotation axis of the gas distribution. How could a tilted disk form out of this gas? Maybe the hot inner component is not a rotationally supported structure (disk) but rather a filament or hot channel.

Further insight into the dust properties can be inferred from the depth of the silicate feature. In the total flux, which is dominated by the outer component (Fig. III.3.1a), the absorption depth at 10 µm is moderate, $\tau_{10} = 0.4$, whereas the depth towards the inner component is almost five times larger, $\tau_{10} = 1.9$ (Fig. III.3.1b, c, d). Obviously, most of the dust column is located in the outer component.

The Dust Torus in the Circinus Galaxy

The Circinus galaxy at a distance of 4 Mpc is the nearest Seyfert galaxy. It shows all signs of a classical Seyfert 2: narrow allowed and forbidden emission lines, strong silicate absorption and a heavily absorbed X-ray spectrum. An extended cone of emission line gas and the presence of broad lines in the polarized optical flux (caused by scattering) provide direct evidence that the central engine is hidden from our direct view behind a substantial amount of dust. Circinus is a spiral galaxy seen almost edge on. Thus, several magnitudes of visual extinction might be caused by the dust lanes in the spiral disk, behind which the nuclear region is located.

The large southern declination of Circinus ($\delta = -65°$) makes it an almost ideal target for the VLTI: it can be observed for up to 12 hours during long winter nights, thus allowing the projected baseline orientation between each pair of UTs to swing by up to 180° due to the earth's rotation. In five observing runs during the MIDI guaranteed time observation program, we collected 21 visibility points, most of them with the shortest VLTI baselines UT2-UT3 and UT3-UT4. They provide the most complete uv-coverage obtained for any extragalactic target so far.

As with NGC 1068, at least two components with Gaussian brightness distribution are required to model the correlated fluxes: A compact component (major axis $a = 0.4$ pc, axis ratio $b/a = 0.2$) and an almost round extended component (FWHM: 1.9 pc, see Fig. III.3.3). Contrary to the case of NGC 1068, the colour temperatures of the inner and outer component both lie around 300 K, differing by less than 50 K. However, the outer component does not seem to be smoothly filled with dust at a constant temperature. Comparing its average surface brightness with that of a black body leads to a covering factor of only 20 %. Moreover, the observed correlated flux values are poorly reproduced by the smooth Gaussian model but rather seem to "wiggle" around it when plotted as a function of baseline orientation. In order to test whether a patchy brightness distribution could improve the fit, we modified the smooth Gaussian distribution by a foreground screen of randomly distributed variations in transmission. A thousand different screens were realized, the images were Fourier-transformed, and finally compared with the observed correlated fluxes. Indeed, we found several patchy screens which reproduce the observations much better than the smooth model. The best-fit model is displayed in the right panel of Fig. III.3.3. Interestingly enough, it shows a bright patch on the axis of the ionisation cone. We regard this as evidence that our interferometric data contain hints for the existence of hotter dust close to an open funnel which confines the ionising radiation.

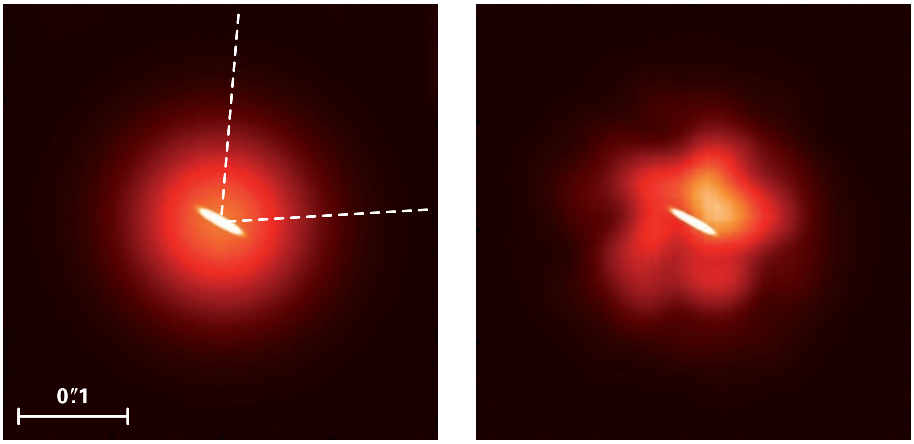


Fig. III.3.3: The dust torus in the Circinus galaxy. The left panel shows the smooth model (composed of two Gaussian brightness distributions, the right panel visualises the best-fit patchy model. Dashed lines indicate the opening angle of the ionisation cone.

The size and orientation of the inner, disk-like component again fit very well to the known disk of water masers, which in their radial velocity distribution show a Keplerian rotation pattern (Fig.III.3.4). Although the location of the dust emission with respect to the maser disk cannot be determined by our MIDI observations, it is very likely that both disks are spatially coincident: in this case the inner dust component would also have to be interpreted as a rotationally supported disk.

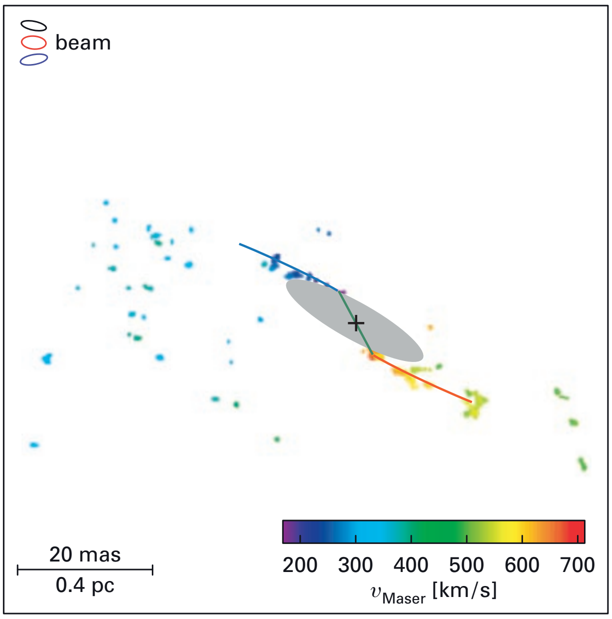
It is worth noting that the depth of the silicate absorption towards the dust components in Circinus shows a different behaviour from that observed in NGC 1068. In Circinus, the depth of the silicate feature towards the inner component is shallower than towards the outer component. Obviously the dust column through the outer dust component is not very high and the absorption trough is partly filled by silicate emission from the dust disk.

The Radio Galaxy Centaurus A

The Radio Galaxy Centaurus A (= NGC 5128) plays a key role in extragalactic astronomy: at a distance of only 3.8 Mpc, it is the closest large elliptical galaxy, the closest galaxy merger, and the closest violent AGN. At its distance, 1 pc corresponds to 53 mas. The radio source can be traced over seven orders of magnitude of an angular scale, from the VLBI jets (a few mas) to the outer lobes (several degrees). Extinction in the dust lane generated by the spiral galaxy merging with the elliptical severely obscures our view towards the nucleus of Centaurus A. Thus, observations at infrared wavelengths are mandatory.

Centaurus A was observed in 2005 with MIDI using two telescope combinations, UT3-UT4 and UT2-UT3. With both combinations two visibility points were obtained, separated by about two hours. The projected baseline with UT3-UT4 was oriented roughly perpendicular to the parsec-scale radio jet, while UT2-UT3 was aligned parallel to it. We found (Fig. III.3.5) that the mid-infrared emission is marginally resolved perpendicular to the jet axis with a 60 m projected baseline, whereas it remains unresolved along the jet axis. Accordingly, we conclude that the 8 to 13 μm emission from the core of Centaurus A is dominated by an unresolved point source (FWHM < 6 mas), which contributes between 50 % and 80 % of the total flux at $\lambda = 13$ μm and $\lambda = 8$ μm, respectively. The extended component is tiny (FWHM ~ 30 mas), and seems elongated perpendicular to the

Fig. III.3.4: Overlay of the compact dust component in Circinus over the location of the (warped) disk of water masers from Gallimore et al., 2004. Colors indicate the radial velocities of the maser sources.



radio axis (see sketch in Fig. III.3.5). However, better uv-coverage (including longer baselines) is required to constrain the size, shape and orientation of this extended component more accurately. We interpret the extended component as dust emission from a small, inclined disk (diameter ~0.6 pc). The unresolved component is identified with the nonthermal "synchrotron core" of Centaurus A, since we find that – after correcting for the foreground extinction of $A_V = 14$ mag (derived from the depth of the silicate absorption) – its flux level and spectrum lies perfectly on the extrapolation of the power-law spectrum observed at millimeter wavelengths. Together with photometry at shorter wavelengths (from HST and the AO camera NACO at the VLT) the flux of the unresolved point source fits perfectly to a canonical synchrotron spectrum: it is characterized by a rather flat powerlaw $F_\nu \sim \nu^{-0.36}$, cutting off exponentially at a frequency $\nu_c = 8 \times 10^{13}$ Hz. We interpret this "synchrotron core" as the base of the radio jet. Our interferometric results on Centaurus A demonstrate that mid-infrared radiation processes are not restricted to thermal dust emission.

The thermal dust emission from the core of Centaurus A is very feeble, more than 20 times weaker than that of the Circinus galaxy at the same distance. We think that both a lack of dust in the inner parsec and the absence of a sufficiently strong heating source are responsible for this. Certainly, Centaurus A neither contains a torus which severely blocks our line of sight nor a UV-optically bright central accretion disk. Most likely, the accretion onto its black hole happens via an advection-dominated accretion flow (ADAF), which is very inefficient in converting accretion power $\dot{m}c^2$ into radiation.

Models of the Torus

The concept of a doughnut-shaped "torus", completely filled with gas and dust, is an oversimplified geometrical picture. Already 20 years ago, Julian Krolik and Mitchell Begelman pointed out that the "torus" must consist of a large number of individual clouds orbiting around the AGN core. However, frequent cloud-cloud collisions would make such a system very unstable: within a few orbital time scales, it should settle into a geometrically thin disk. Other arguments for a clumpy sub-structure of the torus include: the broad and continuous distribution in X-ray absorbing hydrogen column densities found in Seyfert 1 and Seyfert 2 galaxies, and several cases in which an AGN changed its broad line spectrum, indicating a change in central obscuration. Radiative transfer calculations of "clumpy" torus models revealed that another problem with the continuous torus models – namely their prediction of a strong silicate emission in Seyfert 1 galaxies, which is rarely observed – can be solved by shadowing effects in a clumpy structure. In a recent study we demonstrate by fully 3D radiative transfer calculations that a wide variety of cloud distributions is able to reproduce the observed mid-infrared spectra. Moreover, when simulating interferometric observations of such a clumpy torus, we find similar "wiggles" in the correlated fluxes as those observed in Circinus.

Despite the success of radiative transfer models in explaining the infrared SEDs of AGN, they cannot solve the stability problem pointed out by Krolik and Begelman: how could one maintain the geometrically thick distribution of clouds? To address this question, a hydrodynamical model is required that simulates a realistic mass injection into the torus and follows the evolution of the gas clouds. We currently are developing a torus model for Seyfert galaxies that starts from the following assumptions: The centre of the galaxy harbours a massive young stellar cluster (age between 40 and 100 million years). Stellar mass loss via planetary nebulae and stellar winds inject gas and dust into the system, while frequent supernova explosions stir up the gas. Locally, the gas gets compressed and the subsequent cooling instability leads to the formation of dense and cool filaments (see Fig. III.3.6). In between the filaments, cavities of very hot plasma form over-pressured regions, which expand radially along the density gradient. Thus, the cool filaments also become radially stretched. The cool gas and dust streams inwards along the filaments and accumulates in a very dense turbulent disk with a few parsec radius.

In a second step, the radiative transfer through the simulated density distribution is calculated (assuming a standard gas-to-dust ratio in all cells below the dust sublimation temperature). The emerging mid-infrared images (right panel in Fig. III.3.6) reproduce the filamentary density structure. They can explain the "patchy" outer torus observed in Circinus rather nicely. Note, however, that the central turbulent dust disk appears dark in our simulations (right panel in Fig. III.3.6). A set of torus

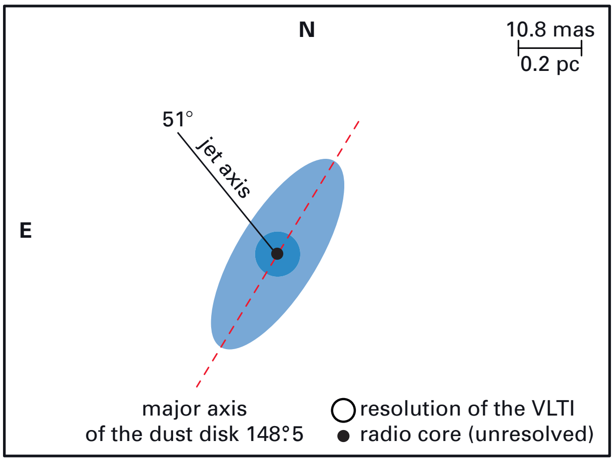


Fig. III.3.5: Sketch of our model for the *N*-band emission from the central parsec of Centaurus A. An unresolved point source is surrounded by a faint dust disk.

models is generated by varying the mass injection and supernova rates. Observing those under various aspect angles can well account for the wide spread in hydrogen column in Seyfert galaxies (over three orders of magnitude) while the change in silicate depth (from absorption to moderate emission) remains limited.

MIDI AGN Snapshot Survey

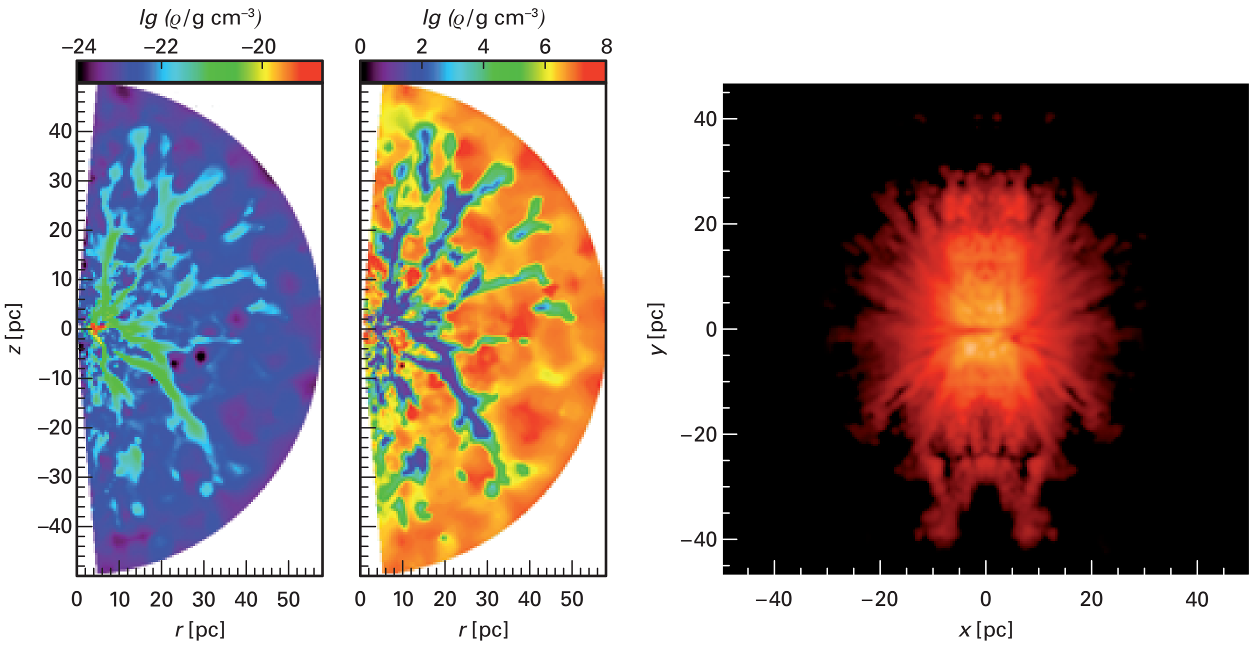
In addition to the detailed studies described above, we carried out an AGN snapshot survey during the guaranteed time observations of the MIDI consortium. This program tried to identify all those AGN, which are bright enough in the *N*-band to be observed with MIDI. The preliminary target list was selected from AGN with known *N*-band flux $S_N > 1$ Jy. Since most of the available *N*-band photo-metry was obtained in large apertures, it was necessary to observe all targets with TIMMI 2 at the ESO 3.6 m telescope (beamsize 0″.7) to get the core flux at $\lambda = 12\,\mu$m. The final target list (Table 1) contains all southern AGN with S_N(core) > 300 mJy. Thirteen of the targets have been observed during the snapshot survey, three more were tried by other observers. From 11 of these 16 targets, MIDI could detect interferometric fringes (indicated by ×, ○ in Table 1). Three of the sources, for which MIDI observations were attempted, could not be observed since their nuclei were too faint for the adaptive optics system MACAO. Only one source, the starburst nucleus in NGC 253, seems too extended to show an interferometric signal.

From the snapshot survey, size estimates or (mostly) limits on the spatial extent of the AGN-heated dust could be derived for seven AGN. These observations indicate that the dust distributions are compact, with sizes on the order of a few parsecs with no clear differences between Seyfert 1 and Seyfert 2 galaxies. Most targets have been observed only with the shortest baseline UT2-UT3, and remain unresolved within the errors (which are dominated by the measurement of the total flux F_{tot}). Additional observations with longer baselines will be required to determine the size and flux of their dust tori (if present). Despite its northern declination (+40°), we recently managed to observe the nearest Seyfert 1 galaxy, NGC 4151 with the VLTI. It is clearly resolved at $\lambda \sim 10\,\mu$m with a 60 m baseline. But, seen from the VLTI, the uv-coverage of this Seyfert 1galaxy will always remain very limited. The closest southern Seyfert 1 galaxy which is bright enough for MIDI observations, NGC 3783, is three times more distant than NGC 4151. To get a direct comparison, more distant (and luminous) Seyfert 2 galaxies have to be studied as well.

Summary

At first sight, our results for the dust structures in the Seyfert 2 galaxies NGC 1068 and Circinus look quite similar: they both contain an elongated inner component which is embedded in a larger dust distribution, heated to about 300 K. The observed difference in torus size is expected from the fact that NGC 1068 is about 10 times

Abb. III.3.6: Hydrodynamical torus model. The left and middle panels show the gas density and temperature in a meridional slice. The right panel displays the image at $\lambda = 12\,\mu$m which would be observed from an edge-on view onto this torus. The simulations refer to an AGN that is about five times more luminous than NGC 1068.



Name	Type	z	Scale [mas/pc]	SN(core) [mJy]	MIDI	Remarks
NGC 253 core	LE	0.00080	57.3	1100	–	no fringes detected
*NGC 1068	S2	0.00379	14.0	15000	×	well observed (16 visibility points), see text
NGC 1365	S1.8	0.00546	11.0	610	×	marginally resolved in snapshot survey
IRAS 05189-2524	S2	0.0425	1.0	550		AO correction with MACAO failed
MCG-5-23-16	S1.9	0.00827	5.7	650	×	done in snapshot survey
Mrk 1239	S1	0.0199	2.5	640	×	done in snapshot survey
NGC 3281	S2	0.01067	4.4	620		AO failed on nucleus, nearby star not used
*NGC 3783	S1	0.00973	5.0	590	×	observed by Beckert et al., 2008
NGC 4151	S1	0.00182	14.0	1400	×	resolved in snapshot survey
3C 273	QSR	0.1583	0.3	350v	×	one interferometric measurement
Centaurus A	RG	0.00332	53.0	1220	×	first results with short baselines, see text
IC 4329 A	S1	0.01605	3.1	420	○	fringes detected
*Mrk 463	S1	0.0504	1.0	340		not yet tried
Circinus	S2	0.00145	50.0	9700	×	well observed (21 visibility points), see text
NGC 5506	S2	0.00618	8.0	910		AO correction with MACAO failed
NGC 7469	S1	0.01631	3.1	410	○	fringes detected
NGC 7582	S2	0.00539	9.0	320		no fringes detected

Table. III.3.1: Target list and results of the AGN snapshot survey carried out during MIDI guaranteed time observations (GTO). Targets marked by * were released from the GTO list early. The signs × and ○ in the column "MIDI" indicate successful MIDI observations (×: complete interferometric measurement, ○: fringes detected, but unstable weather conditions prohibited complete observation).

more luminous than Circinus. In both sources, the inner component is aligned with the location of water masers.

On the other hand, one might argue that the differences between these objects are even more significant: only in NGC 1068 do we find dust heated to almost the sublimation temperature, while in Circinus any strong temperature gradient between the innermost dust and outer parts of the torus is absent. Moreover, the elongation of the hot dust component in NGC 1068 appears significantly tilted with respect to the source axis as defined by the radio jet and the ionisation cone, whereas the dust disk in Circinus seems to fit perfectly into an axisymmetric torus model. The outer torus in Circinus appears patchy or filamentary, as predicted by hydrodynamical models. The low absorption depth in the silicate feature towards the inner component indicates that our line of sight towards the dust disk is not severely blocked by the outer structure ,and most of the large hydrogen column towards the X-ray core must be located within $r = 0.2$ pc. In contrast, NGC 1068 exhibits a huge dust column towards the hot component. Here most of the absorbing gas and dust is located *outside* a radius of ~ 1 pc.

From these differences, it seems evident that the torus in the Circinus galaxy is not just a scaled-down version of that in NGC 1068. Thus, the question arises: Is there such a thing as the standard torus in Seyfert galaxies? In any case, the "torus" possesses a complex structure, which not only *appears* different (due to line-of-sight effects) but may also differ *intrinsically* between individual AGN. This is not necessarily in conflict with the essential assumption of the unified scheme: it is still possible that Seyfert 1 and Seyfert 2 galaxies are intrinsically the same class of objects. In order to verify this generic assumption, one has to prove that similar tori as in NGC 1068 and Circinus also exist in Seyfert 1 galaxies. The detection of an extended component in NGC 4151 with MIDI marks a promising first step in this direction. Finally, our results on Centaurus A demonstrate that the absence of broad emission lines cannot always be explained by an obscuring torus. Intrinsic properties of the accretion flow onto the black hole might be equally important.

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In collaboration with:
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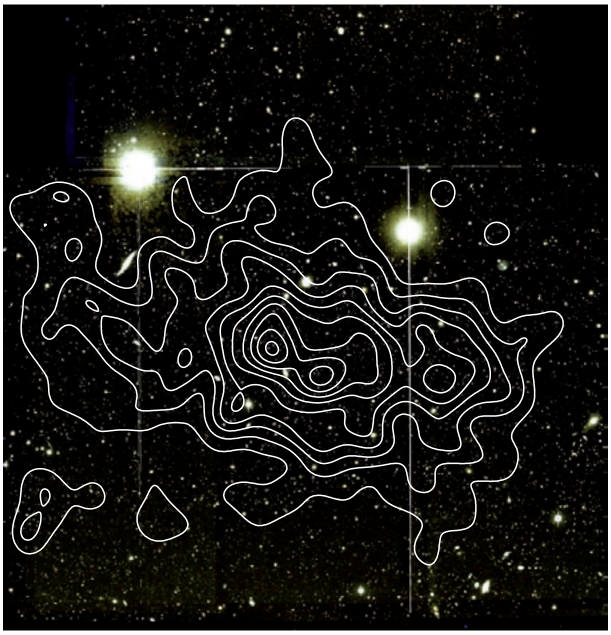
III.4 The Faintest Galaxies

How faint can a galaxy be? All galaxies, large or small, are concentrations of stars and gas at the center of a massive dark matter halo. But were the conditions met in all dark matter halos for stars to form? Over the last few years, numerous new dwarf galaxies have been discovered around the Milky Way, some of them with a hundred times fewer stars than any known before. The fact that an entire galaxy may consist of only a few hundred stars, far fewer than most globular clusters, has challenged our views on what a galaxy could be and how they could form. As such, much remains to be understood of these darkest systems of the universe, in order to use them as probes of cosmology. The faintest galaxies in the universe have become a newly revitalized research frontier.

Dwarf galaxies play an essential role in the formation of large galaxies. Throughout time, it is their absorption by their more massive counterparts that helped create galaxies that we observe today, such as our own Milky Way. The stellar content, the dynamical and kinematic properties, the spatial distribution around and the rate of infall of dwarf galaxies onto their host can all be linked to the cosmological properties of the Local Group. The small number of known dwarfs have, however, been a persistent conundrum: not only does a sample of 10 – 20 objects (the only ones that had been detected as of 2004) limit the amount of reliable information that one can extract on the cosmology, but also comparisons with dark matter simulations reveal that one should expect vastly more small dark matter sub-halos orbiting the Milky Way or other galaxies, compared to the number of observed Local Group satellites (that is, dark matter sub-halos containing stars). To reconcile simulations with observations, it has been postulated that dark matter sub-halos that are not massive enough in the early ages of the universe simply cannot retain enough gas, the necessary fuel to form many stars throughout time. This leads to dark, or at least extremely faint systems, whose detection is highly challenging. Indeed, wide field surveys of the two massive spiral galaxies of the Local Group, the Milky Way and the Andromeda galaxy, are revealing that they are surrounded by many more dwarf galaxies than was previously known: over the course of only a few years, their number has at least doubled.

The new systems, which lack the brightness to appear on photographic plates previously used to map the Local Group, are extremely dim and extend the realm of galaxies to objects that are 100 times fainter than before. Fig. III.4.1 illustrates the difficulty in finding these galaxies: the sky image, one of the first to be obtained with the Large Binocular Telescope, does not reveal any obvious concentration of light that one could assume to be a galaxy. However, if one considers each of the very faint stars of this field individually, they are found to distribute themselves in a clear overdensity, represented by the white contours. The challenge of finding these faint systems resides in the necessity to work with relatively deep surveys that cover a significant fraction of the sky and in which the distribution of faint stars can be studied on large scale. Two surveys with a strong involvement from the MPIA or MPIA scientists have been instrumental in reshaping our view of the Local Group satellite system: the Sloan Digital Sky Survey (SDSS), whose mapping of one quarter of the halo of the Milky Way revealed at least ten new galaxies, and the Panoramic Andromeda Archaeological Survey (PAndAS), which has currently observed more than half of the halo of the Andromeda galaxy and tripled the number of dwarf galaxies known to orbit this large spiral galaxy. Fig. III.4.2 and III.4.3 show the newly found galaxies around the Milky Way and Andromeda and, given the large fraction of the sky that remains to be surveyed, underline how incomplete our knowledge of the satellite system of the Local Group remains.

Fig. III.4.1: The Canes Venatici I dwarf galaxy observed with the Large Binocular Telescope. The galaxy itself is not visible on the image, but a mapping the distribution of faint stars in the field reveals a clear overdensity, traced by the white contours.



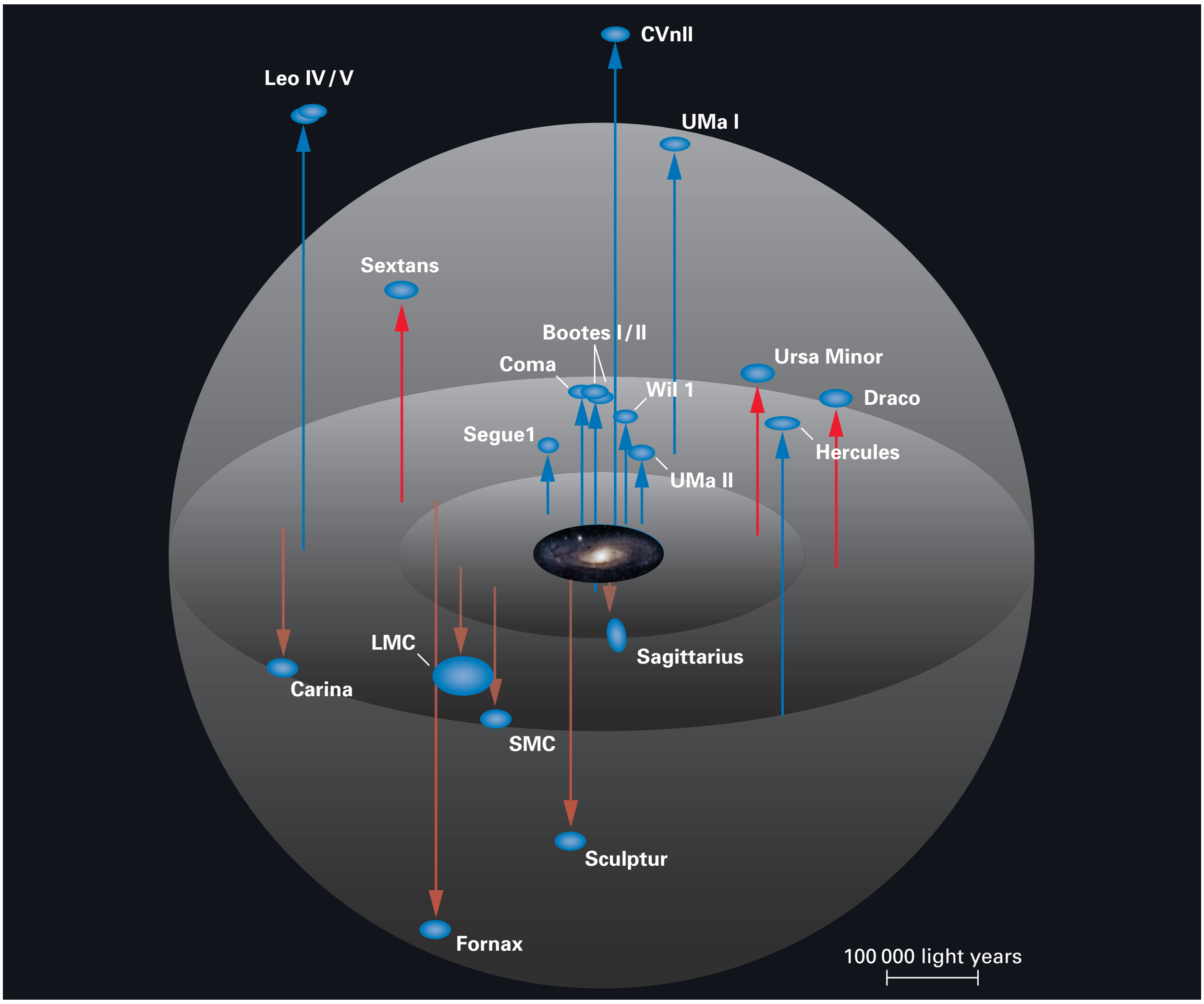


Fig. III.4.2: The distribution of satellite dwarf galaxies around the Milky Way. Systems known before the 21st century are indicated with red arrows whilst the numerous newly discovered systems found with the Sloan Digital Sky survey since 2004 are indicated with blue arrows. The coverage of the survey, which only covers one quarter of the sky, explains the anisotropic distribution of these satellites and highlights how incomplete our knowledge of Milky Way satellites is in other regions of the sky.

The most dark matter-dominated systems in the universe

The degree to which the discovery of these satellites solves the discrepancy with the number of dark matter sub-halos in simulations is still a matter of debate, as hundreds (and not tens) of dwarf galaxies should have been discovered if every sub-halo were to contain stars. The nature of the new discoveries, and whether they truly are dark matter dominated, is evidently a crucial point for this comparison. Such confirmation comes from spectroscopic surveys of their brightest stars, whose motion can be linked to the potential well in which they reside. In the absence of any dark matter halo, stars cannot move rapidly with respect to one another without having the satellite (a simple star cluster, in this case) evaporating. On the other hand the stars observed in these new systems span a range of radial velocities that betrays the presence of a large fraction of invisible matter, just as for brighter, previously known, dwarf galaxies. Thus, they are likely to also be dwarf galaxies, albeit with very low total brightness. But their faintness has another important consequence. Given that their dark matter mass is, under the most conservative assumptions, not much lower than that of brighter dwarf galaxies, their puny stellar content makes them the most dark matter dominated systems known in the universe, as shown in Fig. III.4.4. It therefore appears that dwarf galaxies, whether the bright ones or the faint new ones, all inhabit dark matter halos that are much more similar in dark matter mass than in stellar content.

Some mechanism has prevented stars from efficiently forming in the newly discovered systems. This also means that in these dwarf galaxies, stars and gas are un-

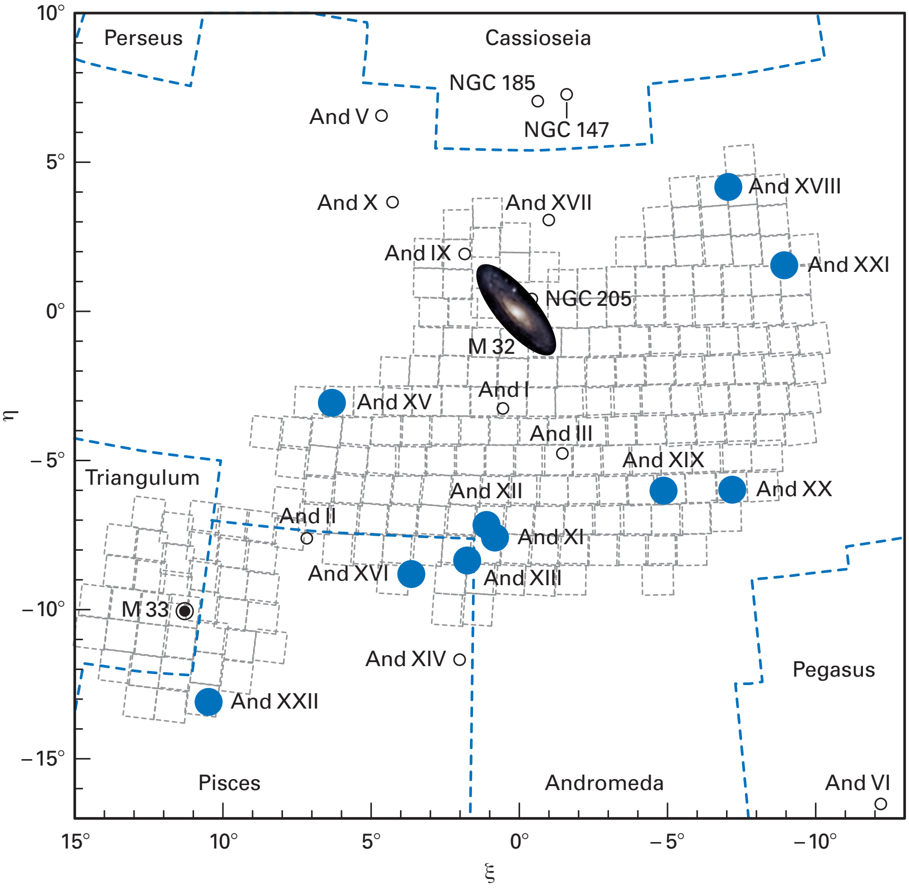


Fig. III.4.3: The distribution of satellites around the Andromeda galaxy. The extent of the PAndAS survey is represented by the dotted squares, and the 10 new satellites are highlighted in blue. The vast coverage of the survey can be deduced from the limits of the sky constellations.

likely to have strongly influenced the dark matter halo itself, making them the ideal laboratory with which to improve our understanding of the properties of the elusive dark matter particles.

But are these dwarf galaxies simply the faint siblings of their brighter counterparts or do they represent a new family of galaxies, with somewhat different properties, that have eluded us until now? More and more effort is now being spent on trying to understand whether these systems reflect the faint end of the dwarf galaxy luminosity function, whether they are remnants of brighter progenitors, or whether they are entirely different objects. Such studies are, however, based on the observed properties of these systems, which are very difficult to obtain given the very low numbers of stars one has to work with. As a simple comparison, both Bootes I (one of the new discoveries) and Draco (the previous faintest galaxy known) are systems containing similarly "metal-poor" old stars, at similar distances from us, yet their difference in brightness means that the number of stars observable in Bootes I is only about a tenth of that of Draco. Characterizing these systems therefore requires careful statistical analyses to study the impact that such small data sets have on the calculated overall properties, or requires obtaining very deep observations of these systems to reveal their more numerous faint stars. Both of these avenues of work are currently being explored at the MPIA.

A comprehensive study of the darkest galaxies

The SDSS has been an invaluable tool in discovering faint dwarf galaxies around the Milky Way, but much remains to be done to learn all we can from survey data alone. To reach this goal, a team led by MPIA scientists Nicolas Martin, Jelte de Jong and Hans-Walter Rix has, for the first time, performed a comprehensive and homogeneous analysis of all the new discoveries from SDSS data. This analysis has been focussed on two main aspects: an accurate measure of the spatial structure of the faint galaxies and, in parallel, a modeling of their stellar populations as well as how the small number of their stars impacts on these determined properties.

The new dwarf galaxies are, like their brighter siblings, spheroidal balls of stars moving within their dark matter halo. However, it has been realized that they are more flattened than previously known dwarf galaxies, up to the point that they sometimes appear quite "cigar-like". It is currently unclear what mechanism could

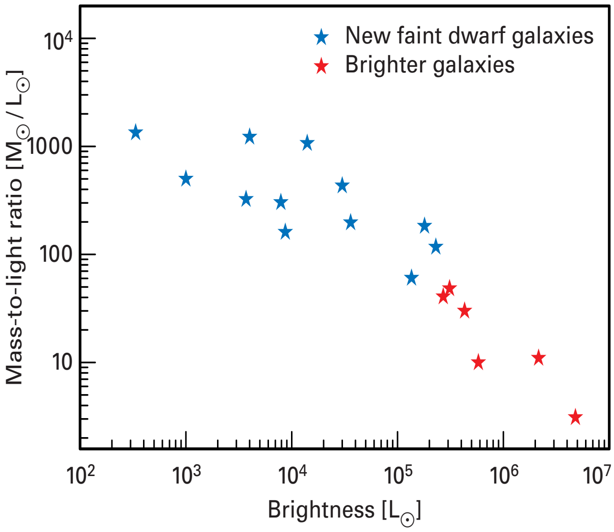
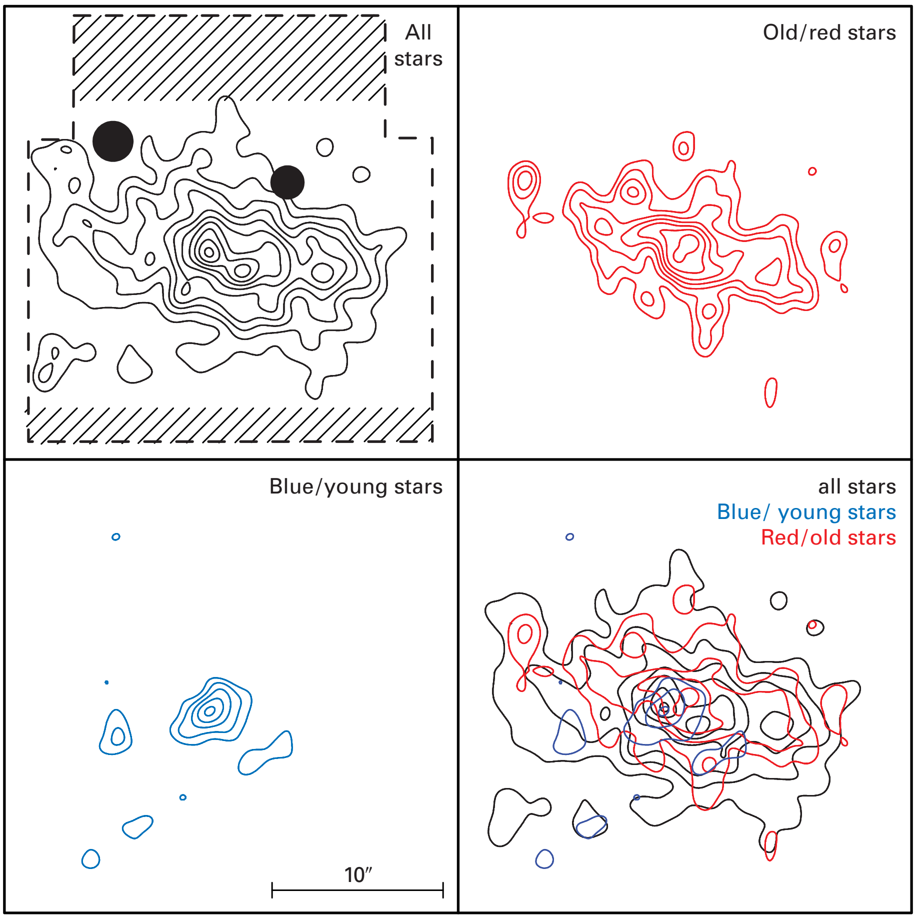


Fig. III.4.4. The ratio of mass to light measured in Milky Way dwarf galaxies. All dwarf galaxies have a similar mass, which translates in ratios reaching very high values for the darkest galaxies (blue points) that are much more dark matter dominated than the previously known (brighter) galaxies shown in red.

have driven the stars into such a morphology. Could they in fact be disk galaxies, seen from an inclined angle, instead of being spheroidal systems? Although this would be an appealing solution, no sign of rotation has been discovered in these systems. Could we be seeing the influence of their massive dark matter halo on their very few stars, which are forced to distribute themselves in accordance with the shape of the halo? Or is their elongation the consequence of the Milky Way's tidal forces tearing them apart and slowly transforming them into stellar streams? There is currently no observational evidence of stars escaping these systems but, given how dim the galaxies themselves are, such tidal streams would be exceedingly sparse and very difficult to observe.

The apparently irregular morphology of the new faint galaxies – visible, for instance in Fig. III.4.5 – has also been argued to be the sign of tidal distortion induced by the presence of the nearby Milky Way. In fact, if one is to account accurately for the small number of observable stars in one of these galaxies, it becomes obvious that this is a premature conclusion produced by observation-

Fig. III.4.5: The galaxy shown in Fig. III.4.1 has a complex structure that includes a double core at its center (top-left panel). Isolating stars based on their age reveals that this double core is due to the presence of a stellar cluster of young stars, offset from its center (bottom-left panel) whilst the bulk of its stars are distributed over all the dwarf galaxy (top-right panel). The bottom-right panel directly compares the two populations.



al limitations. This is also problematic for another property of galaxies that is usually seen as immutable: their global brightness. In brighter dwarf galaxies, there are enough stars that one is always observing a system that is globally the same, independent of the evolutionary state of a single star. The measured brightness of faint satellite galaxies strongly depends on whether they have one or two stars that are becoming giant branch stars, reaching the luminosity of about 3000 suns. As this happens, the brightness of the galaxy itself can be multiplied by 10! These issues lead to a fundamental limit on the understanding of these stellar systems and only by studying the population of faint galaxies in its entirety can we hope to alleviate these limitations induced by the analysis of individual systems alone.

Recent research at MPIA has also focussed on investigating the properties of the faint galaxies' stars. Simple models would suggest that these systems might not have evolved much since they formed their first stars in the early ages of the universe. They should therefore contain only old stars that are "metal-poor", meaning that these stars were not able to reprocess and enrich the surrounding gas and are therefore very deficient in elements heavier than helium. Consequently, it came as a surprise that some of the newly discovered systems, whether they reside around the Milky Way or around Andromeda, present signs of the presence of multiple stellar populations. In more than one faint galaxy, even the shallow SDSS data show evidence of extended periods of star formation, as well as the presence of stars enriched in metals. They therefore do not appear to be the simple systems one would naively have imagined them to be, and they certainly will prove invaluable in constraining models of how galaxies form stars.

This discovery has been confirmed by the systematic survey that the MPIA is currently conducting to observe all of the new dwarf galaxies with either the Hubble Space Telescope or eight-meter-class telescopes. From these, it has been possible to map the stellar contents of the satellites and track how the different populations of stars distribute themselves. Fig. III.4.5 shows how the stars of the galaxy already presented in Figure III.4.1 can be separated into an old and extended stellar population – the typical population that one would expect in such a galaxy – and a puzzling group of young stars. Unexpectedly, these are less than 2 billion years old and very clumped in the galaxy. Something must have happened recently in this galaxy for these stars to be present: either it has absorbed a nearby young stellar cluster (but such a cluster should be the rarest of oddities in the remote regions this galaxy inhabits) or it retained enough gas through its history to fuel the formation of this cluster in its womb. This provides ample evidence that the darkest galaxies are far from being simple stellar systems and, together with other such observational evidence, epitomize a complexity that is reminiscent of their brighter counterparts.

The PanStarrs 1 sky survey, covering more area and imaging more deeply than SDSS, offers the next opportunity to pursue our census of the faintest galaxies in the Universe. The "Milky Way and Local Group" key project in this survey is lead by MPIA, promising more discoveries in the years to come.

Nicolas Martin, Jelte de Jong, Hans-Walter Rix

IV. Instrumental Developments and Projects

At the MPIA, present instrumentation activities and projects include high-fidelity imaging instruments for the LBT and the ESO VLT, interferometric instruments for the VLT Interferometer, studies of future instruments for the E-ELT, and survey instruments for Calar Alto and the Whise Observatory, as well as participation in the survey projects PanSTARRS, SDSS-III and HAT-South. In space-based astronomy, MPIA is engaged in the development and operation of focal instruments for the HERSCHEL and JWST missions, in phase A studies for the ESA Cosmic Vision projects EUCLID, PLATO and SPICA, and in the GAIA mission.

IV.1 Instruments for the LBT

LUCIFER 1 and 2: Multi-Mode Instruments for the Near Infrared

Each of these two identical systems consists of a highly resolving infrared camera, a long-slit spectrograph, and a multi-object spectrograph; they will be the central infrared devices on the LBT.

The outstanding event for LUCIFER in 2008 has been the acceptance in Europe of the first instrument by LBTO in July and its following commissioning time: Struggling hard against technical problems during the summer, the LUCIFER team has made large and successful efforts to keep the project in schedule. Even the very complex multi-object spectroscopy mode MOS has been implemented and accepted in time.

Following the acceptance review, LUCIFER 1 was packed in Heidelberg and shipped via aircraft to Tucson. In August LUCIFER I was re-integrated on Mt. Graham, and finally on September 7th the first image could be taken and the first commissioning run was performed. Since then the observational capabilities LUCIFER in NIR imaging and spectroscopy have been tested successfully during several commissioning runs.

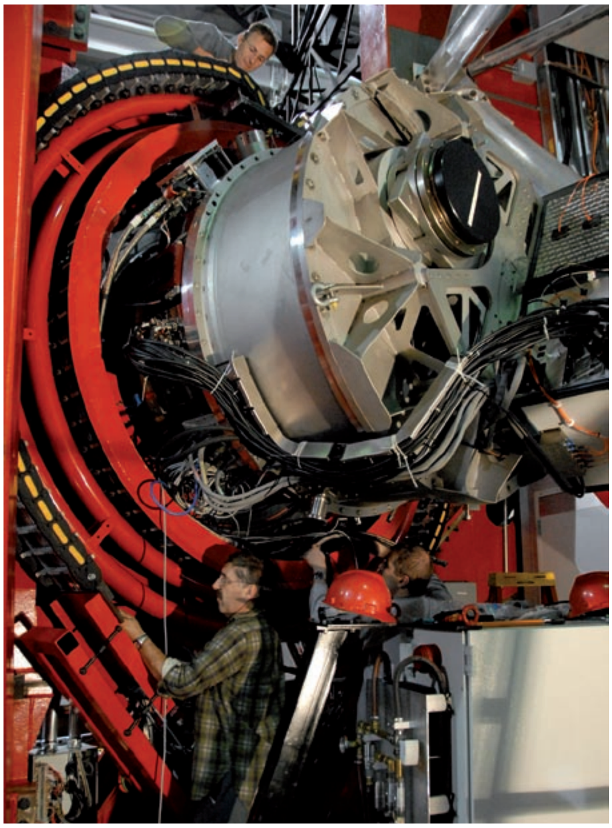


Fig. IV.1.1: LUCIFER 1 during the integration at the LBT, cables and the flexible tube for the cooling system are mounted.

The adaptive optics mode at LBT is not yet available. Thus, until now the high resolution camera f/30 has not been commissioned. Currently the assemby of LUCIFER 2 is being prepared at MPIA, its integration and commissioning will follow about one year later.

Werner Laun, Michael Lehmitz, Rainer Lenzen.
In collaboration with LSW Heidelberg,
MPE Garching and other partners.

LINC-NIRVANA – The Interferometric Imager

LINC-NIRVANA (LN) is a Fizeau-type interferometric imaging instrument for the Large Binocular Telescope (LBT) in Arizona. Operating in the 1.0 – 2.4 μm wavelength range, LN will combine the light from the two 8.4 m diameter primary mirrors of the LBT onto a single focal plane, producing panoramic imagery with a sensitivity corresponding to that of a 12 m telescope and a spatial resolution that would normally require a 23 meter telescope. LINC-NIRVANA is a large (6 × 5 × 4.5 m) and complex device. In many ways, it is a precursor of the instrumentation for future Extremely Large Telescopes.

During 2008, the LINC-NIRVANA team continued to make steady progress on the assembly, integration, and testing of the instrument. Highlights during this period include completion and testing of one arm of the warm optics in the LBT laboratory. This environment permits easier performance verification and testing than on the elevated optical bench in the integration hall.

Several cryogenic components were completed in 2008. These include the critical detector support mechanism, which must provide cooling and electrical connections for the infrared sensor, while also de-rotating the detector to follow the sky. The LN team has also been working closely with the MPIA and Arizona groups who are characterizing the vibration environment of the LBT.

Verification and flexure testing of individual subsystems on the LN bench revealed a number of components which were not delivered according to specifications, requiring re-design or modification. While disappointing, this thorough checking is a prerequisite to the success of a complex instrument such as LN. Finding such nonconformities at the telescope would lead to considerably greater expense and time delay.

The Design Reference Mission science teams, together with the data reduction software groups in Bonn and Genova, continued their collaborative work throughout

Fig. IV.1.2: The LINC-NIRVANA warm optics under test in the LBT laboratory.

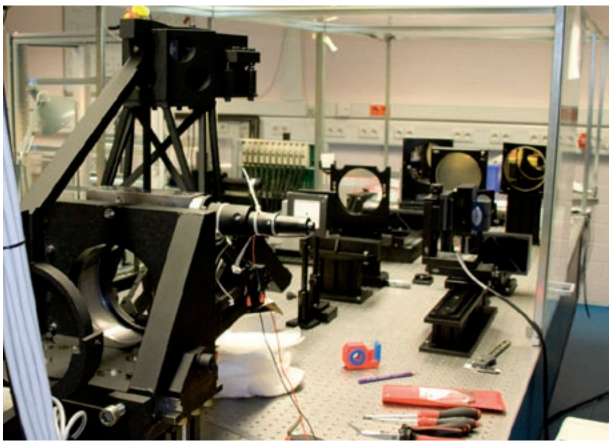


Fig. IV.1.3: The detector rotation unit prior to a cold vacuum test.

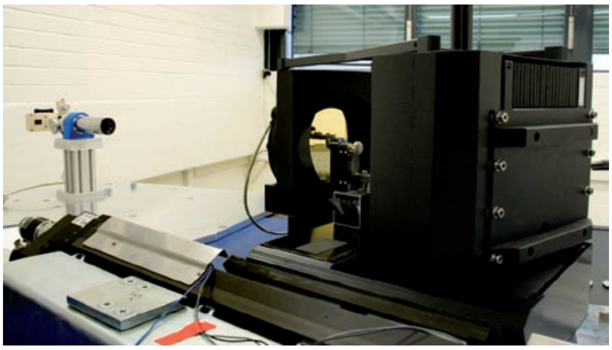


Fig. IV.1.4: Flexure testing of components on the LINC-NIRVANA optical bench.

2008. There now exists a substantial infrastructure to simulate realistic LN images, which can be reduced and analyzed exactly like the real data. These simulation exercises have helped refine the LN science case, as well as streamline the observation preparation software and the observer interface.

LN is a collaboration between the German and Italian LBT partners, with major contributions coming from MPIA Heidelberg, INAF (Padova, Bologna, Arcetri, Rome), Cologne, and the MPI for Radioastronomy in Bonn.

H. Baumeister, Th. Bertram, J. Berwein, P. Bizenberger, A. Boehm, L. Borelli, F. Briegel, M. Brix, F. De Bonis, M. Egner, R. Follert, W. Gässler, T. Herbst (PI), F. Kittmann, M. Kürster (PM), F. Labadie, W. Laun, U. Mall, D. Meschke, L. Mohr, V. Naranjo, A. Pavlov, H.-W. Rix, R.-R. Rohloff, E. Schinnerer, S. Schmidt, J. Schreiber, C. Storz, J. Trowitzsch, K. Wagner
in collaboration with:
INAF (Padova, Bologna, Arcetri, Roma, Genova), University of Cologne, MPIfR Bonn

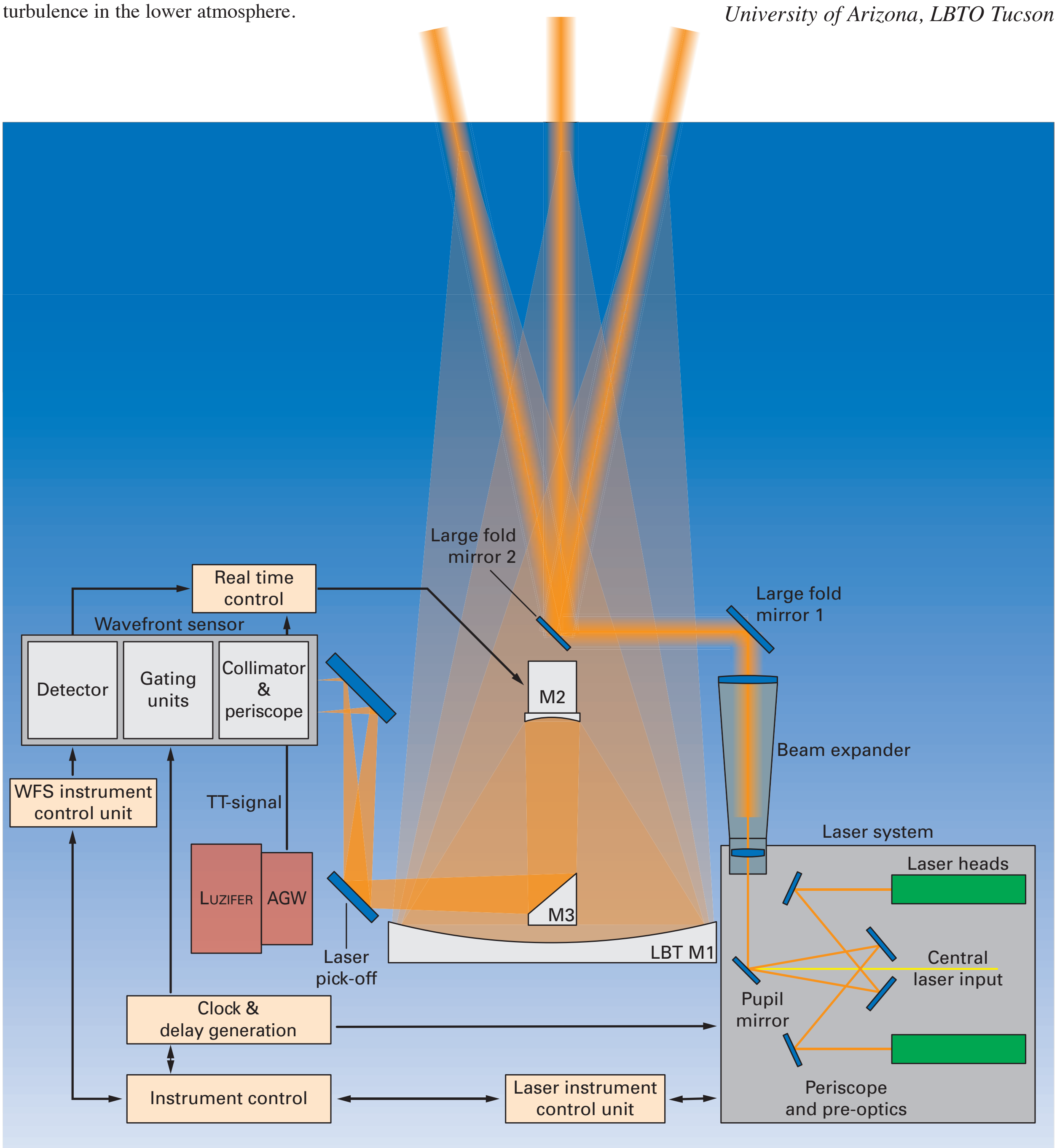
ARGOS – The Advanced Adaptive Optics System

ARGOS, the Advanced Rayleigh Ground layer adaptive Optics System for the LBT, aims to improve the atmospheric seeing within a wide field of view by a factor of at least 1.5 in full width half maximum, as well as the energy concentration by at least a factor of 2. At the same time telescope efficiency will be improved by an enhanced operability above median seeing.

Fig. IV.1.5: The ARGOS system of one LBT eye. Three lasers are launched over the back of the adaptive secondary mirror on sky. The light scattered back at 12 km altitude is sensed with a wavefront sensor and the signals are used to correct for the turbulence in the lower atmosphere.

In March Phase A (planning) was finished with a successful review. The feasibility of such a system was demonstrated and it was shown that LUCIFER, the near infrared imager and multi object spectrograph of LBT, will benefit most from its prompt implementation. The project went directly into Phase B, which will end with the preliminary design review in February 2009. The MPIA is responsible for the overall software and control, as well as the calibration scheme and calibration unit for the system.

Wolfgang Gässler, Diethard Peter, Thomas Blümchen, in collaboration with: MPE Garching, INAF-OAA Florence, LSW Heidelberg, AIP Potsdam, University of Arizona, LBTO Tucson



Characterization of the LBT

The Vibration Monitoring System

The installation of a vibration monitoring system at the LBT was begun in order to systematically monitor of the vibration behaviour of the telescope structure. The system constitutes a joint venture of the LINC-NIRVANA team and the team at Steward Observatory, Tucson, that develops the American interferometer LBTI. Both groups jointly define and purchase or develop the hardware and software required for the monitoring system. The LBT observatory has a supporting role especially during installation.

Fig. IV.1.6: Test measurements with accelerometers attached to the recently installed rigid secondary mirror of the LBT. Reflected in the mirror one can see the instrument platform with LUCIFER 1 at the far right mounted in its derotator.

A total of 45 accelerometers will be attached to the primary, secondary and tertiary mirrors as well as at the mounting points of both interferometers. In its initial phase the system will serve to identify the main vibration sources and to remove them as far as possible or, at least, to mitigate them. In a later phase the accelerometer signals will be inserted into the main interferometric control loop that compensates the optical path differences between the two telescopes of the LBT.

Martin Kürster, Mario Brix, Vianak Naranjo, José Luis Borelli, Tom Herbst, Wolfgang Gässler, Thomas Bertram, Frank Kittmann. In collaboration with the LBTI and LBTO teams

The Differential Image Motion Monitor

During 2008, the MPIA delivered the Differential Image Motion Monitor (DIMM) to the Large Binocular Telescope. DIMM provides observers with a measure of the current seeing conditions, information that is essential to the success of scientific observations, as well as to ongoing commissioning and testing of the telescope and its instruments. With longer term monitoring, we hope to correlate the seeing measurements with other seasonal and meteorological indicators to help predict upcoming observing conditions and allow more effective planning.

DIMM determines the seeing by measuring the differential motion of a stellar image as the light takes two different paths through Earth's atmosphere. A single small telescope equipped with a mask and glass wedges produces the two separated images of the star, and a high-speed digital camera records 5 to 10 millisecond exposures to freeze the stellar positions. Because the technique relies on the differential motion of the images, the DIMM is insensitive to vibrations, windshake and tracking errors.

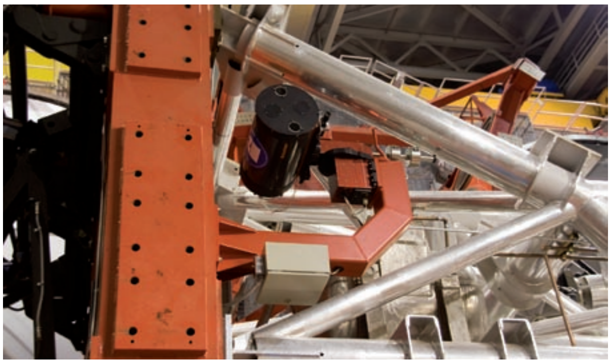


Fig. IV.1.7: The MPIA DIMM (the small telescope on J-shaped mount) located near the top end of the Large Binocular Telescope. Note the two apertures to select different paths through the Earth's atmosphere.

Due to construction restrictions at the LBT site, DIMM is mounted on the telescope itself. Although not strictly in free air, this location permits an unambiguous evaluation of the best possible imagery delivered to the LBT instruments. As such, it is an ideal complement to ongoing commissioning activities. Mounting DIMM on the LBT presented significant challenges, however, since the device must point at and track a target while the LBT, to which it is attached, points at and tracks a different target.

During 2008, the team commissioned DIMM and performed several campaigns of seeing measurements. The next goal, scheduled for early 2009, is to increase the level of automation and hand the instrument over to the LBT Observatory.

Johannes Schmidt, José Luis Borelli, Ralf-Rainer Rohloff, Armin Böhm

The Infrared Test Cameras

There is a fundamental rule of instrumentation development: Do not try to commission and test one complex system with another complex system. Within the Large Binocular Telescope project, there are many such complex systems, including the telescope itself, the fully adaptive secondary mirrors, and the auto-guiding and wavefront sensing units mounted at the various focal stations.

The MPIA, in combination with its partners in Bologna, built and delivered to the LBT a pair of relatively simple infrared test cameras. Operating in the near infrared wavelength range (1.0 to 1.8 microns), these cameras allow the engineers to take rapid sequences of images to capture and measure image motion, transient optical aberrations, and other indicators of telescope and instrument performance. A tenfold zoom lens system permits high angular resolution measurements of individual stars, as well as wider field observations.

During 2008, the Infrared Test Cameras played a central role in commissioning and testing of LBT systems. For example, the first camera has been in daily use in the test tower in Arcetri, Italy to verify performance of the adaptive secondary mirrors. The second unit has seen regular service at both the bent and direct Gregorian foci to commission the focal stations and test the rigid secondary mirror (see Fig. IV.1.8). Throughout all these difficult campaigns, the cameras have performed with extraordinary reliability.

Daniel Meschke, Ralf-Rainer Rohloff,
in collaboration with:
University of Bologna, Bologna Observatory

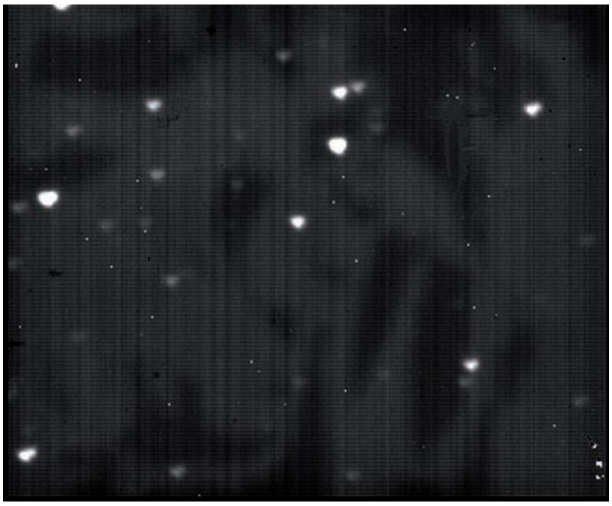
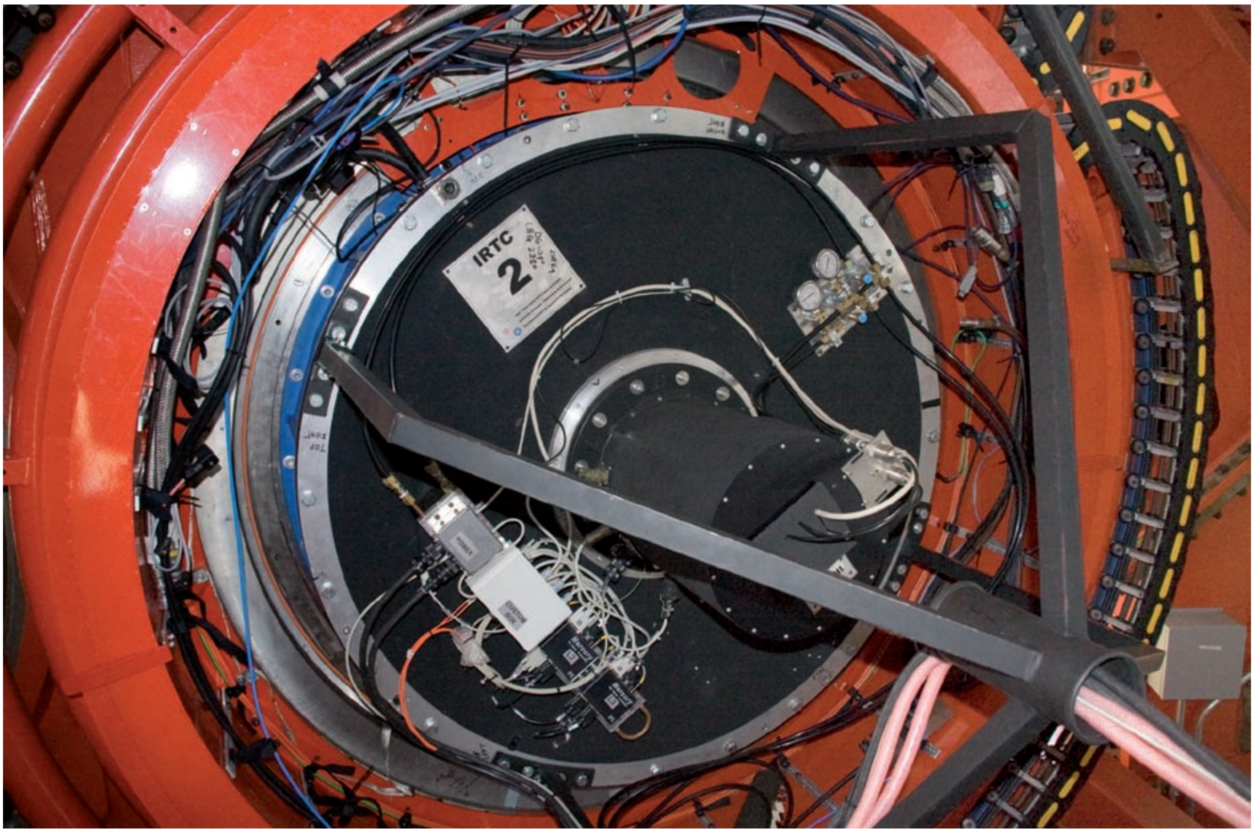


Fig. IV.1.8: *Left* – the First Gregorian Light image taken with the test camera on April 15th, 2008. The full width at half maximum (FWHM) for point sources on this image is approximately 0.6 arcseconds. *Below* – the Infrared Test Camera #2 mounted on the Gregorian focal port of the LBT for telescope tests. Normally, the LUCIFER instrument occupies this location.



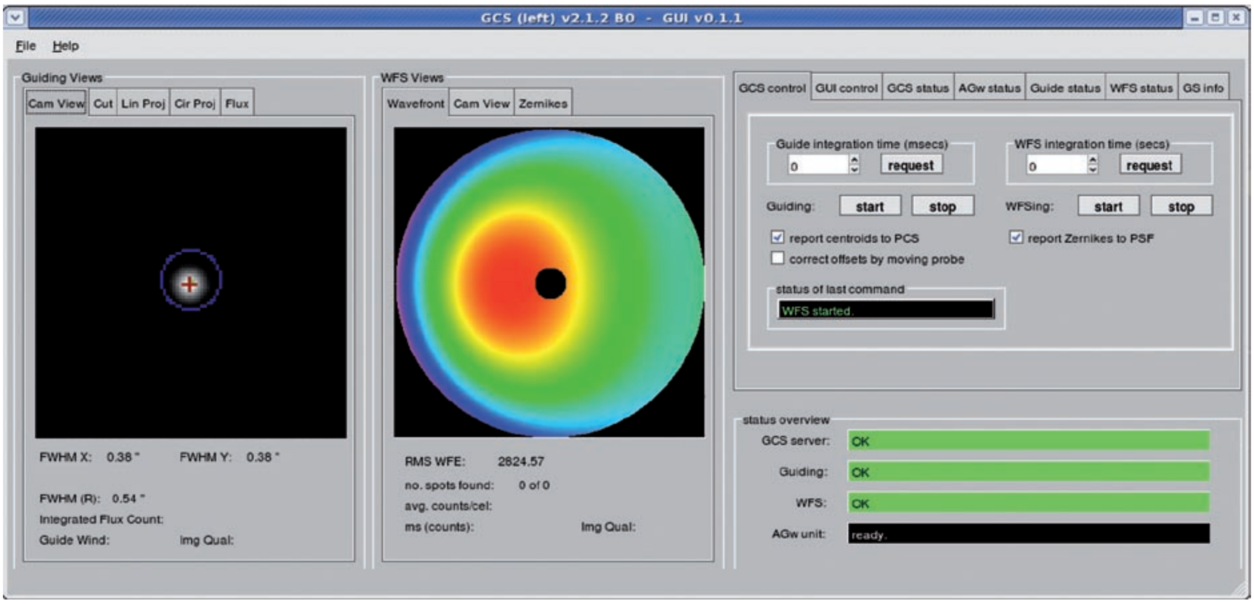


Fig. IV.1.9: Main window of the GCS graphical user interface. The individual areas show (*from left to right*): guide camera image of the guide star, representation of the wavefront reconstructed from the wavefront sensor measurements, GCS control panel (*top*) and status overview (*bottom*).

Telescope Control Software

MPIA contributes to the construction and development of the LBT with two work packages related to the telescope control software.

– IIF, the instrument interface software for the communication between the astronomical instruments and the telescope,

– GCS, the combined software for telescope guiding and control of the primary mirror active optics.

Following its successful performance in routine operation with the two LBC prime focus cameras a strongly modified version of this software was developed for the near-infrared test cameras. Due to its increased flexibility this new version caught the attention of the other instrument builders and is now employed together with LUCIFER 1. It will also be used with MODS 1 in 2009.

The GCS package has also had its first successful operation together with LUCIFER 1, during which it analyzed camera images produced by the Acquisition, Guiding and Wavefront sensing unit. Its commissioning will be continued in 2009.

Martin Kürster, José Luis Borelli, Torsten Leibold, in collaboration with the LBTO software team

IV.2 Instruments for ESO

PRIMA and SPHERE – Second Generation Instruments for the VLT

The Optical Delay Lines for PRIMA

PRIMA, the instrument for Phase Referenced Imaging and Micro-arcsecond Astrometry, will enable the Very Large Telescope Interferometer (VLTI) to perform narrow-angle astrometry in the K-band with two auxiliary telescopes (ATs) as well as phase-referenced aperture synthesis imaging with instruments like AMBER and MIDI. In its astrometric mode, PRIMA will be able to measure the angular separation between two stars that are separated by up to 30 arcsec, with an accuracy of 20 to 30 microarcseconds.

In order to support and speed up the full implementation of this astrometric capability and to carry out a large astrometric exoplanet search program, MPIA, in collaboration with the Observatoire de Genève and the Landessternwarte Heidelberg, has built the Differential Delay Lines (DDLs) for PRIMA and is developing the astrometric observation preparation and data reduction software. In return for this contribution, our consortium has been awarded guaranteed observing time at two ATs to carry out a systematic astrometric Exoplanet Search with PRIMA (ESPRI).

The design of the DDLs has been developed by the consortium in close collaboration with ESO. The DDLs consist of Cassegrain-type, all-aluminum retro-reflector telescopes (cat's eyes) with about 20 cm diameter that are mounted on stiff linear translation stages. A stepper actuator at the translation stage provides the long stroke of up to 60 mm. A piezo actuator at the M 3 mirror in the cat's eye provides an additional fine stroke adjustment over about 10 μm with an accuracy of 1 nm.

Both actuators are driven by one control loop, such that the optical path length can be smoothly adjusted within 120 mm (twice the stroke length) and with an accuracy of 2 nm. Together with an internal metrology sys-

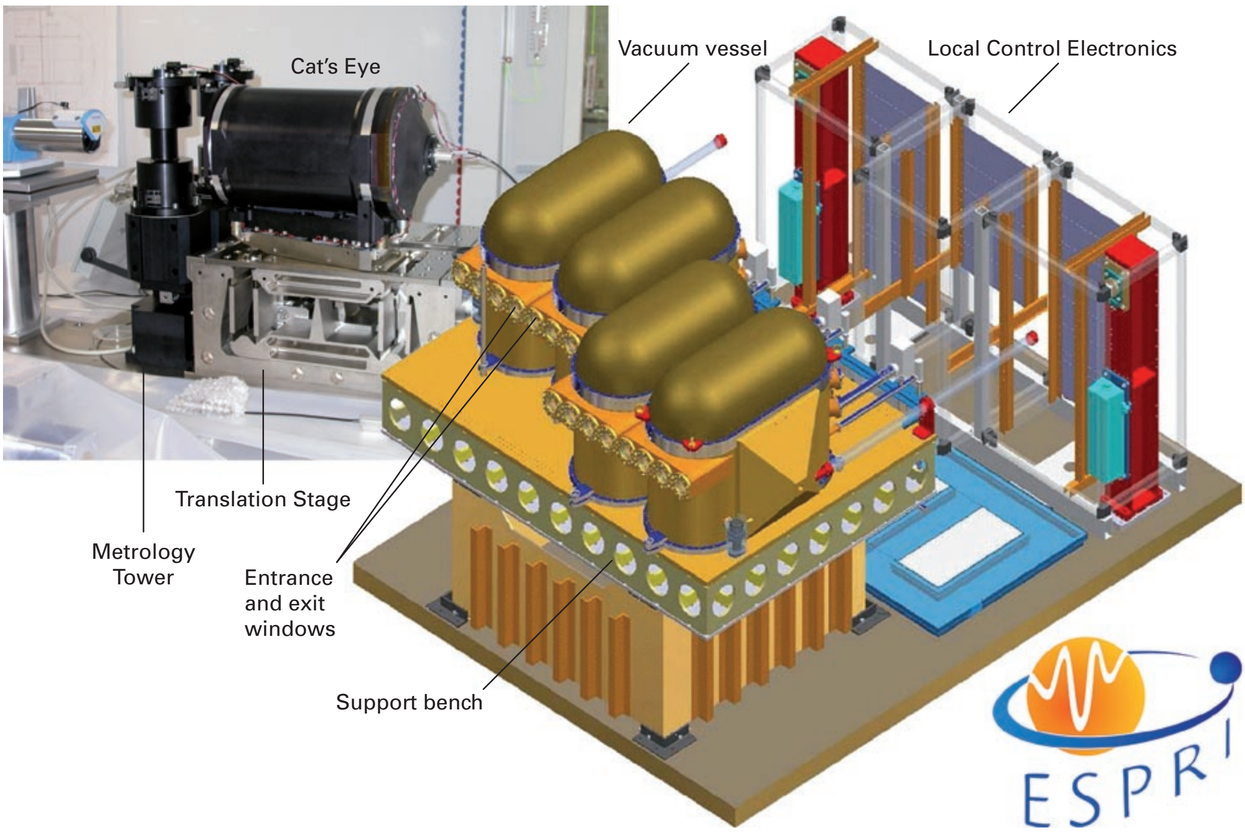


Fig. IV.2.1: Schematic view of the Differential Delay Lines as assembled in the VLTI lab. The top left photograph shows one cat's eye telescope on the translation stage, with the internal metrology tower in front, set-up for acceptance tests in Geneva. Each vacuum vessel contains two such DDLs. *Bottom right:* the ESPRI project logo.

Fig. IV.2.2.: Vianak Naranjo and Harald Baumeister are integrating the Cat's Eye Optics into the DDLs in the VLTI beam combination Laboratory on Paranal in August 2008.

tem, the DDLs are mounted on a custom-made optical bench in non-cryogenic vacuum vessels (Fig. IV.2.1).

The cat's eye telescopes were developed at MPIA and manufactured by AXSYS in Detroit. They where delivered to MPIA between August 2007 and January 2008. In a dedicated optical laboratory at MPIA they were then extensively tested. In March 2008, the cat's eyes were shipped to Geneva, were they were integrated with the other DDL components. In July, the DDLs successfully passed the provisional acceptance review in Europe. Immediately afterwards, the complete DDLs were disassembled, packed, and shipped to Paranal, were they arrived safely within one week.

A large team of engineers from ESO, Geneva, and MPIA started on August 17th, 2008, to integrate and align

Fig. IV.2.3: The complete DDL installation team in front of Cerro Paranal and the VLTI in August 2008. On the right, P. Bizenberger, V. Naranjo, and H. Baumeister (from right) from MPIA.

the DDLs into the VLTI Laboratory on Paranal (Fig. IV.2.2 and Fig. IV.2.3). The integration and alignment went smoothly and without major problems. At the end of this assembly and integration mission, on September 3rd, the team even managed to obtain first fringes with PRIMA on sky using the Fringe Sensor Unit FSU A on a star with $K = 0.44$ mag.

Because fixes of technical problems with Star Separator Units were delayed at ESO, the on-sky commissioning of PRIMA started in October 2008 only with single-star fringe-tracking tests. Altogether, four commissioning runs 10 days each are foreseen in Period 82 between October 2008 and March 2009 to test and optimize the fringe-tracking performance of PRIMA. The goal is to fringe-track on stars up to $K = 8$ to 8.5 mag. Dual-star astrometric commissioning of PRIMA will start only in Period 83 in mid 2009 and will require at least six commissioning runs 10 days each.

When PRIMA will be ready for astrometric operation (expected in 2010, Period 85), we intend to carry out a systematic astrometric Exoplanet Search with PRIMA (ESPRI), which will address the following key questions:

(i) precise determination of the planetary mass distribution,
(ii) detection of new Saturn- down to Uranus-mass planets around nearby stars,
(iii) formation and evolution of multiple planet systems, and
(iv) exploring planet formation as a function of stellar age and mass.

With these objectives in mind, we have defined three lists of potential targets, containing in total nearly 900 stars:

- stars with known radial velocity planets,
- nearby main-sequence stars within 15 pc around the Sun, and
- young stars with ages between 5 and 300 Myr within 100 pc around the Sun.

We are currently carrying out an extensive preparatory observing program to identify suitable astrometric reference stars and to characterize target stars for the planet search. With a final detection rate for reference stars of 10 to 15 percent, we will then monitor between 100 and 150 stars for astrometric signatures of extrasolar planets.

Harald Baumeister, Peter Bizenberger, Uwe Graser, Thomas Henning (PI), Ralf Launhardt (Project Scientist), André Müller, Vianak Naranjo, Tim Schulze-Hartung, Johny Setiawan, Karl Wagner, Patrick Weise, in collaboration with: Observatoire de Genève, Landessternwarte Heidelberg, ESO

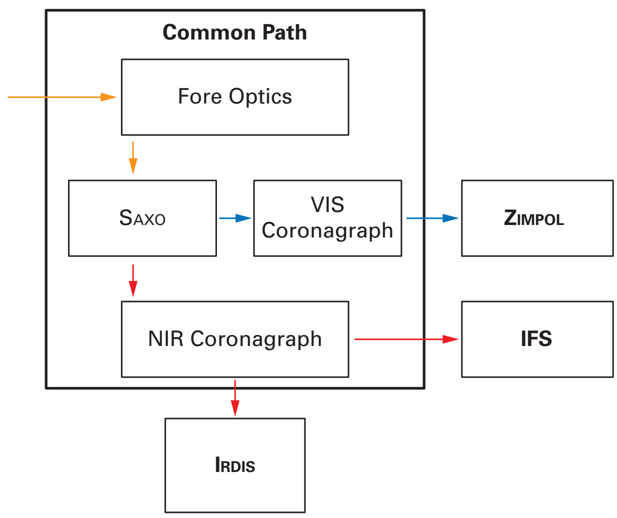
SPHERE – Spectro-Polarimetric High-contrast Exoplanet Research

SPHERE is a Planet Finder instrument for the VLT. Seven years after the first idea was born, the instrument has passed its final design review in 2008 and is now finally under construction.

This project goes back to an idea developed in 2001 at the ESO workshop on 2nd generation VLT and VLTI instrumentation. At this workshop, the conceptual idea of a Planet Finder instrument for the VLT was presented. Subsequently, ESO called for proposals for the realization of such an instrument and received two suggestions: One by a consortium led by the Laboratoire d' Astrophysique de Grenoble (LAOG), the other from a consortium led by MPIA. Two phase-A studies were conducted to prove the validity of the concepts, and on this basis ESO decided to go for a unified concept that now is named SPHERE and includes elements of both original proposals: the adaptive optics concept and the InfraRed Dual-band Imaging and Spectroscopy (IRDIS) camera from the original LAOG proposal and the Zürich Imaging Polarimeter (ZIMPOL), as well as the NIR Integral Field Spectrograph (IFS) from the original MPIA concept.

The specifications on all parts of SPHERE are extremely tight, the goal for the final wave front error on the coronagraphic focal plane is below 36 nm rms, the final closed-loop Strehl ratios achieved on the focal plane detectors being 84 percent for IRDIS at 1600 nm, 74 percent for IFS at 1300 nm, and 46 percent on ZIMPOL at 800 nm. Tight specifications are also put on other quantities.

Fig. IV.2.4: SPHERE consists of four major parts: the common path module, which includes the high-performance AO system SAXO (SPHERE Adaptive optics for eXoplanet Observation) and the advanced coronagraphic devices, the near-infrared dual-band imager IRDIS, the visual differential polarimeter ZIMPOL, and the near-infrared integrated field spectrograph IFS.



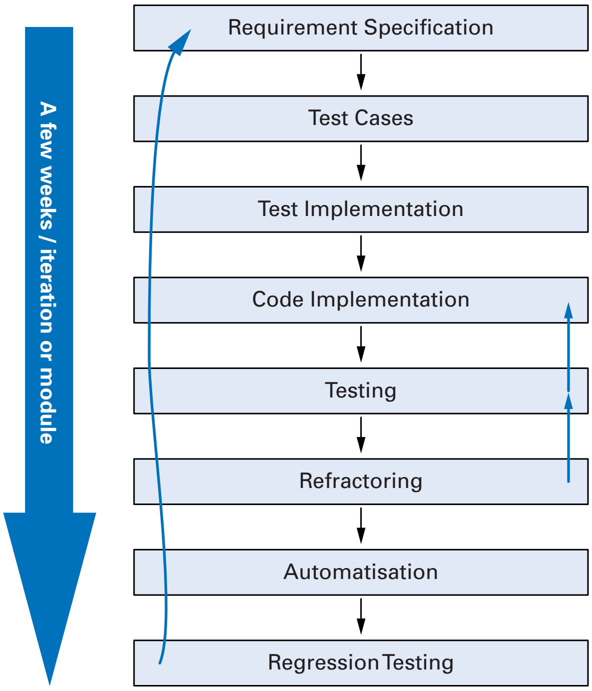


Fig. IV.2.5: Data product association map of the Integrated Field Spectrograph (IFS).

E.g., the accuracy with which the flat field sensitivity of the NIR detectors, two Teledyne HAWAII 2RG arrays, needs to be known at least to 1 percent, the goal being 0.1 percent. In fact, this flat field error, together with residual static aberrations, sets the limit of planet detectability. The true advancement of SPHERE with respect to more conventional VLT instruments lies in the fact that no residual error budget is made and resulting detection limits are taken as given. Instead, it attempts to characterize and calibrate every single remaining error in order to achieve the theoretical performance limit for planet detection on the VLT. As a result, SPHERE will come with a sophisticated data reduction and analysis system, consisting of 79 data reduction "recipes" (highest number so far: 23 for VIMOS) that will handle raw science, calibration, and monitoring data.

For the effort of providing the SPHERE instrument, as well as data reduction and analysis facilities, the consortium will be rewarded 260 nights of guaranteed time. Unlike previous instrument building consortia, the SPHERE team has decided not to split the rewarded guaranteed time up into small individual programs, but to carry out a large, coherent survey pursuing the goal of establishing a detailed picture of planet formation and evolution. The bulk of the survey (200 nights) will be devoted to explore the population of outer giant planets as a function of stellar mass and age. For this purpose, target stars are grouped into 5+1 bins: three bins of stellar mass (earlier than F, G-K, M and later) and two bins of age (young, i.e. a few 10^7 yr, versus mature, i.e. older than 10^8 yr) will be covered along with an additional bin holding "prominent targets". The remaining nights will be split between dedicated observations of circumstellar disks (20 nights), the attempt to discover planets in reflected light using ZIMPOL (about 20 nights), and various smaller programs.

MPIA's responsibility within the SPHERE consortium covers the two atmospheric dispersion correctors, the two most expensive components in the common path module. We are also contributing a dithering stage that will allow the IRDIS HAWAII 2 RG detector to be moved laterally between integrations. This procedure will help to further increase the flatfield accuracy of the system by successively using up to 100 pixels to image a point in the sky and thus averaging down the flat field sensitivity uncertainty. This stage will be operated by so-called piezo actuators, a co-development of Physik Instrumente (P.I.) and MPIA. These actuators, based upon the P.I. NEXLINE series, provide high resolution, large travel range, and a strong holding force while unpowered. We are the first institute to use these actuators under cryogenic conditions: the characterization and validation of the unit is being carried out in MPIA's lab.

The prime responsibility of MPIA, however, is the data reduction and handling system of SPHERE, which includes the aforementioned 79 data reduction recipes. Fig. IV.2.5 shows an exemplary data product association map of IFS. Note the three different calibration recipes for determining the flat field of the instrument – the so-called "detector flat field calibration" is carried out about every 20 minutes in order to ensure accurate understanding of the detector pixel-to-pixel sensitivity variations. Also novelty of the SPHERE instrument are the data analysis recipes, which operate either on the result of the data reduction ("Level 1 data analysis") or on raw data ("Level 2 data analysis") and apply sophisticated methods to analyse the data for the presence of faint point sources in the field – SPHERE's primary science case, the detection of planets.

In a system as complex as SPHERE and its data reduction and analysis procedure, errors that limit the final detectability of extrasolar planets not only originate in the hardware of the system, but also in the data handling. Complex algorithms combine individual frames and correct each of them for de-centering, field rotation, and field distortion, at the same time determining and removing the speckles resulting from (quasi-)static aberrations. Numerically introduced errors are the unavoidable consequence of such complex algorithms. To ensure that these errors do not become dominant in the total budget, we have adopted a complex test and verification scheme that verifies each step of the data reduction and analysis cascade using several classes of simulated (ideal, erroneous, or pre-reduced), as well as real detector data. For each intermediate data product, the resulting accuracy is compared to the requirement in the calibration plan, and its influence on subsequent recipes is carefully tracked.

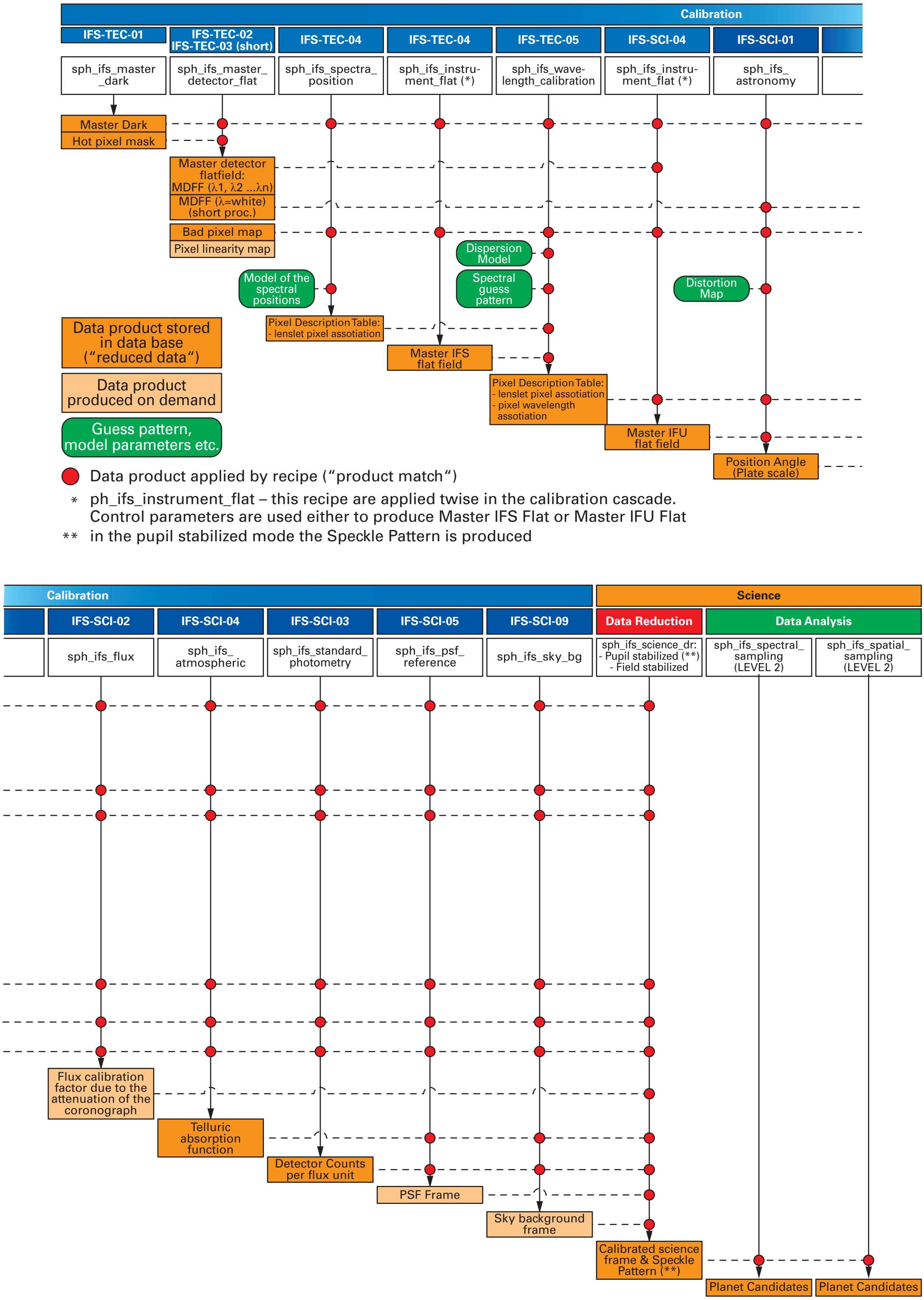


Fig. IV.2.6: Illustration of the concept of agile development chosen für the SPHERE pipeline.

In this way, we will be able to immediately detect a potential error introduced by the data reduction library itself, and seek to resolve it.

The concept of “agile development”, which has been chosen for the SPHERE pipeline and which is illustrated in Fig. IV.2.6 makes it possible to follow exactly the approach described above. Frequent releases of intermediate prototypes will undergo even more frequent testing, and updates and revisions will be made according to the results of the testing and to changed or updated requirements. This has already proven to be very useful in the earlier phases, when the calibration plans themselves were under heavy development and have been described as a “moving target” by the software developers. In the end, this will allow us to continuously supply the most up-to-date version of the SPHERE pipeline software to support all phases of instrument use – from initial subsystem integration and verification, via the system integration and characterization, to the commissioning and science operation phases on the telescope.

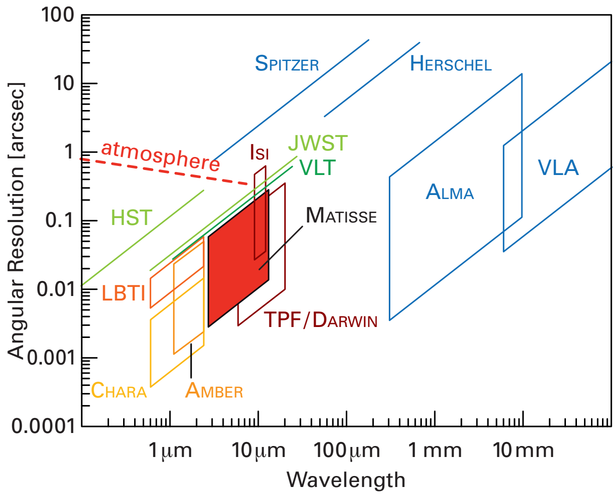


Fig. IV.2.7: The angular resolution of MATISSE as a function of wavelength, compared with other astronomical instruments. The limitation due to the Earth's atmosphere is indicated.

Markus Feldt (Co-PI), Christian Thalmann,
Joe Carson, Thomas Henning (Co-PI),
in collabortion with:
LAOG (Grenoble), LAM (Marseille),
LUAN (Nizza), OPD (Padua),
ONERA (Paris), LESLA (Observatoire de Meudon),
Observatoire de Genève, ETH Zürich,
University of Amsterdam, ASTRON (Leiden)

MATISSE and GRAVITY – Second Generation Instruments for the VLTI

MATISSE – The Multi Aperture Mid-Infrared SpectroScopic Experiment

This is one ot the three second generation instruments for the VLTI, which were selected by ESO in 2006 for a phase-A study. In 2007 the MATISSE consortium obtained from ESO the go-ahead to develop the instrument according to the submitted phase-A study. During 2008 the concept was further refined; the official design phase started with the kick-off meeting held in Nizza in November of this year, the preliminary design review will take place in October 2009.

During the year 2008 the concept of MATISSE evolved as follows: The single, very large cryostat (1.9 × 1.9 × 1.5 m) was replaced by two separated cryostats 1.15 × 0.90 × 1.5 m in size, mounted 52 cm apart. These two units are operated independently behind the table which supports the “warm” optics. The two cryostats are almost identical, but they are operated at different temperatures. The cold optics for the *N* band are cooled down to just under 40 K, while for the *L*/*M* band a temperature of 50 to 60 K is sufficient. As detectors a HAWAII II RG was choosen for the *L*/*M* band and a Raytheon Aquarius for the *N*-Band. They are kept at about 35 K (HAWAII II) and 6 to 10 K (Aquarius), respectively.

Both detectors are being tested by ESO together with their readout electronics, characterized and passed to the MATISSE consortium. Each cryostat is equipped with a two-stage Pulse Tube Cooler from Cryomach (CHPT-410). The first one was ordered at the end of the year. In january 2009, in a cryostat especially developed for this purpose, we started the tests of its cooling power, temperature fluctuations and vibrations.

Meanwhile, a location could also be found for MATISSE in the VLTI Laboratory on Paranal. In tight collaboration with the GRAVITY team a proposal was prepared, as to how both instruments could take the adjacent places of the instruments MIDI and VINCI without blocking the access and transit through the lab. The agreement found still has to be definitively approved by ESO-Paranal.

The composition of the consortium and the duty list for its members were changed only marginally in comparison to the previous year. Now the software for the data reduction will be developed in equal parts at the MPI for Radioastronomy in Bonn and at the Observatoire de la Côte d’Azur (OCA) in Nizza. Also the development of the “warm optics”, part of the operating software, as well as the overall concept and the management of MATISSE belong to OCA. The “cool optics” in the cryostats will be constructed by Astron in Dwingeloo, and the Dutch colleagues will also make smaller contributions to the instrument and data reduction software (DRS). The MPI for Radioastronomy will provide most of the DRS as well as the integration of the detectors delivered by ESO into the MATISSE Instrument, including the corresponding software.

The MPIA is responsible for the cryostats and for all of the electronics, including wiring, and software for controlling the instrument. Moreover, from 2015 onward, the MPIA will also take care of the detectors. In february 2008, Sebastian Wolf moved from MPIA to the chair in Astrophysics at the University of Kiel – from there he will coordinate the activities of the MATISSE Science Team. At the MPIA Thomas Henning is now leading the project MATISSE.

Thomas Henning, Uwe Graser, Werner Laun, Christoph Leinert, Vianak Naranjo, Udo Neumann, Karl Wagner

GRAVITY – Interferometric Phase Referenced Imaging

This instrument is an adaptive optics assisted second generation instrument for the VLTI. It will combine the light from all four 8 m Unit Telescopes of the VLT for interferometric phase referenced imaging with a resolution of 4 milli-arcsec, and for narrow-angle astrometry with an accuracy of 10 micro-arcsec for objects as faint as $K = 20$ mag.

GRAVITY will take advantage of the unique 1.7 arcsec diameter field of view of the VLTI. By measuring the angular separation of two objects located within this field, the astrometric accuracy should be improved by a factor of up to 10 beyond the present goal for PRIMA. To achieve this, GRAVITY will be assisted by adaptive optics. After passing its Phase A review at the end of 2007, GRAVITY is now in its preliminary design phase. First light of GRAVITY at the VLTI is foreseen for late 2012.

The instrument is being developed by four partners: Max Planck Institute for Extraterrestrial Physics (Principal Investigator Institute), PHASE (itself a consortium of French Institutes, including Observatoire de Paris and Observatoire de Grenoble), University of Cologne, and MPIA.

MPIA is developing the infrared wavefront sensors as a major instrumental component for GRAVITY. While the interferometric instrumentation of GRAVITY will be in the VLTI laboratory, the near infrared wavefront sensors are located closer to the unit telescopes in order to optimize their sensitivity towards fainter targets.

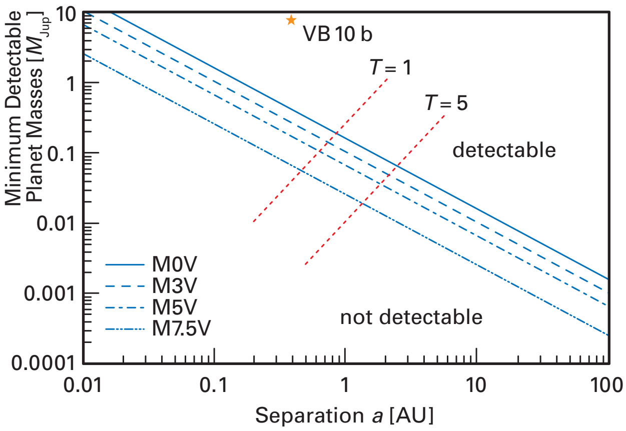


Fig. IV.2.8: GRAVITY exoplanet detection capabilities around late-type and very-low-mass stars at a distance of 6 pc as a function of semimajor axis of the planet orbit, and for a range of stellar masses between 0.1 (M7.5V) and 0.5 (M0V) times the mass of the Sun. For reference, the location of recently announced exoplanet candidate VB10b, which was also detected by astrometry (Pravdo and Shaklan 2009, astro-ph/0906.0544), is indicated. The two dotted lines indicate the detection limits for a 1 year survey ($T = 1$) and a 5 year survey ($T = 5$). In a 5 year survey, GRAVITY might be able to detect exoplanets below 10 Earth masses.

A total of four near-infrared wavefront sensors will be built, one for each of the Coudé rooms of the four Unit Telescopes.

The defining science case for GRAVITY is an astrometric study of the close environment of the supermassive black hole in the center of the Milky Way. With an accuracy of 10 micro-arcseconds, GRAVITY will be able to study orbits of stars and disk flares as close as a few times the Schwarzschild radius of the black hole, and hence test General Relativity in its strong field limit. MPIA's main science interests include an in-depth study of young, massive starburst clusters with the aim to derive precise masses for the most massive stars, study cluster dynamics, and search for intermediate mass black holes potentially hidden in the very centers of these clusters. In addition, we intend to survey very low mass stars in the solar neighbourhood for planetary mass companions.

Wolfgang Brandner, Stefan Hippler, Ralf Klein, Natalia Kudryavtseva, Rainer Lenzen, Vianak Naranjo, Udo Neumann, Jose Ramos, Ralf-Rainer Rohloff

AstraLux-Sur – a Guest Instrument for La Silla

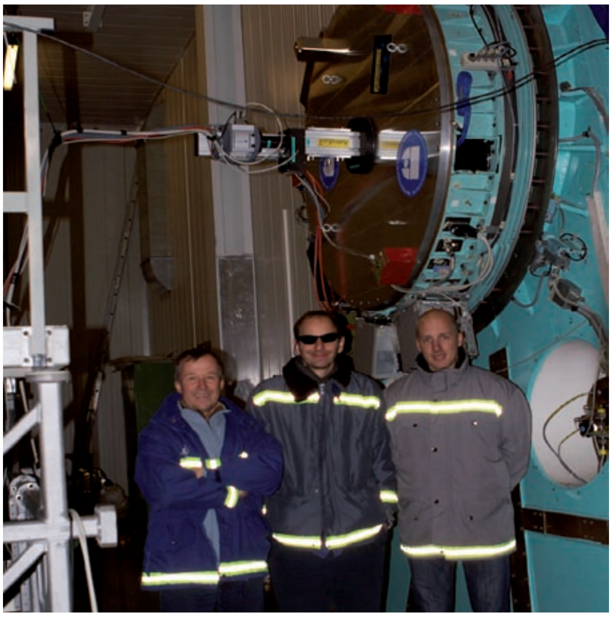
This instrument is based on Lucky Imaging, a method to select among many rapid short exposure images, which achieves close-to diffraction limited imaging from the ground in the visual and near-infrared range with 2 to 4 m class telescopes.

While diffraction limited observations from the ground are usually accomplished with the help of adaptive optics in the near-infrared *H*- and *K*-band at most 8 to 10 m class telescopes, Lucky Imaging aims for similar performance at shorter wavelengths, in particular in the wavelength range from 0.7 to 1.1 μm. In July 2006 we installed the Lucky Imaging instrument AstraLux at the 2.2 m telescope of the Calar Alto observatory (see annual report 2006). The simplicity, robustness, and great success of this instrument – more than 10 publications thus far – led to the idea, in early fall 2007, to build a similar instrument for the 3.5 m NTT at the La Silla observatory in Chile.

Just 8 months after the project started, in May 2008 we shipped the heaviest piece of AstraLux Sur to Chile; the adapter flange, which weights 225 kg, was especially designed for the NTT adapter/rotator counterpart. At the same time, the camera mount, filter wheel, Barlow lens, an electron multiplying, thinned and back-illuminated CCD (model iXon$^+$), four computers, and an electronic rack, all arrived at the observatory in one piece.

The First light target of AstraLux Sur in the night starting on 19th July 2008 was was the binary star Gamma Lupi with $\sim 0\farcs7$ separation. Even though the observing conditions were rather poor and the NTT was closed for most of the night, with the exception of about half an hour, we could test the opto-mechanical interface with the telescope, our computing equipment, in particular the online data pipeline and the communication with the NTT control system. Pointing and focusing worked nicely. Determination of image orientation, image scale, optical throughput, and first photometric observations could be performed. Apart from this 25 min window during the first night, no observations were possible in nights 1, 2 and 3 due to high wind speeds and snowstorms. In night 4, the telescope could be opened during the second half of the night, and in night 5, observations could start about two hours after sunset. Observing conditions were non-photometric for most of the time, and the seeing varied between 1″ and $2\farcs5$. Because of the high wind speeds, the observations were also subject to very short coherence times. Since November 2008 – with the second AstraLux Sur observing run – observations with AstraLux Sur can be carried out from the remote control building. Several computer screens are available to control the instrument, as well as for online data reduction and inspection.

Fig. IV.2.9: The AstraLux Sur commissioning team (left to right): Stefan Hippler, Wolfgang Brandner, and Boyke Rochau. The AstraLux Sur instrument (with yellow and green labels) is attached to its adapter flange (blue white MPIA label), which itself is connected to the Nasmyth adapter/rotator at the NTT.



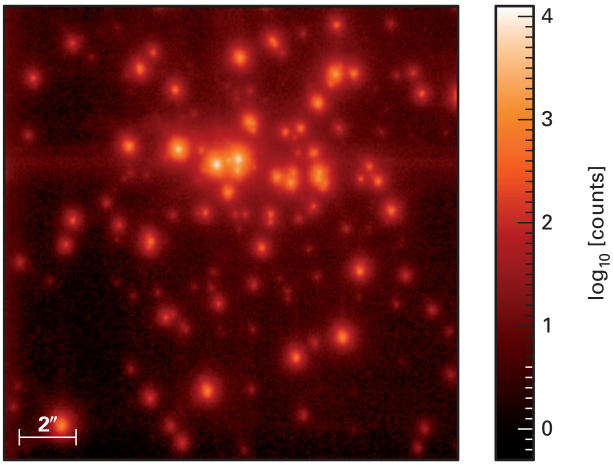


Fig. IV.2.10: The core of the Galactic starburst cluster in the giant HII region NGC 3603, which serves as one of our astrometric calibration targets, as seen by AstraLux Sur in the SDSS z' band at the NTT. The 1 percent image selection yields a resolution (FWHM) of 120 milli-arcseconds.

In summary, after the first two observing runs in 2008, the performance of AstraLux Sur is quite similar to that of its sister instrument on Calar Alto. The full diffraction limit was reached in I-band with a FWHM of about 50 milli-arcseconds. In general an angular resolution of 100 milli-arcseconds is achieved in the I- and z-band.

Carolina Bergfors, Wolfgang Brandner, Sebastian Daemgen, Kerstin Geissler, Thomas Henning, Stefan Hippler, Felix Hormuth, Armin Huber, Markus Janson, Boyke Rochau, Ralf-Rainer Rohloff, Karl Wagner.

IV.3 PANIC – the Panoramic Near Infrared Camera for Calar Alto

The PANIC project was started at the end of 2006. The aim of this project is to build a near infrared wide field camera for Calar Alto. It is the first joint project between MPIA and IAA, Granada. MPIA is responsible for mechanics, detectors and read-out, IAA for the optical design and software.

After continuous design work on the instrument in 2008, the optical design has now been fixed and approved by an international review committee. It is a pure lens design with 9 lenses. The image quality is 80 percent ensquared energy in 2 pixels over the whole field for all wavelengths. The wavelength range also includes the astronomical *z*-band, so PANIC will cover the whole spectral range from the *z*- to the *K*-band (0.8 – 2.5 microns). PANIC can be attached to both, the 2.2 and the 3.5 m telescope on Calar Alto. At the 2.2 m telescope the instrument will have a pixel scale of 0.45 arcsec/pix. With its field of view of 0.5 × 0.5 degrees it will be perfectly suited for survey-type observations. The image scale will be halved at the 3.5 m telescope, which will make the instrument well suited for observations requiring high spatial resolution.

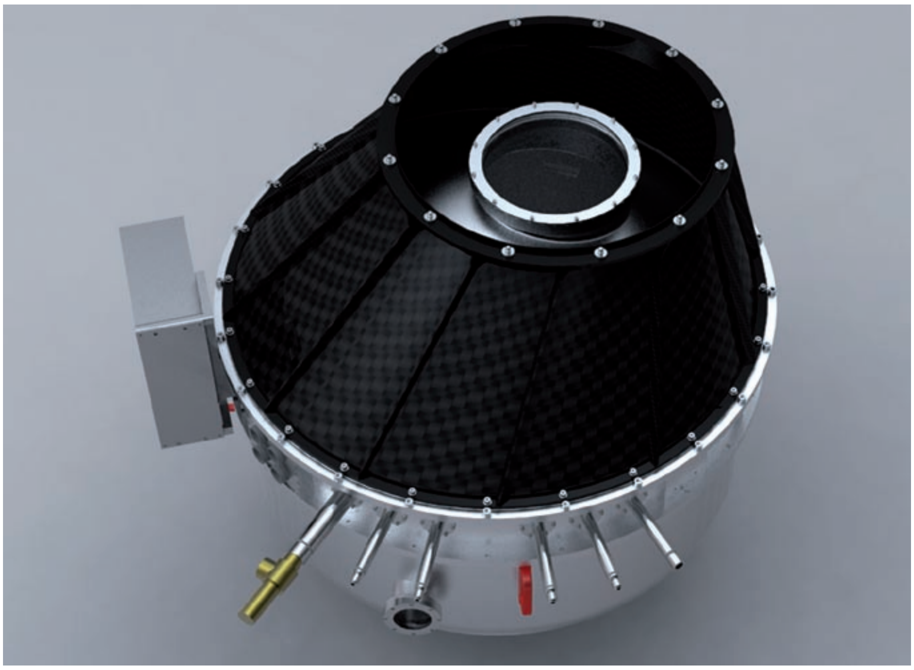
The spectral band will be defined by filters; four filter wheels are located in the optical beam and allocate space for 20 filters. The optical design allows the use of narrow band filters for which the band-width is 1 percent of the central wavelength.

Since the operating temperature of the detectors is 77 K (or –196 °C), optics and detector are inside a cryostat which is cooled by liquid nitrogen. Mechanical tolerances for the optics are tight, on the order of 50 microns for several optical elements. Therefore, all optical elements are attached to one optical bench. This minimizes mechanical flexure, and the mechanical requirements can be met, as proved by finite element analysis, for nearly all telescope positions.

Computer generated images of the instrument are shown in Fig. IV.3.1 and Fig. IV.3.2. The diameter of the instrument is about 120 cm, its weight is about 400 kg. The total length of the optical path within the istrument is 180 cm, but it is folded by three mirrors to give a compact shape of the instrument.

The detector of PANIC is a module which consists of four 2 × 2 K Hawaii-2RG detectors. These detectors will be delivered in early 2009. For testing purposes a multiplexer was already delivered and has been successfully tested with our read-out electronics. This multiplexer alone has some very limited imaging capabilities. Fig. IV.3.3 shows an image taken with the multiplexer only a few days after start of the tests. The read-out electronics is the latest development of the standard MPIA read-out electronics. Use of modern highly integrated parts makes it light-weight, compact and cheap. The optimization of the read-out process was started using the multiplexer; tests with an engineering grade detector will follow.

Fig. IV.3.1: Computer generated outside view of the cryostat. The dark-grey cone is the telescope adaptor, the connectors for liquid nitrogen are clearly visible. The box to the left contains the read-out electronics.



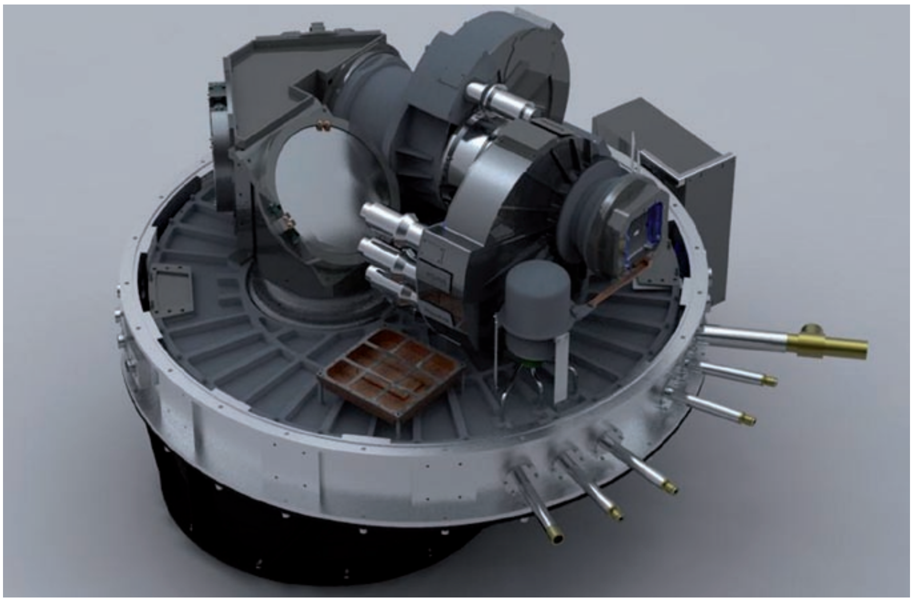


Fig. IV.3.2: Computer generated image of the interior of the PANIC cryostat, showing the optical elements attached from below to the optical cold bench: the folding mirrors (*left*), modules for the aperture stops and filters (*center*), and detector focal plane array (*right*).

The instrument will be computer controlled. An user friendly observation tool will make its use simple by supplying a mask the observer has to fill out. This ensures that all information which is needed for a pipeline batch reduction is available. A quick-look data reduction facility will allow on-line quality check of the collected data. When all data have been collected, a pipeline will repeat the reduction in an optimized way. The aim of the pipeline is to supply the astronomer with astrometrically and photometrically calibrated images and object catalogues.

J. Fried, R.-R. Rohloff, Harald Baumeister, A. Huber, A. Böhm, K. Wagner, J. R. Ramos, M. Alter, H. Ehret, U. Mall, V. Naranjo, W. Laun, C. Storz.
In collaboration with IAA, Granada

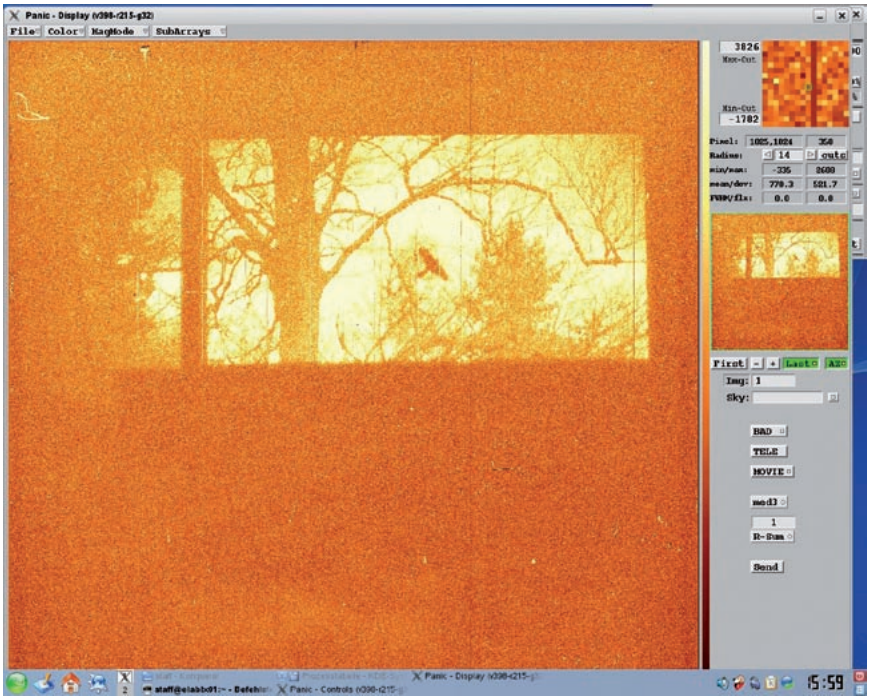


Fig. IV.3.3: A look out of a window imaged onto the multiplexer demonstrates basic functioning of the read-out electronics.

IV.4 METIS and MICADO – Phase A Studies for the E-ELT

ESO proposed to study a number of possible instruments for the E-ELT, the European 42 m telescope. Following the T-OWL and MIDIR study, both discussing a mid-infrared instrument of the next generation, consortia have been founded to provide phase-A studies for METIS, a mid-infrared imager and spectrograph, and for MICADO, an imaging camera for deep observations with multi-conjugated adaptive optics.

METIS – the Mid-infrared E-ELT Imager and Spectrograph

In collaboration with the Universities of Leiden, Amsterdam, Leuven and with CEA-Saclay and UK-ATC, MPIA started the study of METIS in May 2008. In the wavelength bands 3.0 – 5.5 µm and 8 – 13.5 µm METIS will provide diffraction limited direct imaging, polarimetry and coronography down to 15 mas spatial resolution. In addition, this imager is equipped with grisms providing low spectral resolution spectroscopy, again combined with high spatial resolution.

It is also foreseen that METIS willoffer high-resolution spectroscopic capabilities up to $R = 100\,000$, providing exceptional observation capabilities for studying extrasolar planets, protoplanetary disks and galactic or extragalactic star formation regions. A detailed science case for such an instrumental concept has been developed and delivered to ESO by the end of 2008 as part of the mid-term review.

MPIA is responsible for the specification and design of the imager and the adaptive optics. Following the optical design of the imager, that has been halted at the time of the mid-time review at the end of 2008, the cryo-mechanical design concept is currently being elaborated.

Special effort has been made to find a really compact solution for a two channel instrument (see Fig. IV.4.2). The imager will provide low-resolution slit spectroscopy up to $R = 4000$ with the help of direct-ruled grisms.

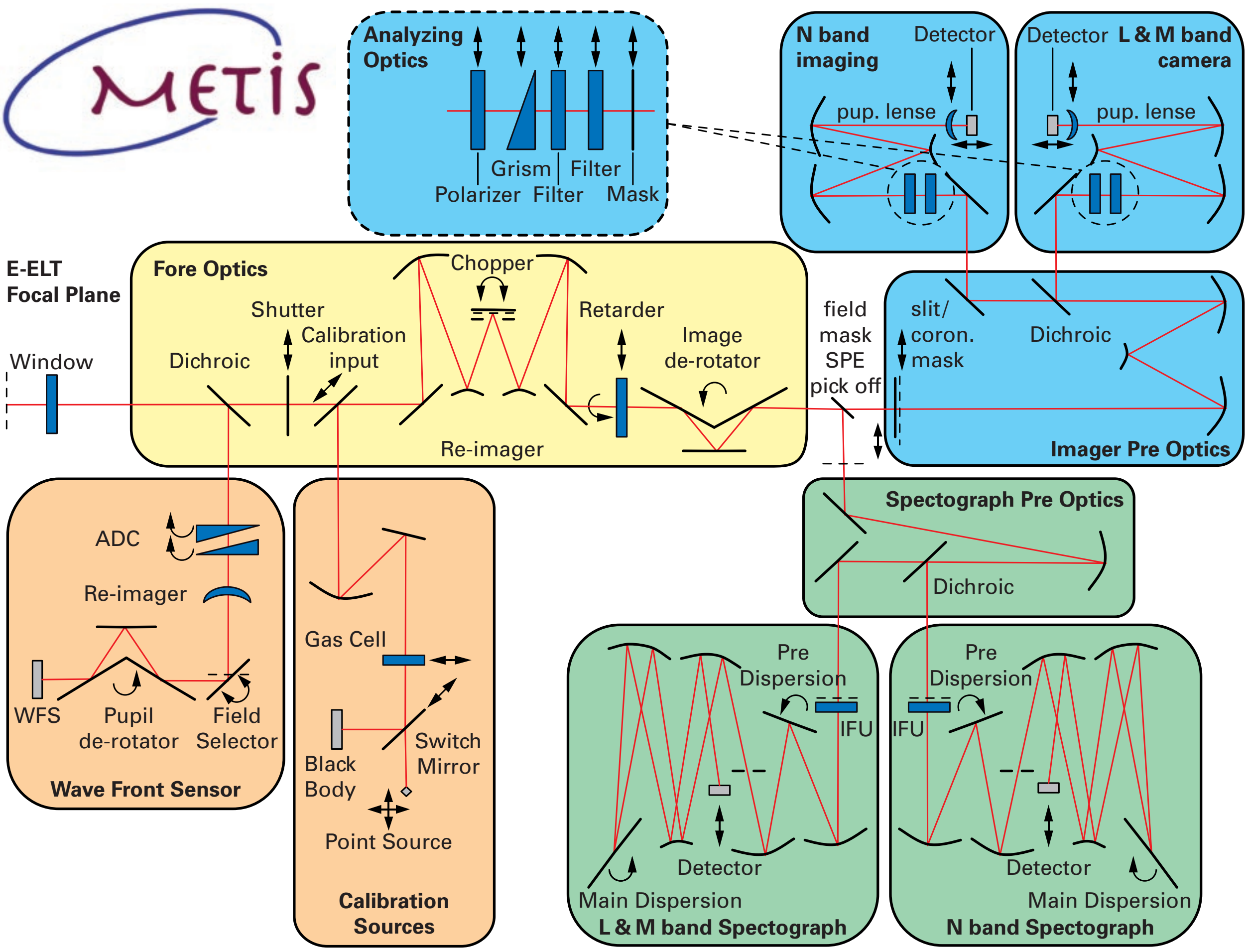


Fig. IV.4.1: Functional overview of the whole METIS instrument for the mid-infrared.

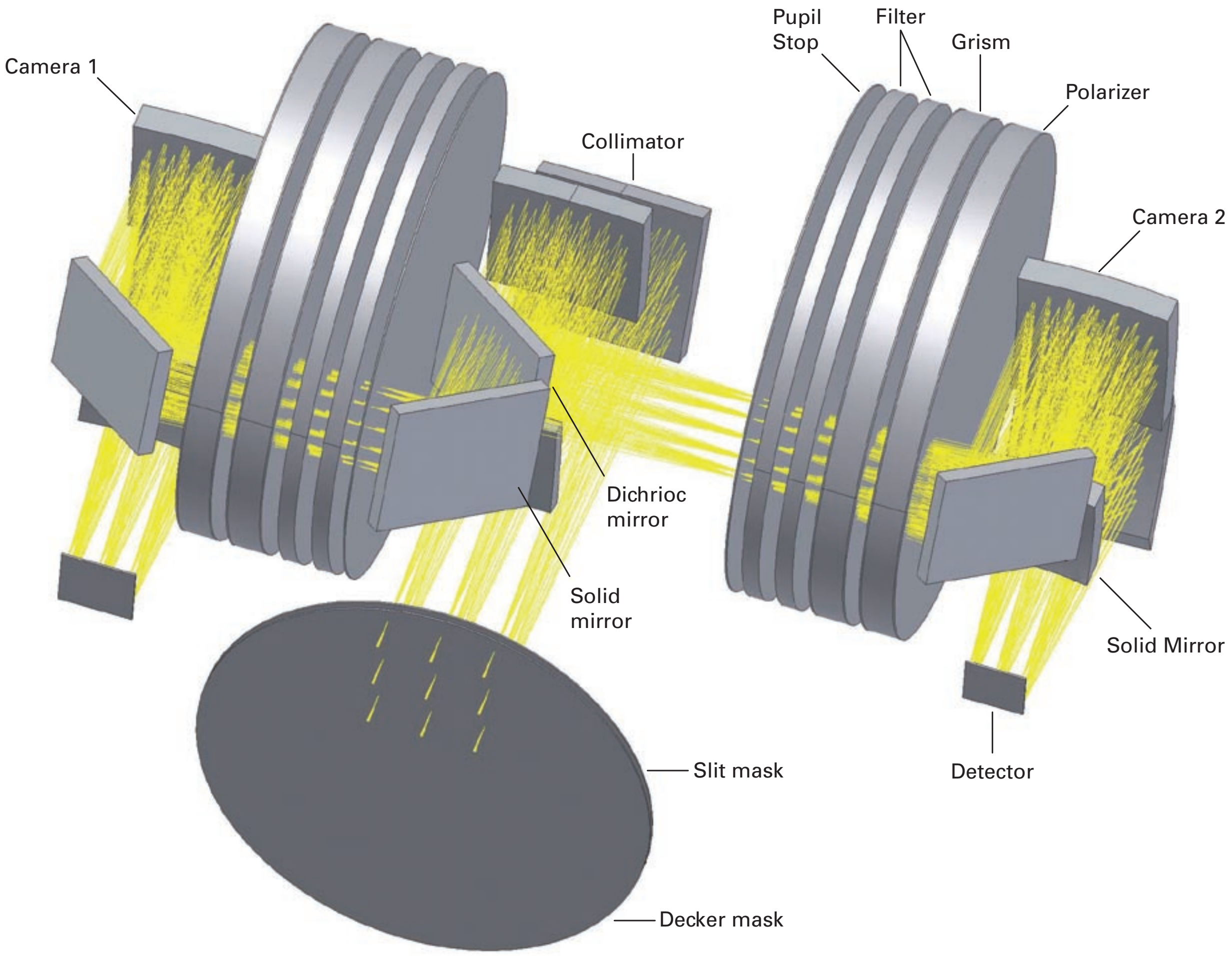


Fig. IV.4.2: The METIS imager. Optical design and a first mechanical concept is shown.

Coronography is implemented using special coronographic phase masks. In combination with the fore-optics, where halfwave plates can be inserted, the imager provides polarimetric capabilities using Wollaston prisms and wiregrid analyzers. Differential imaging capabilities may be implemented once the dual band mid-infrared detectors are available. The standard detectors for METIS are the ORION InSb detector for the 2.5 – 5.5 μm and the Aquarius Si:As detector for the 8.0 – 13.5 μm wavelength range, both developed by Raytheon. The field of view will be 18 × 18 arcsec.

The E-ELT will be equipped with a complex AO-system to reach diffraction limited resolution even down to near-infrared wavelengths. A special wavefront sensor might be proposed for METIS to cover special mid-infrared requirements.

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Thomas Henning, Stephan Hippler,
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In collaboration with:
Sterrewacht Leiden, CEA Saclay,
UK-ATC Edinburgh, KU Leuven

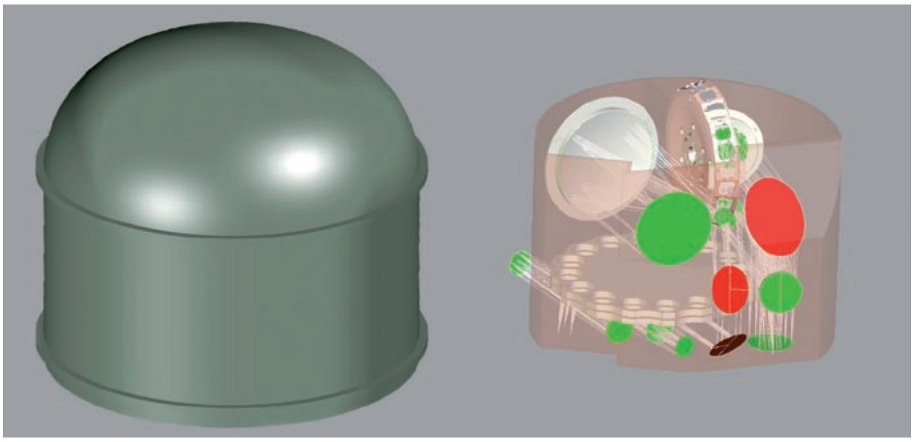


Fig. IV.4.3: The MICADO cryostat (*left*) is approximately 2 m in diameter. The all-reflective optical design (*right*) is optimized for high throughput and image fidelity.

MICADO – The MCAO Imaging Camera for Deep Observations

MICADO is a potential first-light near-infrared imager for the European Extremely Large Telescope (E-ELT). A team of 15 scientists and engineers from Germany, The Netherlands, and Italy is currently exploring the design options and tradeoffs of MICADO in a Phase A study, which began in early 2008.

The first part of the study examined various opto-mechanical and cryogenic solutions for the imager. This effort culminated in a successful mid-term review in December 2008. The second half of the study, which will occupy much of 2009, concentrates on preparing an advanced conceptual design, including plans for construction, implementation, and operation of the instrument.

The baseline design is a high-resolution near-infrared imager for the J to K photometric bands (1.0 – 2.4 μm), with a possible extension shortward to the I-band (~ 0.8 μm). MICADO sits at the output port of the MAORY multi-conjugate adaptive optics module, which is being studied by colleagues in Italy and France. The goal is to achieve a field of view of 50 arcsec at 3 milliarcsec resolution. Because some of the key science cases are difficult to achieve with this configuration, MICADO includes a second, smaller, but higher-resolution channel with an 8″ × 8″ field. This channel can support long-slit spectroscopy, OH suppression filters, and other specialized devices such as polarimeters.

MICADO is optimized for photometric sensitivity and astrometric accuracy, allowing MPIA astronomers to measure objects as faint as 29th magnitude and to follow the motions of celestial objects with unprecedented detail. This capability enables science cases ranging from tracing extremely faint stars at the center of our Milky Way, to the cores and resolved stellar populations of nearby galaxies, to populations of faint galaxies and active galactic nuclei at high redshift.

Tom Herbst, Knud Jahnke, Hans-Walter Rix.
In collaboration with: MPE Garching, Universitäts-Sternwarte München, Federation of Dutch University Astronomy Departments, Osservatorio di Padova

IV.5 Laiwo – the Large Area Imager for the Wise Observatory

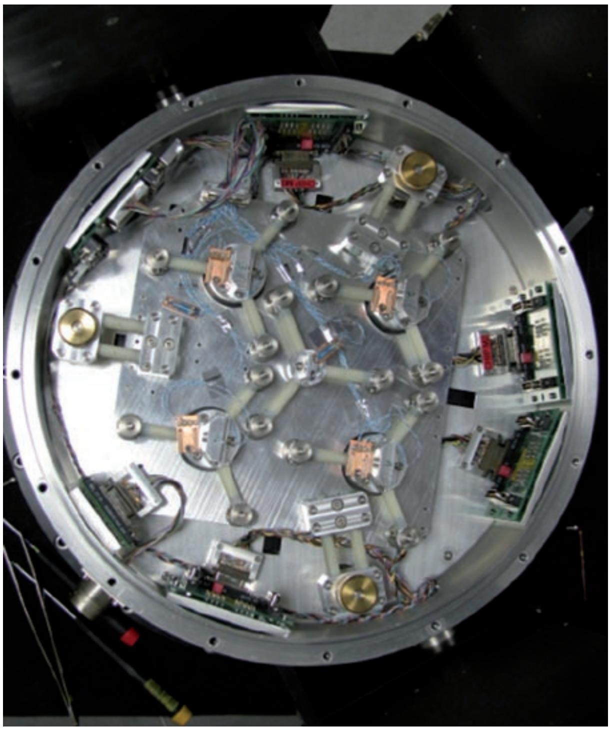
Laiwo, an imager with a field of view of one square degree, was built at the MPIA with the aim to search for transiting extra-solar planets orbiting stars down to I = 16 mag. The project is a collaborative effort between three institutes: the MPIA, the University of Tel Aviv, and the Institute for Astrophysics in Göttingen.

The camera is composed of four front-side illuminated Lockheed CCD486 devices, each with 4000 × 400 pixels, with a pixel size of 15 microns. The camera is divided in two segments: the first segment consists of the cryogenic tank filled with liquid nitrogen to cool the CCDs with the dewar head on the top containing the CCDs and the entrance window. The second segment includes the filter drawer with a ruler inside, where three separate plates of sets of filters among five available (Johnson B, V, R, Cousins I and the Sloan z') can be mounted at the same time. The guider CCD, an e2V CCD47-20 frame transfer device, with 1000 × 1000 pixels, each 13 microns in size, is located at the center of the mosaic surrounded by the four science CCDs (see Fig. IV.5.1).

The camera was finished in September 2007. After a first installation in October 2007 on the 1-m telescope at the Wise Observatory, with a MPIA team of scientific staff (C. Afonso and K-H. Marien), as well as technical staff including a software engineer (F. Briegel) and an electronic engineer (R. Klein), the camera was shipped back to Germany, due to serious problems with the CCDs, that seemed to be unresponsive. A set of new CCDs were purchased, and tested at MPIA. The newly refursbished camera was sent to Israel in September 2008 and installed with the same MPIA team in November. The installation went smoothly, and observations have been performed since then regularly for commissioning. A first set of scientific data was obtained recently, confirming the feasibility of our project. Fig. IV.5.2 shows an image of M 33 taken during the first light campaign in November 2008.

If the camera continues to behave as expected, the survey mode to search for transiting extra-solar planets will start in May 2009. The observing strategy will consist in the continuous monitoring of three fields at any given time, until 3000 image are acquired. We anticipate to have 15 nights per month during three years, covering a total sky surface of 30 square degrees. Observations will be coordinated with the 1.2 m Monet telescope located in Texas, USA, which is operated by the University of Göttingen, Germany. The network of these two telescopes will increase the number of measurements, enhancing the estimated number of planets discovered. Dozens of transiting extra-solar planets are expected to be found during the three year observation campaign.

Fig. IV.5.1: View of the top of the dewar where the 4 Laiwo CCDs are located.



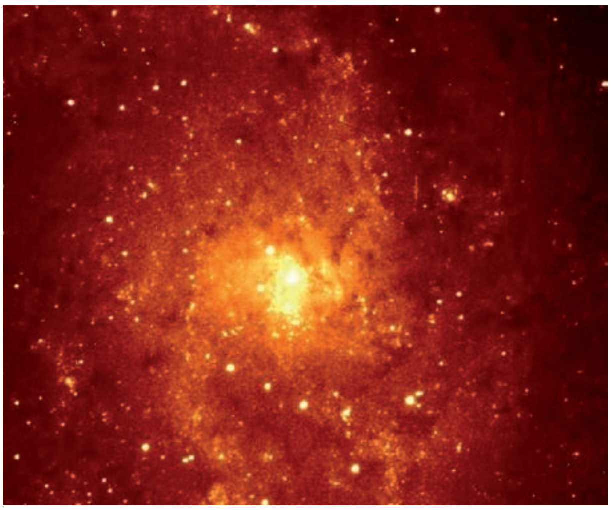


Fig. IV.5.2: A "first light" picture of M 33, obtained with the Laiwo camera.

Cristina Afonso, Thomas Henning
In collaboration with: Tel Aviv University, University of Göttingen

IV.6 Instruments for Space Observatories

PACS – the Photodetector Array Camera and Spectrometer for HERSCHEL

Europe's new far infrared and submillimetre space observatory HERSCHEL is scheduled for launch in 2009 together with the PLANCK spacecraft aboard an ARIANE-5 rocket. MPIA is one of the major partners developing the PACS instrument which will enable imaging and spectroscopy in the wavelength range from 60 to 210 µm with unprecedented spatial resolution. After successful delivery of the PACS hardware contributions, MPIA focuses now on building up the PACS Instrument Control Centre.

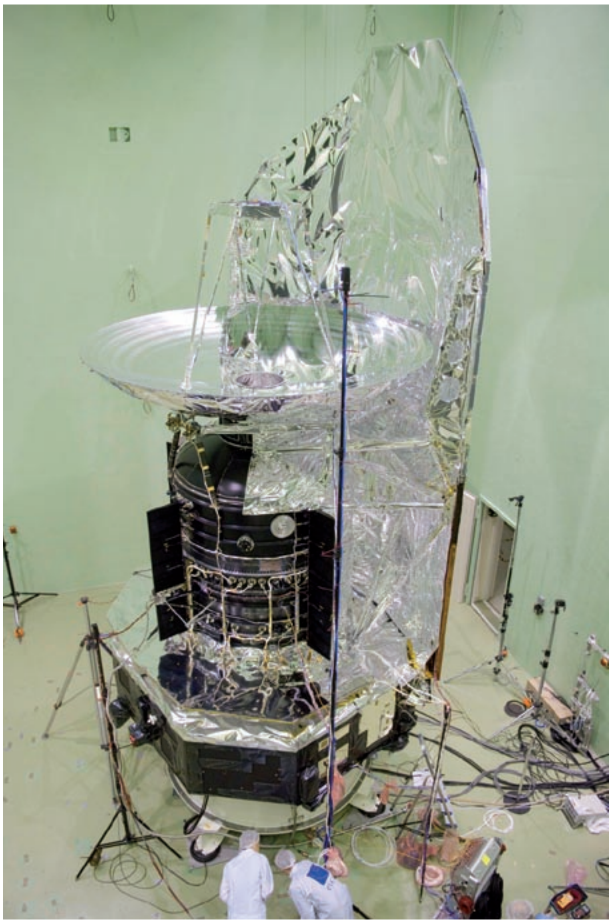
The Instrument Control Centre (ICC), to be located at the PI institute MPE in Garching, will bear responsibility for operations, calibration and data reduction of the PACS instrument. MPIA is one of four institutes of the PACS consortium which significantly participated in establishing the PACS ICC. MPIA coordinates the calibration of the PACS instrument and has been responsible for establishing the PACS performance verification plan, which covers the first in-flight calibration of the instrument, and the central PACS calibration document. Both documents were essential for achieving major milestones for the launch readiness of the PACS instrument – the "ICC readiness" and "HERSCHEL Ground Segment Readiness" reviews, which have been successfully passed in 2008.

The performance verification (PV) plan consists of about 1000 individual observations totalling 750 hours of observing time and will assess the performance and sensitivity of the instrument in flight. The PV activity will also establish an initial calibration in space and will verify the validity of astronomical observation templates (AOTs), which are the basic observing blocks to be used later in the HERSCHEL mission by all observers. Setting up the PV plan is a complex and challenging task since a large number of boundary conditions have to be accounted for in the mission planning. The MPIA team has closely collaborated with colleagues and their software tools at the HERSCHEL Science Centre in Villafranca (Spain). In the year 2008, progress has also been made with the development of the data reduction pipeline software. MPIA coordinates the development of the PACS spectrometer pipeline. The availability of good data from ground tests allowed verifying all processing steps and data products.

MPIA has also been responsible for delivering the PACS focal plane chopper and for characterizing the large Ge:Ga spectrometer cameras and their –270 °C readout electronics. All hardware has been integrated in the PACS instrument and into the HERSCHEL cryostat. After integration of the HERSCHEL 3.5-m-mirror onto the cryostat assembly and cool-down of the instruments to liquid helium temperature at the ESA technology centre ESTEC in Noordwijk (NL), a series of tests of all instrument components and software systems was conducted. These tests comprised a large number of short functional tests before and after vibration of the whole satellite. Dedicated mechanism tuning of the PACS chopper was performed by the MPIA team to verify that the control loop parameters found on instrument level are still valid in the complex satellite environment.

The mechanical tests included the acoustic tests inside the LEAF (Large European Acoustic Facility) and the vibration tests on several shakers at the ESTEC test facilities. Together they verified that the HERSCHEL spacecraft is compliant with specification requirements,

Fig. IV.6.1: The HERSCHEL spacecraft undergoes final preparations inside the Large European Acoustic Facility (LEAF) for the acoustic tests on 5 and 6 June 2008.



ensuring that the flight model is ready for launch (see Fig. IV.6.1.). The end of the mechanical test campaign marked a major milestone for the HERSCHEL spacecraft.

Testing at liquid helium temperature was concluded with the "System Operation Verification Test # 2" in December 2008 with the HERSCHEL satellite located within the large space simulator at ESTEC, all its instruments being cooled to operating temperature, and – like during the real mission – commanded from the Mission Operations Centre at ESOC in Darmstadt. During this test, five mission days of the commissioning and PV phase were simulated in all detail. The members of the MPIA PACS team were involved both in the preparation and conduction of all these tests on site. After this test, HERSCHEL was prepared for shipment to the launch site Kourou in French Guyana.

In January 2008, the HERSCHEL Observing Time Allocation Committee awarded observing time for six "Open Time Key Programs" with MPIA participation, covering several key topics from MPIA's "Planet and Star Formation" and "Galaxies and Cosmology" departments. Together with the five "Guaranteed Time Key Programs" with MPIA contribution (of which two are led by MPIA scientists), the Institute will be deeply involved in the scientific harvest of HERSCHEL's routine science observations, which is expected to start in late autumn 2009.

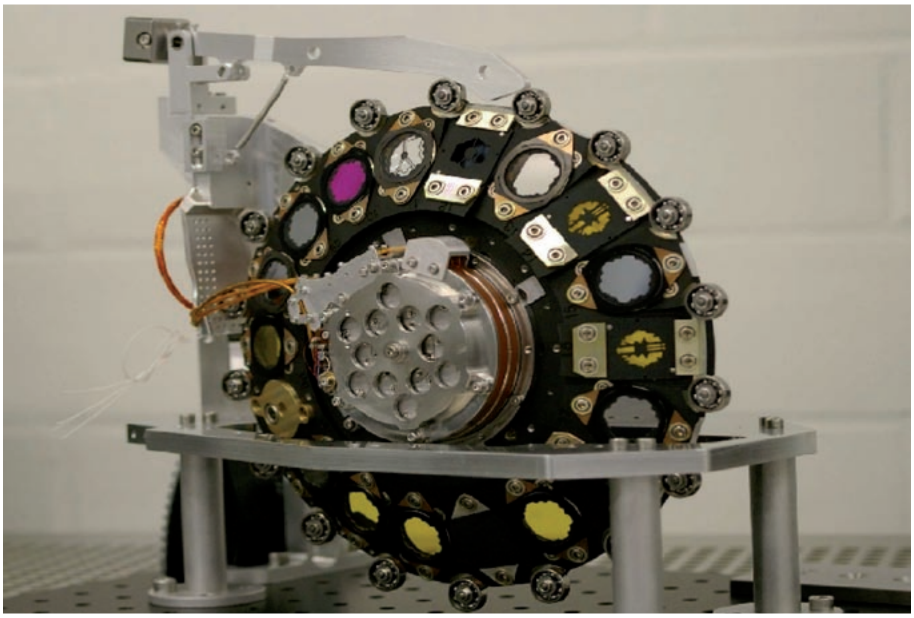
Oliver Krause, Ulrich Klaas, Jeroen Bouwman, Helmut Dannerbauer, Ulrich Grözinger, Thomas Henning, Markus Nielbock, Jürgen Schreiber, Jutta Stegmaier

MIRI and NIRSPEC – instruments for JWST

As German lead institute, MPIA is a major partner to develop the Mid-Infared Instrument (MIRI) for the James Webb Space Telescope (JWST) – the successor of the Hubble Space Telescope (HST). In close collaboration with its industrial contractor C. ZEISS (Oberkochen), the institute is responsible for MIRI's filter and grating wheel mechanisms – the cryomechanical hearts that enable the full operational functionality of the complex instrument. MPIA is also responsible for the electrical system engineering of the MIRI instrument, and members of the Institute are deeply involved in the ground-testing of MIRI. As member of a consortium led by EADS-ASTRIUM Germany, MPIA – together with C. ZEISS – is also involved in the development of the near-infrared spectrograph NIRSPEC for JWST.

Due for launch in 2014, JWST, which is a joint cooperative mission of NASA, ESA, and the Canadian Space Agency (CSA), is optimized to operate over a wide range of infrared wavelengths. At the heart of the JWST observatory there is a large cold telescope the primary mirror of which measures 6.5 m in diameter compared to 2.4 m for the HST. This provides an enormous increase in the capability to investigate the origin and evolution of galaxies, stars and planetary systems. To avoid blinding

Fig. IV.6.2: Engineering model of the filter wheel mechanism for the Mid-Infrared Instrument (MIRI). Filters, graphic masks and a double prism on the wheel disk are actuated by a central torque motor, with the wheel positions being locked by a ratchet latching into the index bearings outer race. The mechanism has a wheel diameter of 30 cm and a total mass of 3.5 kg.



of the sensitive cameras by their own thermal radiation, the primary mirror is radiatively cooled to –230 °C. Such "passive cooling" can advantageously be performed at the Lagrangian Point L2 at 1.5 million km distance from Earth in anti-solar direction. NASA will have the overall responsibility for the JWST mission, which will be launched aboard a European ARIANE-5 rocket.

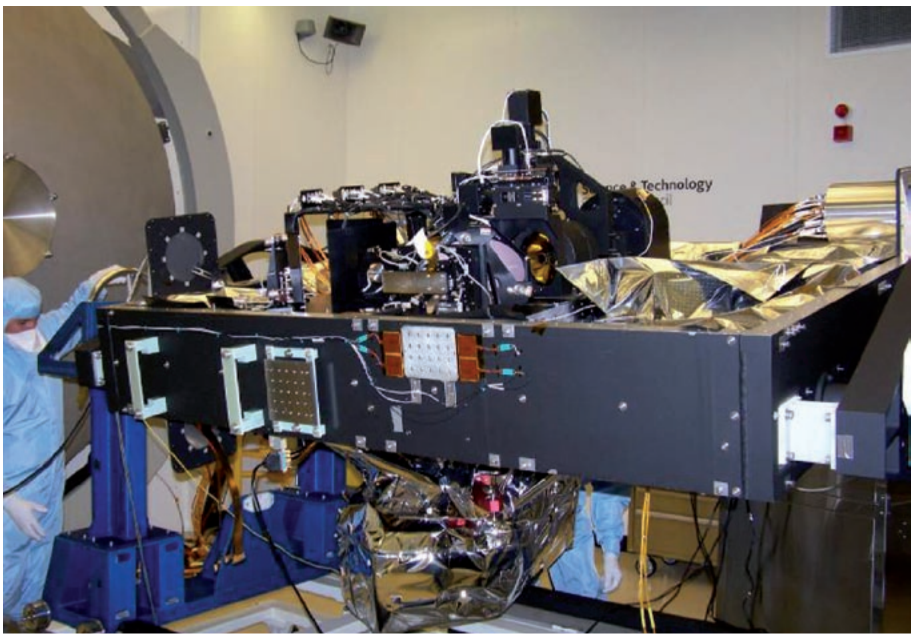
JWST is equipped with four scientific instruments, two of which are built mainly in Europe: MIRI, a camera with coronagraph and spectrometer for the mid-infrared range (5 to 28 μm), is built by a consortium of 20 European institutes, with JPL providing detectors and the cryomechanical cooler. NIRSpec, a near-infrared (1 to 5 μm) multi-object spectrograph, is capable of observing more than 100 objects simultaneously using a microshutter array.

In order to provide a variety of observing modes such as broad/narrow-band imaging, coronagraphy and low/medium resolution spectroscopy, the MIRI instrument is equipped with a filter wheel and two dichroic/grating wheel mechanisms. They allow a re-configuration of the instrument between the different observing modes and wavelength ranges. The main requirements for the three mechanisms with up to 18 positions on the filter wheel (see Fig. IV.6.2) include: reliable operation at $T \sim 7$ K, optical precision, low power dissipation, high vibration capability and full functionality in the temperature range $6\,\mathrm{K} < T < 300\,\mathrm{K}$. To meet these stringent requirements, a space-proven mechanism design based on the European ISO mission and consisting of a central bearing carrying the optical wheels, a central torque motor for wheel actuation, a ratchet system for precise and powerless positioning and a magnetoresistive position sensor has been selected. The same principle is employed in the two mechanisms for NIRSpec, a filter and a grating wheel.

After successful completion of critical design reviews in 2007, all hardware was in place for integration at C. ZEISS in the year 2008, and the assembly of the mechanisms has started. In parallel, the complex cryogenic test environment – including several cryostats – for performance tests has been built up in Oberkochen. The delivery of the MIRI flight models is planned for summer 2009. For NIRSpec, nearly all hardware contributions from MPIA – electrical components such as position sensors, motors, cryo harnesses, and temperature sensors – have been delivered in 2008.

A significant milestone for MIRI could be reached in 2008 with the extensive testing of the verification model (VM) of the MIRI instrument (Fig. IV.6.3) at the Rutherford Appleton Laboratory in Oxfordshire (UK). The goal of the VM – as a fully functional instrument model – was to check the scientific performance, using a telescope simulator to provide calibration stimulus and all electrical interfaces, and to provide additional confidence on the thermal performance of the instrument. MIRI is the first of the JWST instruments to reach this phase of cryogenic performance testing. The cold MIRI VM test campaign included repeated functional tests under ambient and cryogenic conditions, alignment and thermal balance tests, electromagnetic compatibility tests, characterisation of the MIRI telescope simula-

Fig. IV.6.3: MIRI verification model plus telescope simulator in the cleanroom at Rutherford Appleton Labs – the first fully functional model of a JWST science instrument. The instrument can be seen on the bottom of the mounting structure, suspended and thermally insulated by a carbon-fibre hexapod structure. The MIRI telescope simulator is located at the top.



tor, and MIRI VM performance testing. Members of the MPIA MIRI team were preparing, conducting and analysing a significant number of the tests in two cryogenic test campaigns. The VM test campaign was very success-ful: among the tested MIRI performance parameters, the image quality nearly met all the flight model requirements, and also the spectrometer performed very well. In addition, all wheel mechanisms were reliably operated during the whole campaign.

Oliver Krause, Ralph Hofferbert, Friedrich Müller, Thomas Henning, Ulrich Grözinger, Armin Huber, Armin Böhm, Monica Ebert, Karl Wagner, Stefan Meister, José Ramos, Ralf-Rainer Rohloff, Stefan Scheithauer, Thomas Blümchen, Stefan Birkmann, Matthias Alter, Örs Detre, Martin Hennemann, Jeroen Bouwman

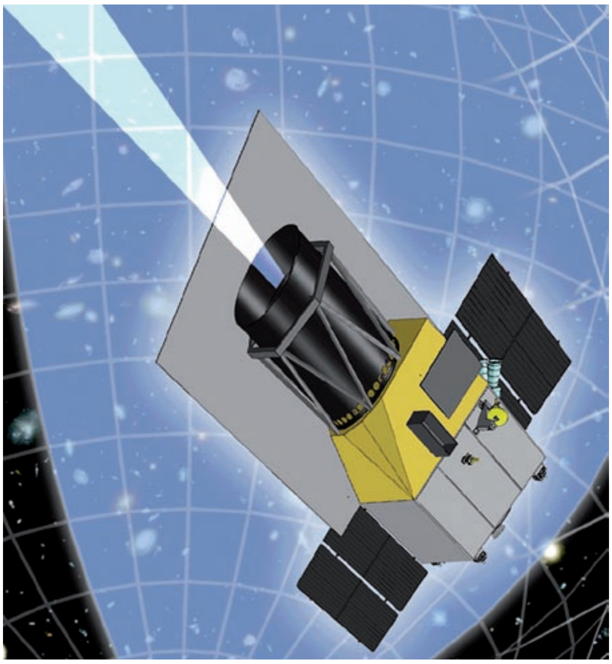


Fig. IV.6.4. EUCLID, a future ESA mission, has the goal of mapping the geometry of the dart universe.

The ESA "Cosmic Vision" Missions

The future of Europe's Space Science program in the 2015-2025 timeframe is currently assessed in the Cosmic Vision (CV) plan issued by the European Space Agency (ESA). In October 2007, the Space Science Advisory Committee selected for asessment studies six M-class and three L-class candidate Cosmic Vision mission concepts resulting from the first "Call for Missions" for the period 2015-2025. In a down-selection process, these mission proposals are competing for launch opportunities in 2017/2018. MPIA is involved in the study of three possible M-Class astronomy missions.

EUCLID, an ESA Cosmic Visions mission, has the goal of mapping the geometry of the dark universe by studying the distance-redshift relationship and the evolution of cosmic structures. To this end, the shapes and redshifts of galaxies and galaxy clusters will be measured out to redshifts $z \sim 2$, that is, to a look-back time of 10 billion years, thereby covering the entire period over which dark energy played a significant role in accelerating the expansion of the universe. The observing strategy of EUCLID will be based on baryonic acoustic oscillations measurements and weak gravitational lensing, two complementary methods to probe dark energy. The EUCLID survey will produce 20 000 deg^2 visible and near-infrared images of the extragalactic sky at a spatial resolution of 0.30 arcsec. It will also yield medium resolution spectra ($R \sim 400$) of about a third of all galaxies brighter than 22 mag in the same survey area.

Two of the original Cosmic Vision proposals, the Dark Universe Explorer (DUNE) and the Spectroscopic All-sky Cosmology Explorer (SPACE), were aiming at achieving very similar science goals (i.e. unravelling the nature of dark energy) through different techniques. Subsequent studies in the course of 2008 resulted in a single mission concept, EUCLID, which implements both techniques, and which is currently undergoing an assessment study. MPIA was participating in both original proposals. In the ongoing EUCLID assessment phase MPIA is responsible for the phase A study of the calibration source, filters and the filter wheel mechanism in the near-infrared channel of the EUCLID imager.

Oliver Krause, Rory Holmes, Hans-Walter Rix

PLATO, the Planetary Transits and Oscillations of stars Mission, will detect and characterize exoplanets by means of their transit signature in front of a very large sample of bright stars, and measure the seismic oscillations of the parent stars orbited by these planets in order to fully characterize exoplanetary systems. These goals will be achieved by a long-term, high-precision, high time resolution and high-duty-cycle monitoring in visible photometry of bright dwarfs and subgiants. The PLATO observations will be complemented by ground-based follow-up observations, including radial velocity monitoring, which will be made easy and efficient thanks to the brightness of the PLATO targets.

Its primary goal is to provide the basis for statistical analyses of exoplanetary systems around stars that are bright and nearby enough to allow for simultaneous and/or later detailed studies of their host stars. PLATO will observe 20 000 dwarf stars with a photometric precision better than 1 ppm/months – corresponding to 27 ppm/hour of observing – and more than 250 000 stars to somewhat less precision. Seismic analysis will lead to the determination of stellar and planetary masses with up to 1 percent precision, and the detection of Earth-size planets, with age determinations to within several 100 million years. PLATO will provide a very wide field of view (800 square degrees). The required short focal length led to the concept of a bundle of 42 small telescopes each of which has a collecting area of 0.01 m².

A ground data centre receives the data, applies final instrumental corrections, provides scientific added-value products, then archives and distributes all resulting PLATO data products. The ground centre will also develop and maintain an ancillary database containing all available information on PLATO targets, including specifically acquired ground-based data, such as radial velocity variations. MPIA has been participating in the payload consortium and has proposed to contribute in the ground data centre with the set-up and maintainance of the database as well as in the development of transit detection algorithms.

Cristina Afonso, Oliver Krause

SPICA, the Space Infrared Telescope for Cosmology and Astrophysics, is the third astronomy mission of ESA's Cosmic Vision, where MPIA is participating in the study phase. The Japanese-led, joint JAXA-ESA mission, is planned to be the next space astronomy mission observing in the far infrared after HERSCHEL.

SPICA will have a single-element, high surface accuracy 3.5 m mirror, cooled to ~ 4.5 K. The combination of large collecting area, low self-emission and diffraction-limited performance over a core wavelength range of 5 – 210 μm, will provide the basis for a sensitive and versatile suite of focal plane instruments. SPICA's large cold aperture will provide up to two orders of magnitude sensitivity advantage, mostly for spectroscopic observations, over existing far-infrared facilities and HERSCHEL.

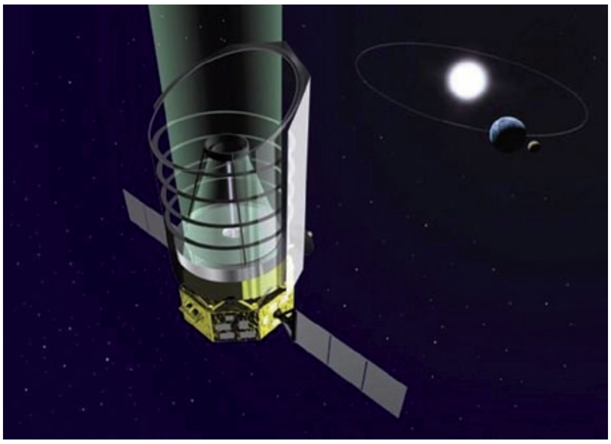


Fig. IV.6.5. SPICA, a joint JAXA-ESA mission, is planned to be HERSCHEL's successor as a far-infrared space observatory.

In the context of Cosmic Vision, SPICA is considered as a "Mission of Opportunity" to which Europe could contribute with a SPICA Far Infrared Instrument called SAFARI, the telescope mirror, and support to the ground segment. The far infrared camera/multi-resolution spectrometer SAFARI is an imaging spectrometer covering the wavelength range from 35 – 210 μm with a spectral resolution up to $R \sim 10\,000$.

Oliver Krause, Jutta Stegmaier, Ulrich Grözinger

IV.7 Survey Projects: PanSTARRS 1, GAIA, and HAT-South

PanSTARRS1 – the Survey Telescope with the world's largest digital camera

PanSTARRS1 (Panoramic Survey Telescope and Rapid Response System, PS1 for short) is an ambitious and ground-breaking survey project. The dedicated 1.8 m telescope, located at the Haleakala observatory (Hawaii), is equipped with the 1.4 Gpix camera GPC1.

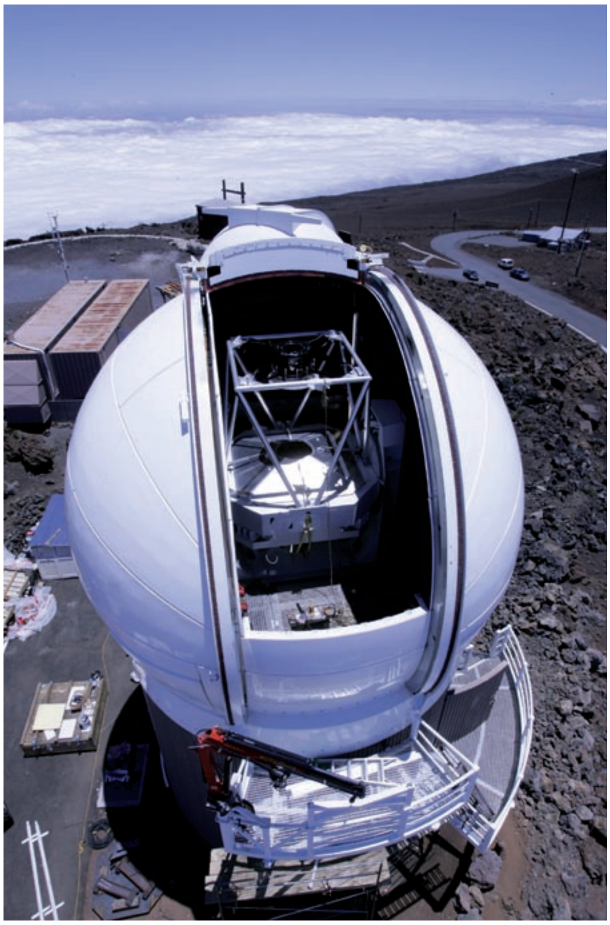
The unique feature of PanSTARRS1 is an unprecedented survey etendue, which is a measure for the speed at which a given area of sky can be surveyed to a given depth. The survey etendue increases with telescope diameter, area of sky covered by the camera in one shot, CCD sensitivity, and image and site quality. PS1 uses a new type of CCD called "Orthoganal Transfer Array" (OTA) that allows to compensate for atmospheric fluctuations (the tip/tilt component of seeing, to be precise) by shifting charges in all four directions during the exposure. In addition, the PS1 OTAs are especially sensitive in the red and very near infrared wavelength regions, allowing to access the wavelength region around 1 micron (*y*-band) for the first time in a large-area survey. With these novel CCDs and a 7-square degree field of view PS1 surpasses previous survey facilites in its etendue (Fig IV.7.2.). Hence, it will also surpass previous surveys in terms of the amount of data generated: about 1 Petabyte of raw image data per year, yielding about 20 Terabytes of catalogs with astronomical objects – about 6000 DVDs' worth of data. MPIA astronomers will access these data via a dedicated computer cluster set up at the MPG's Rechenzentrum Garching.

The PS1 project was initiated by the University of Hawaii's Institute for Astronomy (IfA). In 2006, MPIA committed to join the PS1 Science Consortium (PS1SC), which will fund operations of the PS1 telescope over a 4-year mission. PS1SC will actually perform multiple interlocking surveys, but most observing time is spent on imaging the entire visible sky (3/4 of the entire sky) twice over every year. In this way, it provides both a deeper view of the northern extragalactic sky and the entire Milky Way, and for the first time, time-domain information over such a large area.

In addition to MPIA and MPE, the consortium consists of Johns Hopkins University, Harvard-Smithsonian Center for Astrophysics/Las Cumbres Observatory Global Telescope, the Universities of Durham, Edinburgh and Belfast, and Taiwan's National Central University. The PS1SC has defined twelve key science projects, with topics ranging from the solar system and the identification of potential "killer asteroids" to the most distant objects and largest cosmological structures. MPIA scientists are at the core of four of these key projects. "PanPlanets Search for Exo-Planets by dedicated Stellar Transit Surveys" is led by Cristina Afonso and Thomas Henning, while "Structure of the Milky Way and the Local Group (PanGalaxy)" is led by Eric Bell and Hans-Walter Rix. Two more key projects are co-led with scientists at the IfA: "Low-Mass Stars, Brown Dwarfs, and Young Stellar Objects" is led by Wolfgang Brandner and Gene Magnier and will be hunting for the coolest brown dwarfs, and "Active Galactic Nuclei and High-redshift Quasars" is led by Fabian Walter and PS1SC director Ken Chambers, and will search for the most distant quasars.

GPC1 saw first light in August 2007, demonstrating its impressively large field of view with a picture of the Andromeda galaxy, requiring only a single shot. Fig. I.10, p.18 shows a small section of a more recent picture.

Fig. IV.7.1: The PS1 dome on the Haleakala ("Home of the Gods") mountain, an inactive volcano on the Hawaiian island of Maui.



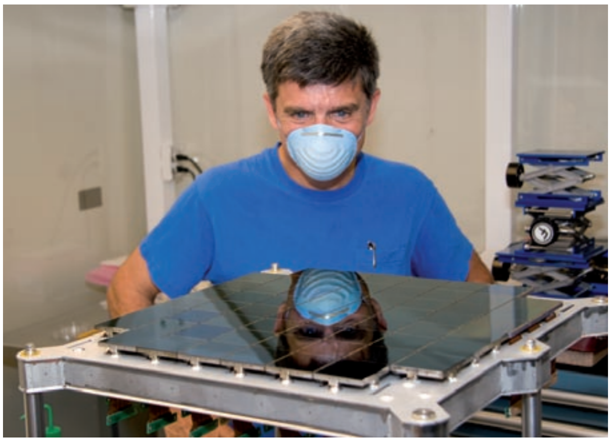


Fig. IV.7.2: The record breaking detector array of the 1.4-Gigapixel Camera GPC 1. (IfA, Univ. of Hawaii)

As in every commissioning of a new telescope and camera, there are a large number of subsystems to put into operation and debug, which happened throughout 2007 and 2008. A particularly challenging task was the optical alignment of the primary and secondary mirror, the large corrector lens L3 (which at the same time is the CCD dewar and vacuum window, with an atmospheric pressure equivalent to the weight of 2000 kg resting on it), and the camera itself.

April 2008 saw a special event in Heidelberg: MPIA hosted the first PS1SC meeting, a one-week workshop with over 80 guests representing all the PS1SC member institutions. The meeting offered the first opportunity for most PS1SC members to meet each other and the PS1 core team face-to-face, after many preceding interactions by email, telephone and video conferences. PS1SC scientists learned first-hand from the software teams about the "Image Processing Pipeline", which performs the basic data reduction, provides searchable object catalogs, detects moving and variable objects, and stacks the multi-epoch imaging to obtain one of the deepest large-area sky surveys to date; and about the "Published Science Products System" (PSPS), an SQL database which will allow querying the enormous amounts of PS1 efficiently. PSPS is built by the same team at Johns Hopkins University that created the hugely successful "Catalog Archive Server" for the Sloan Digital Sky Survey (SDSS). Much of the meeting concentrated on the key science projects, including both overviews of the key projects for everyone's benefit, as well as dedicated internal meetings with detailed discussions about goals, strategies, and resources. The status update by the PS1 team was of course of central interest to everyone. Many visitors commented on the buzzing and lively atmosphere during coffee and lunch breaks, which led to many fruitful interactions on topics within and outside PanSTARRS, and conveyed the excitement about the unique science opportunities offered by this project.

The last few months of 2008 saw an intensive phase with PS1SC scientists characterising the on-sky performance of PS1 in comparison to the design specifications, based on the commissioning data collected so far. Again, there were intensive interactions between scientists at all PS1SC institutions and the PS1 team at IfA. With the PS1 performance having been judged acceptable according to the criteria set out by PS1SC, the science consortium and its director Ken Chambers formally took charge of the PS1 telescope and camera from PS1 PI Nick Kaiser. Over the Christmas break, the camera was refurbished, predominantly by replacing 20 low-quality OTA chips with cleaner ones. After aluminization of the secondary mirror and reinstallation of GPC1, the telescope is being recommissioned. IPP and PSPS software development is continuing at a rapid pace. For 2009, PS1SC scientists are eagerly awaiting the start of regular survey observing – the proverbial "opening of the floodgates" that will bring unprecedented amounts of data to the MPIA's astronomers.

Sebastian Jester, Cristina Afonso, Eric Bell, Wolfgang Brandner, Thomas Henning, Hans-Walter Rix

GAIA – the Galactic Survey Mission

GAIA is Europe's flagship mission in the next decade. When launched in 2012, GAIA will undertake by far the most detailed and accurate astrometric survey ever attempted. It will measure distances to stars using the parallactic effect: the apparent motion of stars due to the orbit of the observing platform about the Sun. GAIA achieves this by measuring angles to very high accuracy, some ten microacrseconds – the angular size of a 1 Euro coin on the moon seen from the Earth. By measuring the positions over a period of five years, GAIA will also measure their proper motions. This, together with the highly accurate spectroscopic determination of radial velocities, will yield the space velocity of the stars and produce a three dimensional map of one billion stars in the Galaxy, complete with kinematics accurate to a few km/s.

Armed with the observations provided by GAIA, astronomers will study the structure, origin and evolution of our Galaxy, including the quantity and distribution of the elusive dark matter. By detecting and mapping the streams of stars (believed to be remnants of galaxies which merged with ours) in the Galactic disk and halo, we can reconstruct the history of how our Galaxy was built up. GAIA will also be able to detected the tiny wobble of stars due to unseen orbiting planets, and is expected to detect over one thousand exoplanets in this way. This method has the advantage over the radial velocity method of being useful for stars over the whole HR diagram, and gives actual mass estimates rather than lower limits. GAIA will also measure the General Relativistic

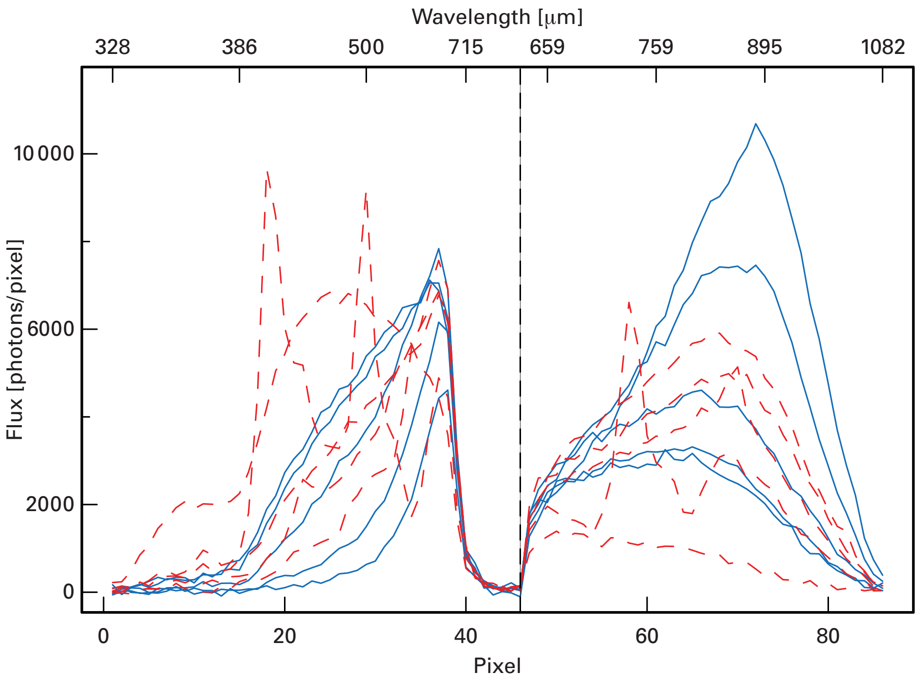
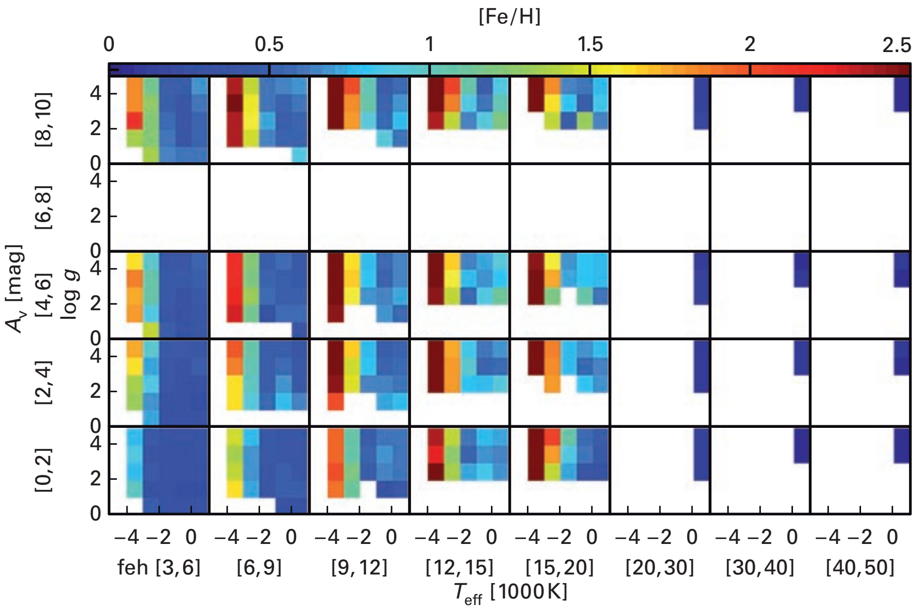


Fig. IV.7.3: Examples of the GAIA spectra for stars (blue solid lines) and quasars (red dashed lines) at $G = 18.5$ (noise included). The spectra are plotted against pixel numbers with the wavelength scale at the top (the dispersion is nonlinear). The spectra are obtained in two channels (blue and red) using prism spectrographs. The resolution is very low, so emission and absorption lines are only visible when these features are very broad.

Fig. IV.7.4: Example performance of one of GAIA's stellar parametrizers (support vector machines) in determining temperature (T_{eff}), interstellar extinction (A_v), metallicity [Fe/H] and surface gravity (log g). The outer axes plot ranges of the "strong" parameters (T_{eff}, A_v), which have the most dominant effect on the spectrum. Each panel then shows, on a colour scale, the RMS error in the determination of [Fe/H] as a function of the two "weak" parameters ([Fe/H], log g), for that range of A_v and T_{eff}. In this way we can show the variation in accuracy over four dimensions (parameters) in a two-dimensional plot. A metallicity error less than about 0.25 dex is good, which we achieve for all cooler stars ($T_{eff} < 9000$ K) over most of the metallicity range, and even for hotter stars with higher metallicities. (Hot stars have a much weaker metallicity signature.) What's encouraging is that this is even possible at high interstellar extinction.



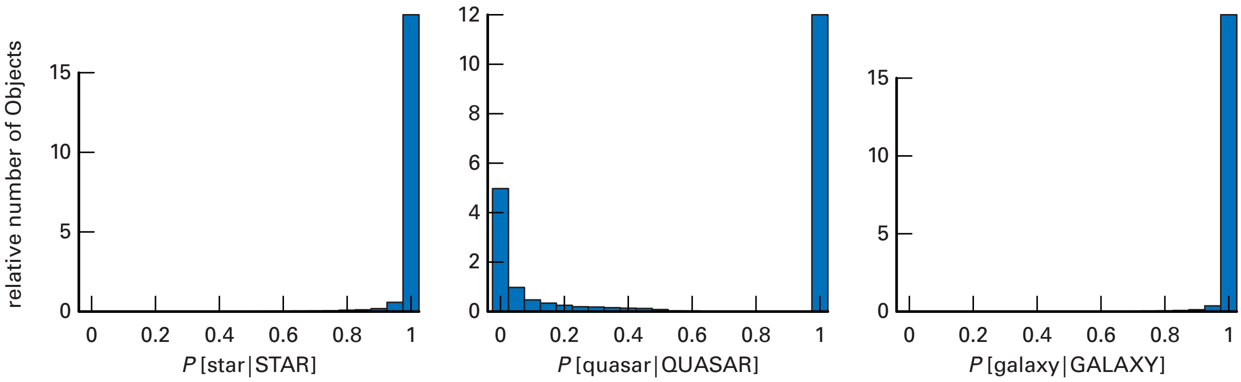


Fig. IV.7.5: Class probability estimates of the Gaia classification algorithm. Each histogram shows the probabilities assigned by the algorithm for objects truely of that class. A perfect classifier would have a peak at 1 and zero elsewhere. This shows the case in which quasars are assumed to be 1000 times rarer than stars or galaxies.

bending of light on solar system size scales with an accuracy not yet achieved, providing new tests of this theory, as well as detect large numbers of potentially impacting Near-Earth Asteroids.

Distance estimates are vital to almost every aspect of astrophysics, converting angular scales to physical ones and yielding intrinsic (rather than apparent) luminosities of objects. Astrometry is the only way of obtaining distances without making assumptions about the source. The high distance accuracy on a large number of objects promises to revolutionize many branches of astrophysics. As an example, an accuracy of 1 percent or better will be achieved on some 11 million stars as far away as 1 kpc. This compares to fewer than 200 stars with a parallax of this accuracy obtained from Hipparcos, all of which lie within 10 pc. Gaia is a mission of the European Space Agency. The data processing will be undertaken by a pan-European consortium, the Gaia Data Processing and Analysis Consortium (DPAC). On account of the complexity and volume of data, this is an enormous task, and the consortium currently comprises some 380 people from 79 institutes in 23 countries.

The Gaia astrometric data can only be properly exploited once we know the physical properties of the stars observed. For this reason Gaia will measure low resolution optical spectrophotometry of every source it observes (Fig. IV.7.3), plus high resolution radial velocity spectra. One of the eight coordination units of the DPAC, lead by Coryn Bailer-Jones at MPIA, is dedicated to deriving astrophysical information from these spectra (other coordination units work on the extraction, processing and calibration of these spectra). A group of five scientist at MPIA, funded by the DLR and MPIA, focuses on two particular aspects of this work. The first is the discrete classification of objects into star, galaxy, quasar etc. Due to the nature of Gaia observations, there will be limited or no information on the spatial shape of the sources, so classification can only be done via the spectrum. The second task is the estimation of stellar astrophysical parameters, in particular the effective temperature, surface gravity, composition and line-of-sight interstellar extinction. These are the fundamental parameters which we need to derive masses and ages and thus convert the Gaia spatial/kinematic map into a mass/age/composition one. With this we will learn about the chemical evolution of the Galaxy, changes in the star formation rate etc.

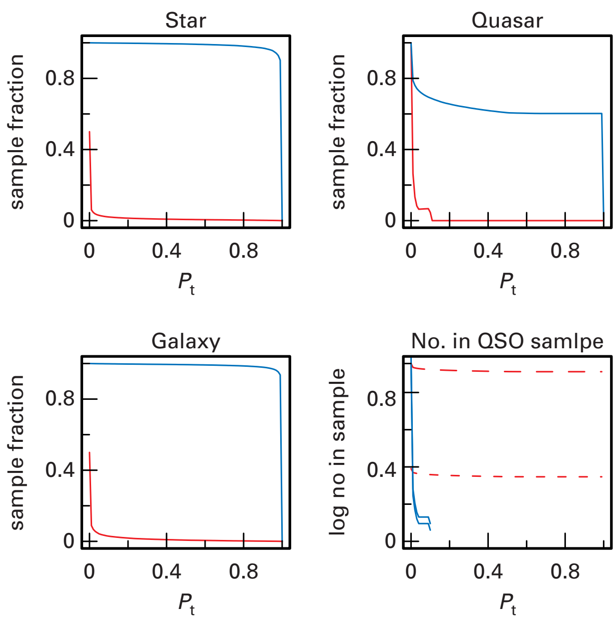


Fig. IV.7.6: Sample building with Gaia. Using an adjustable probability threshold (horizontal axis) in the classifier, we can construct samples of objects which trade off the completeness (blue line) and contamination (red line) in the sample. As the threshold increases we get more conservative in building the sample, so the contamination (fraction of false positives) decreases at the cost of a smaller completeness (fraction of true objects found). We can simultanesouly get a zero contamination quasar sample and very pure (less than 1 percent contamination) yet complete (99 percent) star and galaxy samples.

The MPIA group is using existing – and developing new – pattern recognition techniques to analyse the spectral data. Standard methods include support vector machines, neural networks, principal component analysis and mixture models. An estimate of the performance of our current algorithms is shown in Fig. IV.7.4. Our recent work has investigated how we can build very pure samples of rare objects, such as quasars. (Quasars are astrophysically interesting but will also be used to fix the GAIA astrometric reference frame.) Classification is a probabilistic process: with imperfect data we can rarely be 100 percent confident. So in building samples we must trade off the sample completeness with its contamination. We have developed a simple but potentially powerful method of doing this based on Bayesian principles. It adjusts the normal classifier output probabilities to accommodate our prior expectation of the frequency of source of different classes in a target data set. In this way we can increase our sensitivity to rare objects (Fig. IV.7.5 and Fig. IV.7.6). Our simulations suggest that we can build a sample of quasars down to $G = 20$ with around 50 percent completeness with a contamination of less than 1 in 40 000. This translates to a sample of up to 250 000 quasars with just 6 contaminants. Alternatively, we can build a larger (more complete) sample if we permit a higher contamination.

A second area of investigation has been the development of a new method for estimating parameters from spectra, called ILIUM. Most machine learning try to solve an inverse problem, that is, determine the param-

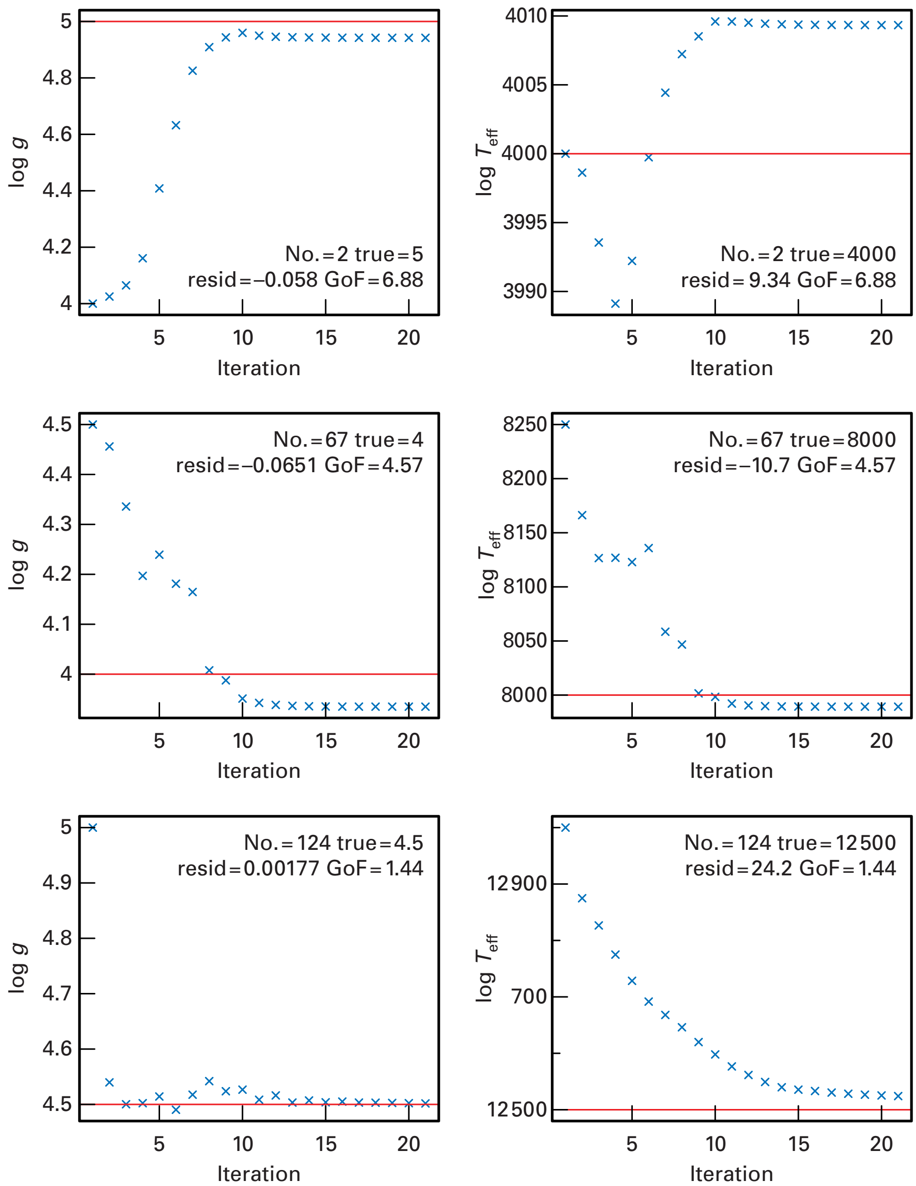


Fig. IV.7.7: The ILIUM algorithm estimates the astrophysical parameters of objects iteratively. The panels show the iterative updates for three stars (*the three rows*) for the surface gravity parameter logg (*left panels*) and effective temperature (*right panels*). The red line shows the true parameter in each case.

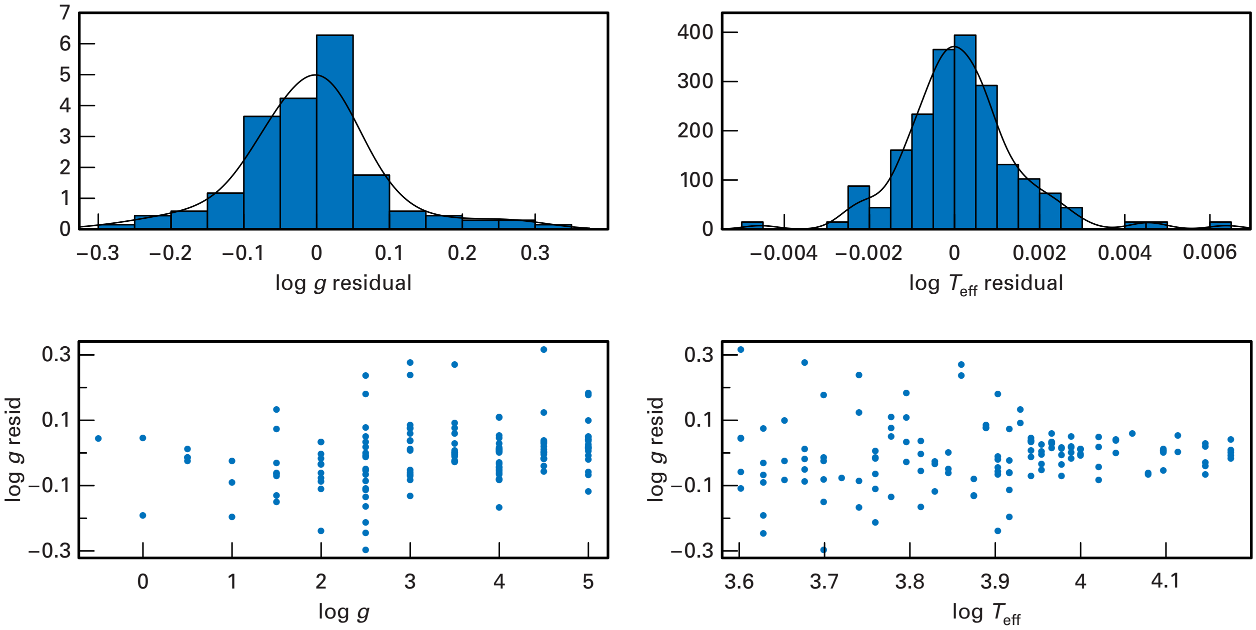


Fig. IV.7.8: Summary of the performance of ILIUM in estimating stellar surface gravity (log *g*) and effective temperature (T_{eff}) by plotting the histogram and trends of the residuals (estimated minus true). The mean absolute errors for log *g* and T_{eff} (shown here for stars at $G = 15$) are 0.07 dex and 0.2 percent respectively, some five times better than a nearest neighbours algorithm applied to the same data.

eters from the data. (It is inverse because the mapping is not one-to-one when we have imperfect data.) In doing so, these methods must implicitly learn the sensitivity of each data dimension (pixel in spectrum) to the parameters. Unfortunately, due to noise and the complexity of the problem, they don't always do this very well. The MPIA group has developed the ILIUM algorithm, a new method which calculates these sensitivities explicitly using synthetic data and uses them in an iterative scheme to estimate the astrophysical parameters (Fig. IV.7.7 and Fig. IV.7.8). Preliminary results suggest that it is slightly better than standard methods and, moreover, automatically provides information that standard methods cannot easily provide (error estimates, goodness-of-fit, relevance of input data in determining the output).

An important ingredient of all classification models is the spectral data on which they are trained. For this we take spectra with known astrophysical parameters and simulate the spectra using a model of the GAIA instrument. We use a range of synthetic and real spectral libraries for this purpose. Our group, in collaboration with colleagues at the University of Athens and Institut d'Astrophysique de Paris, has constructed a new library of synthetic galaxy spectra to increase the variety of objects available for training (Fig. IV.7.9). GAIA is expected to observe around one million galaxies, and using their spectra we will be able to measure their redshifts, types and infer some aspects of their star formation history.

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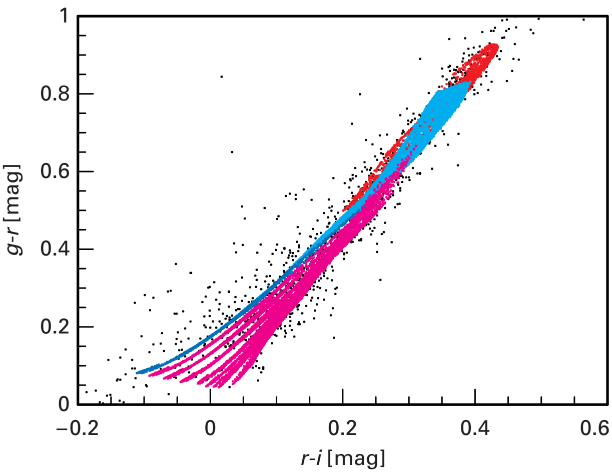
Rainer Klement, Chao Liu, Kester Smith,
Carola Tiede, Paraskevi Tsalmantza

Fig. IV.7.9: Synthesized *g-r* and *r-i* colors for the new library of synthetic galaxies we have constructed for the GAIA classification work. Models of starburst, irregular, spiral and early type galaxies are presented with magenta, blue, light blue and red points respectively. The black points are SDSS galaxies (DR4) with $z < 0.01$, which are used to guide the parameter settings of the models.



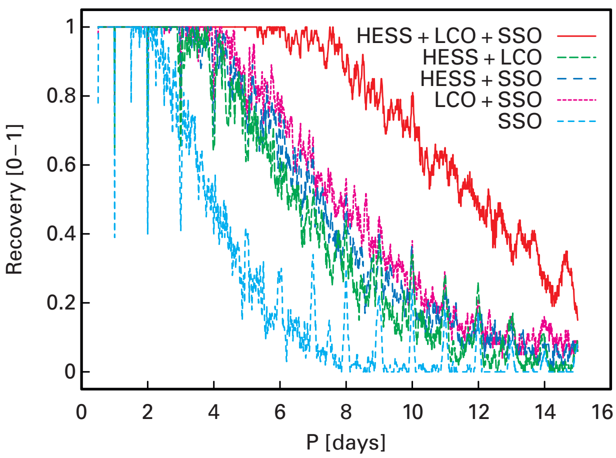
HAT-South – A Network in the Southern Hemisphere to Search for Planetary Transits

The HAT-South project is a network of 24 small-sized automated telescopes located at three different sites in the Southern hemisphere: Las Campanas in Chile, the HESS site in Namibia, and Siding Springs in Australia. The primary goal is to survey a large number of nearby stars to search for transiting extra-solar planets and study their characteristics.

HAT-South is a collaborative effort between the Max Planck Institute for Astronomy (MPIA), the Harvard-Smithsonian Center for Astrophysics (CfA), and the Australian National University (ANU). Each institute is responsible for one of the nodes, in particular the MPIA is in charge of the site preparation and operations of the Namibian site. The PI of the project is Gaspar Bakos from the CfA, Thomas Henning is one of the Co-PIs, and Cristina Afonso is the MPIA node manager. HAT-South stands for “Hungarian Automatic Telescope for the Southern Hemisphere”.

The three sites allow a nearly 24-hour coverage for a range of fields, significantly increasing the detection rate, if weather permits, particularly for planets exhibiting periods larger than a few days and far from integer fractions of a day. Fig. IV.7.10 shows the transit recovery for different site configurations: single site, combinations of two sites, and all three sites together. The southern hemisphere has an advantage over the northern one for transit searches, due to the better visibility of the Milky Way, and hence a higher stellar density. In addition, state of the art spectroscopic facilities necessary for confirming the planetary nature of the transit candidates, are available in the south.

Fig. IV.7.10: Transit recovery versus the period of the planets for different site configurations. Top curve shows a 3 sites simulation with 2-month observing window during the summer (short nights). The curves in the middle show the three possible 2-sites-configurations for the same time-frame. The bottom curve is for a single site.



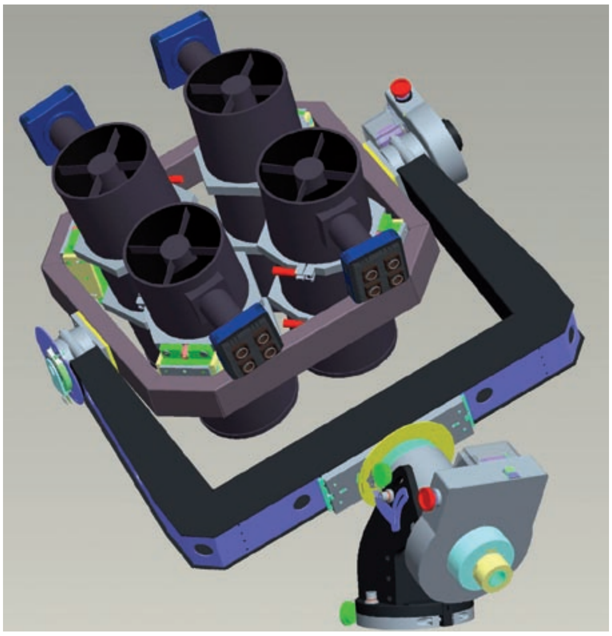


Fig. IV.7.11: Engineering model of one of the TH4 for HAT-South. A forkmount holds four telescope tubes, each 0.18 m in diameter with 0.5 m focal length, holding a 4K x 4K CCD, which yields a combined field of view of 8° x 8°.

Each site is going to harbor two so-called TH4, each carrying an ensemble of four automated 0.18 m f/2.8 Takahashi hyperbolic astrographs (see Fig. IV.7.11), each with an $4\,K \times 4\,K$ Apogee CCD detector, and with a Sloan *r* filter. The field of view of each camera is $4° \times 4°$ with a pixel scale of 3 arcsec, the resulting field of view of each TH4 is thus going to be $8° \times 8°$, i.e. a total field of view from each site of 128°. This configuration will help in the identification of false alarms due to diluted triple systems, mimicking planetary transits. The TH4 units will be protected by a clamshell structure and operated entirely automatically. The infrastructure preparation of the Namibia site has been finished in March 2009. Installation of the telescopes is expected to happen before summer 2009, and a fully operational mode with all three sites toward the end of the year. The HAT-South project is planned to operate during the coming 5 years.

The magnitude range to be explored is $9 < R < 13.5$, equivalent to a medium-depth survey, bridging the gap between the shallow surveys around bright stars ($R < 12$) and deep surveys ($R > 13$) targeting fainter stars. Estimations of the expected number of planets based on star counts from models of the Galaxy, show that the minimum recovery rate would be 2 extra-solar planets per month, or about 25 planets per year. In conclusion, HAT-South is expected to find on the order of 125 transiting extra-solar planets, a large number of which are expected to be suitable for atmospheric studies.

Cristina Afonso, Thomas Henning
in collaboration with CfA and ANU

V People and Events

V.1 Outreach Activities and Conferences

Scientific life at the Institute is also marked by a large number of different events that the MPIA and its partners organize every year. The spectrum ranges from purely scientific meetings to special offerings for school students to public events. Here we provide a brief impression of the activities in 2008.

For many years, the presentation of scientific issues to the general public in an intelligible way has been an important part of the MPIA's work. In addition to conventional elements of public relations work such as press releases, media interviews and lecture series, the MPIA is engaged in a variety of activities to familiarize different target groups with the institute's research and with general astronomical findings. The new generation of potential scientists and their enthusiasm for science is particularly close to our heart. Therefore, the year 2008 once again saw a number of events such as Girls' Day (April), the BOGy internship ("Professional Orientation for Students of Grammar Schools") (October), in-service teacher training as part of the project "Wissenschaft in die Schulen!" ("Science into schools!"), and participation in the Explore Science experience days in Mannheim organized by the Klaus Tschira Foundation. The idea of bundling these activities, which are best described as "Educational and Public Outreach", and making them even more professional had been around for a long time. And so the year ended on a very positive note with a press conference on December 10, 2008, where the plan to establish the Haus der Astronomie (HdA) on the Königstuhl hill was announced. Details of this ambitious long-term project and the cooperating partners can be found in chapter I.4 of this annual report. The HdA press release published at the same time as the prescon-

Fig. V.1.1: The crowded MPIA lecture hall during public lectures of our Sunday Mornig series.

ference was the last of a total of 15 press releases in 2008. All together, they generated a press response of around 200 newspaper articles about the MPIA (excluding the contributions on the Internet).

The year started with one of three public lecture series. March saw the conclusion of the series of lectures by Heidelberg astronomers titled “Astronomy in Heidelberg”, which had been running since the fall of the previous year in the Mannheim Planetarium and was jointly organized by the MPIA, the Center for Astronomy of Heidelberg University (ZAH), and the Mannheim Planetarium.

From May to July the focus was again on Astronomy on Sunday Morning. The now firmly established series of lectures at the MPIA caused the lecture hall to overflow on nine Sundays, despite the unusual time (Fig. V.1.1). In October the university’s ‘Studium Generale’ extra-mural program 2008/2009 began: The MPIA suggested the topic of “Galileo’s first look through a telescope and the consequences for today” and was deeply involved in the planning and execution of the 14 lectures. Renowned cultural and science historians shed light on the modern beginnings of our science and today’s researchers contrasted this with their present understanding and their view of future prospects. This program of contrasts regularly enthralled around 400 listeners, the far-reaching effect of the upheaval 400 years ago was brought out – and provided a good grounding for the forthcoming International Year of Astronomy (IYA 2009) into which the series of lectures extended. In the year under review, our neighboring institute, the Landessternwarte, hosted the IYA preparatory meeting for the whole of Germany, in which several members of the MPIA were involved. Moreover, this year saw many members of the MPIA being invited to give public talks at external organizations.

As in previous years, 2008 witnessed a large number of visitors who were able to find out about the work on the Königstuhl by taking part in guided tours. School classes, in particular, often make use of this offer. Among the special guests on the more than 30 guided tours this year were the Friends of the Mannheim Planetarium (March), a group from the Rhein-Neckar newspaper (August), and the visitors of the International Max Planck Research School (September).

A special event took place on January 31. For the first time, the MPIA issued an invitation to a meeting of the Gesprächskreis Rhein-Neckar (Rhine-Neckar Discussion Group). This is a platform where scientists from basic research institutes and from industrial research in the Rhine-Neckar region report on their projects and hold discussions. The aim of the event, which is organized under the overall charge of the Kirchhoff Institute for Physics (KIP) at the University of Heidelberg, is to promote interdisciplinary contact among scientists, an aspect that was evident at the meeting held at the MPIA. Thomas Henning, Roland Gredel and Klaus Jäger, for example, reported on the activities at MPIA with special emphasis on the technical challenges of observations with new large telescopes such as infrared spectroscopy. Annemarie Pucci (KIP), on the other hand, provided guests with interesting details about infrared spectroscopy of nanostructures. The meeting also included contributions on microscopy in biology and organic photovoltaics.

In addition to this interdisciplinary meeting, purely astronomical meetings involving MPIA were staged. The first Heidelberg Astronomers’ Convention took place in March at the KIP. Its aim was to bring together as many Heidelberg students and scientists working in the field of astrophysics as possible in order to exchange information on current projects.

International meetings worthy of particular note were:

- “Nuclear Clusters across the Hubble Sequence” (February, MPIA)
- Chinese-German Star and Planet Formation Workshop (March/April, Purple Mountain Observatory, Nanjing, China). See also Section V.2.
- “EPoS 2008: The Early Phase of Star Formation” (July, Ringberg Castle)
- “Cosmic Dust – Near & Far” (September, Convention Center, Heidelberg). See also Section V.2.
- Workshop “Cosmic Dust and Radiative Transfer” (September, MPIA)
- IMPRS Summer School: “The Art and Craft of Astronomical Instrumentation” (September, Max-Planck House Heidelberg)
- “Understanding Lyman-alpha emitters” (October, MPIA)
- “Classification and Discovery with Large Astronomical Surveys” (October, Ringberg Castle)
- “The high-energy astrophysics of outflows from compact objects” (December, Ringberg Castle)
- Joint workshop of MPIK and MPIA (December, Ringberg Castle)

In addition to the many meetings for the Institute’s instrumentation projects, a three-day meeting for the PanStarrs1 project and a meeting of the LBT Beteiligungsgesellschaft took place in April. And finally, the Board of Trustees also paid two visits. The meeting, which was cancelled in 2007, took place in February, followed by the regular meeting for 2008 in December.

To sum up, the year 2008 was a very successful one, not only in scientific terms, but also for the organization of outreach activities were concerned. And once again, this was only possible thanks to exceptionally strong commitment to the Institute that a large number of staff demonstrated in the course of the year.

Klaus Jäger

V.2 Two International Conferences

In Nanjing: Chinese-German Workshop on Star and Planet Formation

The investigation of the formation of stars and planets is a fundamental topic in modern astrophysical research, both in China and in Germany. Astronomical institutes and individual researchers from both countries have made profound contributions to this field of research during the last decades and play a leading role in current key projects. This applies for ground- and space-based observational astronomy as well as for theoretical investigations and numerical simulations.

With the goal to explore future collaborations between German and Chinese researchers, the Max Planck Institute for Astronomy and the Purple Mountain Observatory (PMO, Chinese Academy of Science) organized a joint workshop on star and planet formation". The workshop with thirteen participants from the MPIA and various German universities, and thirteen Chinese senior scientists took place in Nanjing from March 31 to April 4, 2008. It was funded by the Sino-German Center for Research Promotion (Beijing, China).

Fig. V.2.1: The participants to the Chinese-German Workshop on Star and Planet Formation at the Purple Mountain Observatory in Nanjing.

The exchange of results from the various research activities of participating groups both from China and Germany formed an excellent framework for discussions about the possibility of mid- to long-term collaborations. Specific areas currently in focus and where the highest potential for future joint projects between Chinese and German scientists and institutions is expected include early phases of star formation, the origin of massive stars, open issues in low-mass star formation, and planet formation. Based on common and complementary research interests and approaches, strategies to establish collaborations in the fields of observational and theoretical star and planet formation research were explored. The workshop also provided the German participants an opportunity to visit the PMO, which is the main institute in China engaged in the study of star and planet formation. A follow-up worshop will be held in the near future, in order to foster the joint research initiatives eabled by this meeting and include young scientists from both countries.

Sebastian Wolf
(on behalf of the MPIA, now University Kiel);
Chinese workshop coordinator:
Hongchi Wang (Purple Mountain Observatory)

In Heidelberg: "Cosmic Dust – Near and Far"

Cosmic dust traces physical and chemical processes taking place in a range of environments, from the solar system to the high-redshift universe. Infrared and millimeter radiation from dust grains has served as the tool to detect and characterize structures from protoplanetary discs around brown dwarfs to distant quasars,. First analyses of collected cometary dust particles open exciting new views on individual cosmic dust particles. Solid particles play an enormous role in the lifecycle of cosmic matter, providing the surface for chemical reactions, and determining the thermal, ionization and dynamical state of matter through their interaction with radiation, cosmic rays, and gas particles.

The international conference "Cosmic Dust – Near and Far" was held in Heidelberg from September 8 – 12, 2008. The goal of the meeting was to bring together the various fields in astrophysics where dust is considered to be a major player in our understanding of cosmic evolution. The meeting covered new findings and future perspectives of cosmic dust research in environments as diverse as the solar system, brown dwarf and planetary atmospheres, the environment of evolved stars, dust in supernovae, the Milky Way and other galaxies, and the early universe. Observational results, theoretical models, and the outcome of laboratory experiments were addressed and their implications for future ground-based facilities and space missions highlighted.

This meeting was a sequel in a series of comprehensive cosmic dust conferences, starting with an IAU Symposium in Albany in 1972 and following the last very successful meeting "Astrophysics of Dust" in the Rockies Conference Center organized by Adolf Witt in 2003. The meeting took place in the beautiful setting of the Heidelberg Convention Center, not far from the place were Gustav Robert Kirchhoff and Robert Wilhelm Bunsen laid the foundation for spectroscopy and cosmic chemistry 150 years ago. The conference attracted more than 270 scientists from 25 countries, demonstrating the enormous interest in the field.

The conference was scheduled at a time when a flood of new exciting cosmic dust data was delivered by the Spitzer Infrared Space Telescope and the Stardust mission. A unique feature of the conference was a specialized workshop on "Cosmic Dust and Radiative Transfer" which took place at the Max Planck Institute for Astronomy after the meeting, organized by J. Steinacker.

Generous financial support was received by the Max Planck Society, the German Science Foundation, the European Space Agency, and the University of Toledo with the help of Adolf Witt. The Tschira Foundation enabled the organization of a public talk by Elmar Jessberger, which attracted a lot of attention.

Thomas Henning

V.3 Awards and Fellowships

Otto Hahn Medal of the Max-Planck-Society awarded to Nadine Neumayer and Anders Johansen

The Max Planck Society has awarded the Otto Hahn Medal each year since 1978 to up to 40 young scientists for outstanding scientific achievements. The award is also endowed with a sum of money in recognition of the price-winners' efforts. The aim of the prize is to motivate very talented junior scientists to take up a career at a university or in research. At the 2008 Annual Meeting of the Max Planck Society in Dresden, the Otto Hahn Medal was awarded to Anders Johansen for his research into the gravo-turbulent formation of planetesimals in the turbulent gaseous disks around young stars, and to Nadine Neumayer for determining the mass of the black hole in the center of the active galaxy Centaurus A, and proving that here, too, this mass correlates well with the total stellar mass in the galaxy.

Nadine Neumayer's work at the MPIA is focused on the relationship between supermassive black holes in the center of galaxies and the properties of the surrounding galaxies as a whole. Although the characteristic properties of the black hole and the galaxy differ by 9 orders of magnitude, the mass of the black hole can be predicted from the total stellar mass of the surrounding galaxy with an accuracy of between 30 and 50 percent. There is still very limited understanding as to how this spectacular mass correlation between the central black holes and the mother galaxies comes about. Nadine Neumayer made an important contribution to establishing this correlation in her diploma thesis. In her subsequent doctoral thesis, she developed and applied innovative observational and analytical methods with high spatial resolution to determine the mass of the black hole in the Centaurus A galaxy to sufficient accuracy. Surprisingly, this active galaxy seemed not to obey the mass correlation. At Eso's VLT, she then succeeded in carrying out observations on the central area of Centaurus A with previously unachieved angular resolution. She was thus able to establish the dynamics in the central area and redetermine the mass of the black hole. This revised value fit into the known relation and provided impressive confirmation of it (see 2006 Annual Report, Chap. II.7).

Anders Johansen has made significant contributions to our understanding of the early phases of planet formation with the aid of computer simulations. This process begins with the growth of small dust particles in the turbulent gas disks around infant stars. Small dust

Fig. V.3.1: Winners of the Otto Hahn Medal: Nadine Neumayer (bottom row, 2nd from right) and Anders Johansen (top row, far right) (Photo: N. Michalke).

particles interact with the gas and thus are accelerated to non-uniform velocities, then collide and adhere to each other by virtue of the surface forces. This causes the particles to grow to approximately one meter. Once these so-called planetesimals have increased to a size of several kilometers, their gravitational forces can cause them to merge and grow to form terrestrial planets and the cores of gas planets. The range between meter-sized bodies and kilometer-scale planetesimals is critical, however, as neither adhesion nor gravitation alone is sufficient for growth in this range. Anders Johansen has been able to impressively demonstrate how a combination of turbulence and their intrinsic gravitation allows the lumps of rock to clear this "hurdle". In extensive computer simulations of magnetically driven turbulence in the disks around young stars he demonstrated how swarms of meter-sized lumps of rock coagulate in cells of turbulence to form huge rock clouds, which then merge under the influence of their mutual gravitational attraction to form minor planets (see 2007 Annual Report, Chap. II.3).

Ernst Patzer Award for Frithjof Brauer, Dominik Riechers and Xiang-Xiang Xue

The Ernst Patzer Award to support junior scientists is financed by the Scientific Ernst Patzer Foundation, which was established by the widow of the philosopher and art lover Ernst Patzer. The Foundation aims to financially promote and support science and research, mainly in the field of astronomy. The awards are presented to young scientists at the MPIA for the best refereed publications during doctoral studies and/or the postdoc phase at the MPIA. The proposals submitted are evaluated by a selection committee appointed especially for this award, which consists of two MPIA scientists and an external scientist. The three 2008 laureates each received 2000 euros.

Frithjof Brauer received the award for his publication "Coagulation, fragmentation and radial motion of solid particles in protoplanetary disks" (Brauer et al. 2008, Astronomy & Astrophysics 480, 859). The publication represents a breakthrough in the numerical modeling of the growth of dust grains in protoplanetary disks. It provides clear insight into the physical processes that dominate the growth of dust grains. To this effect, coagulation, fragmentation and radial diffusion of the particles were all taken into consideration.

In order to simulate on the computer the temporal evolution of dust grains in an accretion disk around a sun-like young star over millions of years, Brauer incorporated two significant algorithms into the computer code, which had been developed by two other researchers at the MPIA: A time-implicit treatment of the growth equations, on the one hand, and an elegant reduction of the two-dimensional problem into a radial and a vertical problem on the other. This considerably reduces the number of grid points necessary and the time required to solve the equations.

The computer simulations show that radial drift and fragmentation inhibit the growth of the dust grains beyond the millimeter range. After a million years or so almost all dust grains have arrived at the central region of the disk near the star where the high temperature causes them to vaporize. This is inconsistent with observations, since dust grains of this size have been detected in the outer regions of the disk.

In his work, Brauer discusses possible loopholes to avoid this contradiction. It seems possible, that turbulence is restricted to the disk's equatorial plane. This would reduce the transport of dust particles away from the plane. Moreover, some observations seem to indicate that radial drift of dust particles is not as efficient as generally assumed. Both effects would facilitate the growth of dust particles to larger bodies. In future simulations, Brauer intends to explore these and other possible solutions.

Dominik Riechers was honored for his publication "Formation of a quasar host galaxy through a "wet merger" 1.4 billion years after the big bang" (Riechers et al. 2008, The Astrophysical Journal Letters 686, L9).

Dominik Riechers' spectroscopic observations of molecular carbon monoxide with high spatial resolution in a quasar at a redshift of $z = 4.41$ are qualitatively and quantitatively an important step towards a general understanding of how galaxies evolve. The angular resolution of 0.15 arcseconds achieved with the Very Large Array corresponds to a linear spatial resolution of 1 kpc for the distance given. Thus a spatial resolution which is usually only achieved in neighboring galaxies was achieved for an object in the early universe (1.4 billion years after the big bang). The spectrally resolved data make it possible to carry out both a spatial and a dynamic study of the gas distribution.

The molecular gas with a mass of just below 10^{11} solar masses is distributed across more than 5 kpc in this quasar and the kinematics show a velocity gradient in a roughly north/south direction. This kinematic structure cannot be explained with a gravitationally bound disk, but rather with a model of merging galaxies. Collisions of gas-rich galaxies ("wet mergers") can both feed the central black hole with matter and explain the quasar activity, as well as providing the required gas reservoir for the central high-mass starburst in this galaxy. The observations provide direct proof that such fusion processes are connected with the quasar activity.

Cosmological models predict a considerably higher rate of galactic mergers for high redshifts (i.e. for the young universe) compared to the local universe. Correspondingly, Dominik Riechers' observations imply that such gas-rich merger processes do indeed play an important role in the formation and evolution of galaxies.

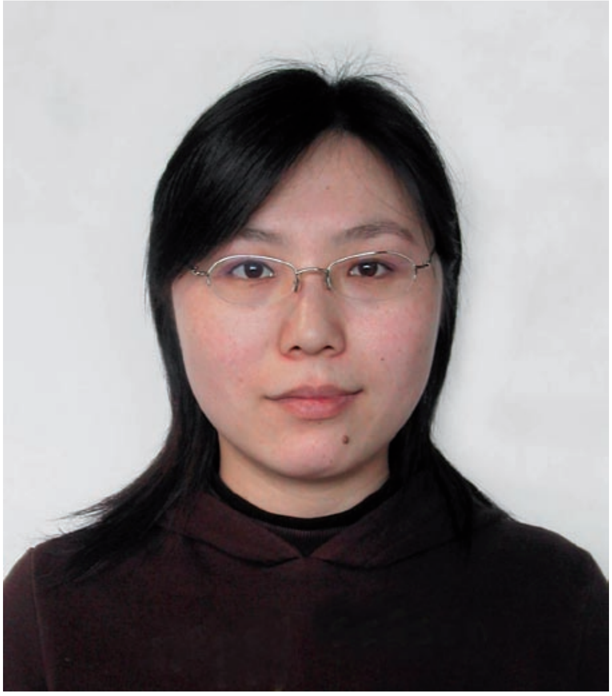


Fig. V.3.2: The Winners of the Ernst Patzer Award, Dominik Riechers and Xiang-Xiang Xue.

Riechers' observational work is of very high quality. At the same time, the subsequent interpretations are important building blocks for our understanding of quasar activity, high-mass star bursts and the evolution of galaxies in the early universe.

Xiang-Xiang Xue has been given the Patzer Award for her publication "The Milky Way's circular velocity curve to 60 kpc and an estimate of the dark matter halo mass from the kinematics of 2400 SDSS blue horizontal-branch stars" (Xue et al. 2008, Astrophysical Journal 684, 1143).

In her work, Xiang-Xiang Xue determined the mass (including the dark matter) of the Milky Way with the highest accuracy possible, using new stellar spectra at a distance of up to 60 kpc. This accurate measurement was made possible by the new data from the extended Sloan Digital Sky Survey (SDSSII), which has greatly increased the number of objects with spectroscopic data (see Chap. II.5).

The analysis involved searching the complete SDSS database to identify blue old stars in the halo of the Milky Way, distinguished by their special position in color diagrams and their spectral line profile. This necessitated using procedures to exclude false identifications. From the distribution of the distances and velocities of these stars, Xiang-Xiang Xue was able to determine the rotational speed and thus the enclosed mass of the Milky Way. The accuracy was a factor of three better than all previous studies of this kind. The result was somewhat surprising: The total mass of the Milky Way is at the lower end of the previously calculated range of values. In addition to this measurement, the result was also compared to model predictions and the significance of the measurement points was investigated.

A particularly distinguishing feature of the work is the care taken with the construction of the data points used and the in-depth analysis that takes into account cosmological models. The presentation is clear and methodical. The result, in particular the downsizing of the observational errors, is of great importance for models of the formation of our own galaxy.

Reimar Lüst Fellowship of the Max Planck Society for Frithjof Brauer

In 1983, the Max Planck Society was able to establish a foundation to support young scientists using donations from industry; the conferment of the Reimar Lüst Fellowship is made possible from its proceeds. Fellowships can be awarded to junior scientists whose achievements as doctoral students or postdocs have made them worthy of special support. The Fellowship is granted for a period of two years. Frithjof Brauer was awarded such a Fellowship in 2008.

Frithjof Brauer's work at the MPIA deals with the numerical modeling of the growth of dust grains in protoplanetary disks. He has incorporated two significant algorithms into the computer code developed by two other researchers at the MPIA. This considerably reduces the number of grid points necessary and the time required to solve the equations (for more details see the previous section on the Ernst Patzer Award).

Fig. V.3.3: Frithjof Brauer won the Ernst Patzer Award andwas awarded a Reimar Lüst Fellowship of the Max Planck Society.

V.4 Bridging the Gap Between Active Research and Schools

A talk with Klaus Tschira about the House of Astronomy

At a press conference held on December 10, 2008 at the Klaus Tschira Foundation it was officially announced that a "Haus der Astronomie" was to be established to bring the entire range of educational and public outreach activities of all Heidelberg astronomers under one roof and increase its level of professionalism. The institution – a first in Germany – was thus officially underway, less than two years after the concept had first emerged. The foundation will cover the costs for the construction of the building on the site of the MPIA, as well as for the initial technical equipment. The Max Planck Society will operate the institution, and the City of Heidelberg, the Federal State of Baden-Württemberg, Heidelberg University and the Klaus Tschira Foundation will bear a share of the personnel costs. In the following, Klaus Tschira talks about the project's history.

Question: The Klaus Tschira Foundation has its headquarters in the Villa Bosch, the former residence of the chemist and industrialist Carl Bosch, who also had a passionate interest in astronomy. Is this what motivated you to become involved in astronomy?

Klaus Tschira: The Foundation is delighted to continue this tradition. I myself was a hobby astronomer when I was still at school.

Did you have your own telescope?

KT: No, I've always been a theoretician.

How did you become involved with the MPIA?

KT: In 2003, the Institute appointed me to the then newly established Board of Trustees. I was already well-known among astronomers because of my involvement with the DIVA space mission.

The Klaus Tschira Foundation first provided financial sponsorship for MPIA activities in 2004 as part of the "Wissenschaft in die Schulen! / Science into

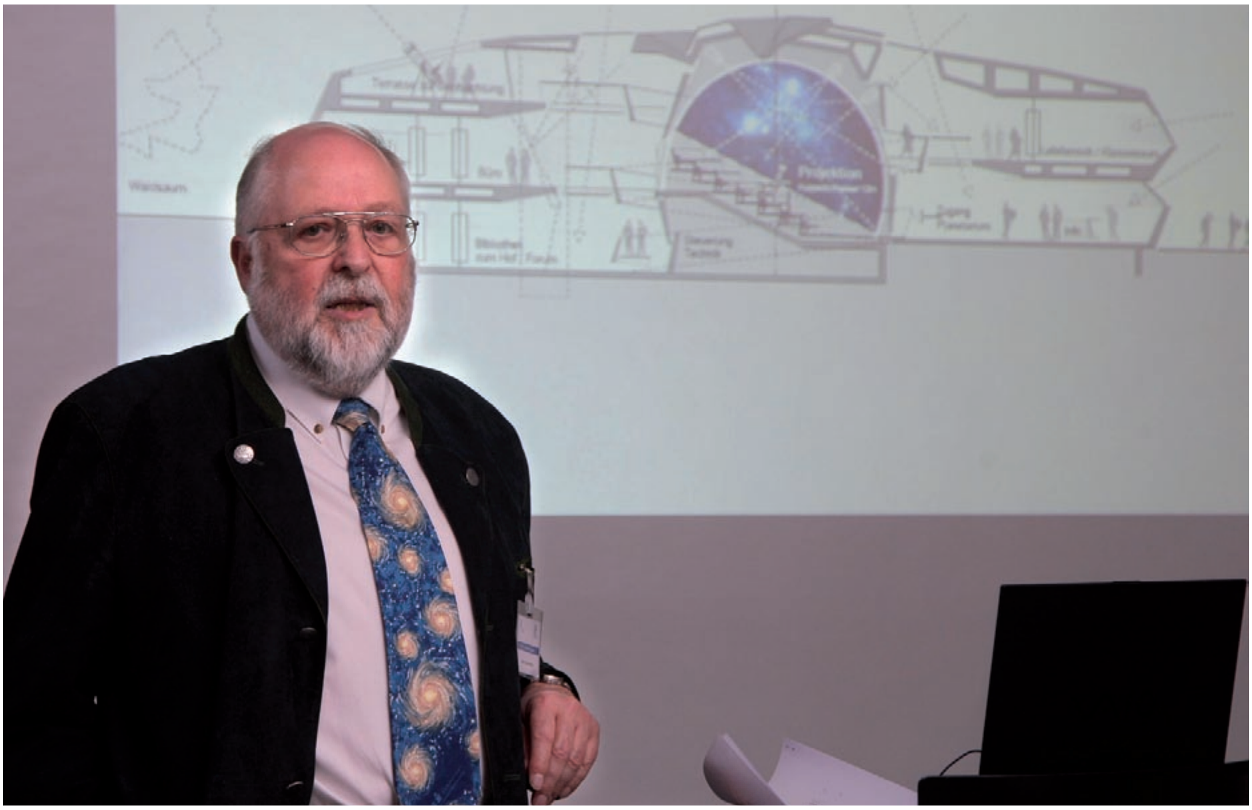


Fig. V.4.1: Klaus Tschira addresses the press conference for the "Haus der Astronomie". In the background, a planning design of the new building. (Photo: KTS) *schools!" project organized by the journal "Sterne und Weltraum".*

KT: I remember that Jakob Staude wanted to employ an educationalist from the field of physics and astronomy to adapt articles on astronomy from the journal for use in schools and make them available to teachers. I liked the idea a lot and so decided to fund this position. By the way, I would like to point out here that this continues an old East German tradition, because in East Germany, astronomy was a normal part of the school curriculum.

So you will be promoting research projects as well as educational projects for schools. Which criteria do you use to decide what deserves support and what doesn't?

KT: I support things I find interesting. As far as school education is concerned, I think young people come into contact with the sciences, in particular with physics, much too late – namely during the problematic phase of puberty. We must awake their curiosity much earlier. These projects are also attracting the attention of those responsible in the Ministry of Education and we are hoping this might provide us with a way of influencing teaching curricula. From a more general point of view, becoming involved with astronomy is naturally a great opportunity to awaken an interest in science, particularly in young people. The "Haus der Astronomie" is meant to provide a short, sound and lively bridge from active research into schools.

The "Science into Schools!" project was the first step along this road. With the support of the Klaus Tschira Foundation and in collaboration with the Publishing House "Spektrum der Wissenschaft", where "Sterne und Weltraum" is also published, the Federal State Academy for Continuing Education and Staff Development for Schools in Baden-Württemberg (Landesakademie für Fortbildung und Personalentwicklung an Schulen in Baden-Württemberg) has now extended this concept to include biology and chemistry. But let's now turn to the matter at hand, the "Haus der Astronomie". Your foundation will cover the costs for the construction of the building and the initial technical equipment. To what extent have you yourself been involved with the design of the building?

KT: When Hans-Walter Rix showed me the proposal, the "Haus der Astronomie" consisted of a room layout plan enclosed in a rectangular building. However, I found this cigar box really boring. I have a penchant for construct-

Fig. V.4.2: Those chiefly responsible in front of computer drawings of the "Haus der Astronomie": Klaus Tschira, Manfred Bernhardt (architect), Herbert Jäckle (Vice President of the Max Planck Society), Thomas Henning (Director at the MPIA), from left to right. (Photo: KTS) ing buildings whose future purpose is obvious from the outside.

Have you adopted this approach in earlier projects?

KT: At the Advanced Training Centre of the European Molecular Biology Laboratory (EMBL), our inspiration came from the structure of the DNA molecule that carries the genetic information for all life, and the building was constructed in the shape of a double helix.

And what was the idea behind the "Haus der Astronomie"?

KT: The architect Manfred Bernhardt and I first thought of Saturn. The building would have had a domed room in the center that could have been used as a lecture theatre. We discussed this idea further and finally came up with the shape of a barred spiral galaxy. This also had a dome-shaped protrusion in the center, and the other rooms could be integrated into the spiral arms of the galaxy. The complex resembles a half galaxy, rather like a fried egg. The current layout strongly mirrors the shape of the M 51 Whirlpool Galaxy. When it is built, with the help of Google Earth you'll be able to immediately recognize that this building is dedicated to astronomy.

The project is now finally underway. Will you continue to follow its progress, and do you want to have an influence on events in the future?

KT: I hope the events taking place there are ones I will want to visit now and again. But I will not interfere with the actual program. I do not feel like a film producer who thinks he must also have a say in the artistic content if he finances the film.

Does the current financial and economic crisis affect your sponsorship activity? Could it possibly delay or even prevent the construction of the "Haus der Astronomie"?

KT: First of all, the endowment fund will remain untouched as far as possible. The project will be financed exclusively from the returns. I hope that the financial crisis will not significantly affect my foundation, but I don't have much concrete information at the moment. It's always been my policy to put aside the funds promised for all the projects I have agreed upon. The "Haus der Astronomie" will definitely be completed.

The Darmstadt architects Bernhardt + Partner have already undertaken other building projects for the foundation and you have now commissioned them to build the "Haus der Astronomie". What is their schedule like?

KT: This will also greatly depend on how quickly planning permission is obtained for this unusual building. We hope to be able to start construction in summer 2009, and that the team can move in by the end of 2011.

The interview was led by Jakob Staude and Thomas Bührke

Klaus Tschira

Klaus Tschira was born in Freiburg in 1940. He studied physics at Karlsruhe Technical College (now Karlsruhe University) before working as a systems analyst at IBM in Mannheim from 1966 to 1972. In 1972, he and four colleagues founded the software company "Systemanalyse und Programmentwicklung" (SAP) in Weinheim; the company then moved to Walldorf where it developed into the global market leader for business management software. From 1998 until 2007, Klaus Tschira was a member of the SAP Supervisory Board.

In 1995, he established the Klaus Tschira Foundation with the aim of promoting the natural sciences, informatics and mathematics and increasing public interest in these subjects. The Foundation has its headquarters at Villa Bosch in Heidelberg, the former residence of Carl Bosch, the Nobel Laureate for Chemistry. In 1997, Tschira founded the European Media Laboratory, an institute for applied informatics. He made a name for himself among astronomers primarily as the patron of the planned Diva astrometry satellite.

Since 2001, the Klaus Tschira Foundation has been organizing advanced training courses for scientists which are designed to enhance their communicative competence. This is also the aim of the Klaus Tschira Prize for Intelligible Science. The promotion of children and young people starts at nursery school age and is manifested, for example, in the Klaus Tschira Competence Center for Early Scientific Promotion established in 2009, the Youth Software Award and the annual Explore Science activity days.

Klaus Tschira has received numerous honors including being made an honorary senator of the universities of Heidelberg, Mannheim and Karlsruhe and also of Heidelberg Teacher Training College, an honorary doctorate from Klagenfurt University and the German Cross of the Order of Merit. As a gesture of thanks for his support for Diva, the asteroid with the number 13028 was named after him.

V.5 Astrobiology is the Greatest Intellectual Adventure of our Time

An interview with Rolf Kudritzki, the new Chairperson of the Scientific Advisory Board

Rolf Kudritzki is an experienced and internationally renowned astrophysicist who has headed the Institute for Astronomy of the University of Hawaii for nine years. His involvement with the MPIA goes back many years: He has twice been a Member of the Scientific Advisory Board with one interruption, and has now been appointed Chairperson of this important committee. In the following interview, he talks about his new responsibilities on the Scientific Advisory Board, provides his assessment of the MPIA in a national and international context, and compares the working conditions of astronomers in the USA and Germany.

Question: In your opinion, what is the task of the Scientific Advisory Board?

RK: I consider an evaluation and critical assessment of the MPIs to be very important and would not have accepted the appointment to this governing body otherwise. Every institute runs the risk of its staff becoming blind to its failings: if it does not react to changes in the current research trends, it can very rapidly enter a state of crisis. Again and again, an MPI or at least a department is threatened with closure.

According to which criteria do you evaluate an institute? Is it predominantly the number of publications?

RK: The number and, even more importantly, the quality of the publications is naturally one criterion. For me personally, however, a more crucial factor is whether the relationship among the staff is scientifically stimulating and creative.

And how do you feel about the working environment at the MPIA?

RK: Extremely good and, above all, cooperative. It is always a real pleasure to meet so many very talented and highly motivated young people there. I have known the MPIA for a very long time, of course, and I have to say that it has acquired a completely new look in recent years. There is an intensive working environment. And it is very refreshing to talk to the staff. Other Members of the Scientific Advisory Board hold the same view, which is why our last expert opinion contained really enthusiastic praise of the MPIA.

What is the reason for this positive change, in your opinion?

RK: I think there are two main reasons. Firstly, all the astronomy in Heidelberg has been given tremendous impetus by the merger of the institutes to the Center for Astronomy Heidelberg. Previously, Munich and Garching jointly formed the largest astronomical center in Germany, and Heidelberg is now in the same league. This benefits all Heidelberg institutes, including the MPIA. And secondly, the two Directors have succeeded in strengthening the international focus of the MPIA. It is no longer possible to conduct top-notch research on a national level. The Graduate Schools are also a very important institution. Having worked in Munich for 18 years and with very pleasant memories of my colleagues there, I have a really good feeling when I look at Heidelberg.

You mentioned the refreshing, helpful environment at the MPIA. Is this comparable to the situation at the University of Hawaii?

RK: The situation there is completely different. All staff members are under much greater competitive pressure than at an MPI because everyone is dependent on third-party funds and must continue to be successful. I must undergo an annual assessment to see if I still adequately carry out my Director's duties, for example. I have to write a report, and the President of the University consults my colleagues about my performance. And something else which is also very important: An assessment of this type can be very harsh. Although my professorial post at the university is safe, I can, in principle, lose the Director's post from one year to the next. I consider this performance assessment to be perfectly right and proper, but in such a situation, colleagues can quickly become competitors, of course. The Director's job in this situation is to preserve the good environment, while at the same time maintaining the high scientific standard.

Your quality as a university lecturer is also continuously assessed. Is this aspect really so important?

RK: Oh yes. Lecturers in the USA who do not give good lectures will never be appointed to a top position at a university nowadays. The situation is completely different to the situation in Germany, and I think the American way is the right way. It is often said that some astronomers and physicists simply do not possess the gift of lecturing well. I do not believe this. If someone really puts in the effort, he can get his subject across. We already ensure that our doctoral students can present their research results in a clear and intelligible way. I consider the quality of teaching at American universities to be significantly better than at German ones. Incidentally, I also believe that the idea that members of an MPI do not need to deliver any lectures at all to be fundamentally wrong.

Fig. V.5.1: Rolf Kudritzki, the new Chairperson of MPIA's Scientific Advisory Board. (Photo: Th. Bührke)

It is precisely these excellent researchers who must be there for students and, as the top-flight universities in the USA demonstrate, good teaching does not impede first-class research. On the other hand, one has to admit that the MPG operates exceptionally well as a pure research institution, which is why I can understand the reluctance to change this "well-oiled" system.

Let's return to your position as Chairperson of the Scientific Advisory Board. You have been following the development of the MPIA for decades and have known the Directors and many of the staff for a long time, too. Is it really possible to be critical and, where necessary, negative in your criticism?

RK: It must be possible. A favorably slanted expert opinion helps no one. It must also be possible for colleagues to point out weaknesses. The Scientific Advisory Boards of the MPIs all have high-caliber members, and basically everybody knows everybody else. Astronomers are already something of a global family and this is precisely why we want to help each other, when necessary. And this is sometimes best achieved by means of constructive criticism.

You said that institutes must always adapt to new research directions. If you were to advise the MPIA as to which direction should be strengthened in the future, what would you recommend?

RK: In searching for a long-term orientation, I would start by considering where the strengths of the telescopes of the next generation will lie. The James Webb Space Telescope and the 30- to 40-meter telescopes will place special emphasis on infrared astronomy and concentrate

Rolf Kudritzki

Rolf Kudritzki was born in 1945 and studied physics at the Technische Universität Berlin, obtaining his 'Diplom' in 1971. He then became a research assistant at the Institute for Astronomy and Astrophysics in Berlin, where he received his doctorate in 1973. This was followed by a move to the Institute for Theoretical Physics and the Observatory at the University of Kiel, as well as the awarding of his German post doctoral lecturing qualification in 1979. During this time, his work focused on radiative transfer in the atmospheres of hot stars. His particular emphasis on states of non-equilibrium in the atmosphere models that he himself developed lead to a breakthrough in the quantitative analysis of stellar spectra.

In 1982, he was awarded a Professorship at Munich University and became Director of the Institute for Astronomy and Astrophysics, which he expanded and greatly strengthened. He himself considers one of his greatest and most successful tasks to be the collabortion with the Landessternwarte (State Observatory) Heidelberg and Göttingen University to build the FORS multi-object spectrograph, one of the first instruments of the ESO's Very Large Telescope.

In 1999, he became Dean of the Faculty of Physics and in the following year he accepted an appointment as Director at the Institute for Astronomy at the University of Hawaii, a post he holds to this day. The research opportunities in Hawaii are virtually ideal: His Institute is guaranteed a 10 to 15 per cent share of the observation time for all telescopes at the Mauna-Kea Observatory. The seeing here at a height of 4200 meters is the best in the world.

Rolf Kudritzki is a member of numerous societies, including the 'Astronomische Gesellschaft', the International Astronomical Union and the Max Planck Society. In 2009, the Astronomische Gesellschaft awarded him its highest honor, the Karl Schwarzschild Medal.

Further information about Rolf Kudritzki and his research is available at: www.ifa.hawaii.edu/users/kud.

on proto-planetary discs and extrasolar planets, as well as the early evolution of the galaxies. These two fields are precisely the fields of research in which the MPIA is already very well placed.

Does this mean the MPIA is well equipped for the future without having to change?

RK: I am absolutely convinced that in the foreseeable future, a further branch of research will greatly increase in importance: Astrobiology. I believe this will be the greatest challenge in astronomical research, and it will advance our knowledge more than cosmology. I believe the greatest intellectual adventure of our present time is to understand the complete astrobiological evolution. How could stars, planets and finally macromolecules, like DNA, and therefore life itself, develop from a quantum fluctuation and a hot, unstructured protogas? Now, for the very first time, we are on our way to understanding this chain of events.

With new telescopes, astronomers can only go part way to answering these major questions. In the end, an interdisciplinary approach in collaboration with biologists and chemists would be necessary. Wouldn't this be difficult to realize at an MPI for Astronomy?

RK: It would not be particularly easy, of course. The interdisciplinary situation can very quickly lead to biologists and chemists falling between all stools and feeling isolated among the astrophysicists. They should therefore be integrated into the university, if only to have contacts and discussion partners. At our university we are in the process of establishing such an institute with a staff of about 30. This is a huge task. But with ambitious and shrewd directors this should also be possible at the MPIA.

The interview was led by Thomas Bührke

Staff

Directors: Henning, Rix (Managing Director until 31.12.08)

Scientific Coordinator: Jäger
Public Outreach: Staude (Head)
Administration: Voss (Head)

Scientists: Afonso, Bailer-Jones, Bell, Bertram, Birkmann (until 30.9.), Beuther, Bouwman, Brandner, Dannerbauer, De Bonis, De Jong, Dullemond, Dumas (since 1.3.), Dziourkevich, Egner (until 15.4.), Elias, Elting (until 30.9.), Feldt, Fendt, Fried, Gallazzi, Gässler, Gouliermis, Graser, Gredel, Herbst, Hippelein (until 30.9.), Hippler, Hofferbert, Inskip (since 1.3.), Huisken, K. Jäger, Jahnke, Jester, Klaas, Klahr, Klement (since 1.11.), Köhler, Krause, Kurk, Kürster, Launhardt, Lenzen, Linz (since 1.8.), Marien, Matthews, Meisenheimer, Möller-Nilsson (since 1.3.), Müller, F., Mundt, Nielbock, Pavlov, Peter (since 1.8.), Röser, Sandor, Sargent, Scheithauer, Schinnerer, Schreiber, Semenov, Sicilia-Aguilar, Setiawan, Somerville (until 19.3.), Smith, K., Staude, Stilz, Tapken, Tiede (until 14.9.), Trowitzsch, Tsalmantza, van Boekel (since 1.3.), van den Bosch, Walter

PhD Students: Arold, Bergfors (since 15.7.), Besel (since 1.12.), Bicanski, Bigiel (until 30.6.), Birkmann (until 31.3.), Birnstiel, Bocchi (since 21.11.), Boudreault (until 19.11.), Brauer, Burtscher, Cacciato, Chen (until 6.2.), Cisternas (since 15.8.), Csak (since 15.9.), Crnojevic, Da Rio, De Rosa (since 1.11.), Dettenrieder, Downing, Ernst, Esquivel (until 14.11.), Fallscheer, Fang, Federrath, Flock (since 15.11.), Follert (since 1.6.), Foltin (until 30.4.), Foyle, Franco Rico, Gan, Geisler, Geißler, Gennaro (since 1.10.), Haan (until 30.9.), Heinzeller (until 31.7.), Hennemann, Holmes (since 1.8.), Hormuth, Janson (until 30.4.), Juhász, Karim (since 1.9.), Klement (until 31.10.), Koposov, Kuiper, Meyer, Mignone, More, Moster, Moyano, Müller, A. (since 1.3.), Natale, Nicol, Nikolov, Nugrohu (since 15.8.), Pedaletti, Peter (until 31.7.), Pitann (since 1.9.), Porth (since 1.8.), Robaina, Roccatagliata, Rochau, Ruhland, Rodriguez, Sauter (until 31.3.), Schmalzl, Schmidt, K.B. (since 22.9.), Schmidt, T., Schruba (since 1.8.) Skelton, Steglich, Stegmaier (until 30.9.), Stumpf, Sturm (since 1.12.), Tam (until 15.11.), Tamburro (until 31.5.), Uribe (since 15.9.), Valente (since 1.11.), Vasyunin, Vasyunina, Vannoni (until 8.5.), Wang, H., Weise, Xue (until 30.9.), Zatloukal (until 20.10.), Zechmeister, Zsom, Zub

Diploma Students and Student Assistants (UH): Aquino (until 31.1.), Becker (until 13.3.), Bestenlehner, Beyer (until 30.6.), Conrad, Courtial (21.4. – 31.7.), Daemgen (until 30.11.), Flock (until 18.9.), Forck (4.8. – 2.10.), Hoffmann, Junginger (until 14.3.), Kaplan (until 31.3.), Lendl (since 1.10.), Listowski (12.2. – 31.7.), Müller A. (until 31.1.), Pitann (until 31.7.), Schnupp (11.8. – 20.9.), Schulze-Hartung (until 31.10.), Sommerfeld (since 1.2.), Stoev (7.7. – 12.9.), Vogt (1.6. – 22.8.), Wahed (until 31.1.), Waldmann (1.6. – 31.8.)

Diploma and Master Students (FH): Fischer, Keilbach (since 1.9.), Pfannschmidt (since 1.9.)

Postdoctoral Stipend Holders: Bigiel (1.7. – 31.10.), Bik, Blindert, Boudreault (since 20.11.), Carson, Chen (7.2. – 31.7.), Coleman (until 31.3.), Dziourkevitch (until 30.6.), Fan (since 1.9.), Fedele (since 1.8.), Fontanot, Gawryszczak (until 28.2.), Goldmann, Goto, Greve, Gustafsson, Haan (since 1.10.), Ilgner (1.5. – 30.6.), Janson (1.5. – 31.7.), Johansen (until 31.1.), Kang, Kim (since 1.9.), Labadie, Leroy, Linz (until 31.7.), Macciò, Martin, Martinez Sansigre, Maulbetsch, Mordasini (since 1.11.), Mosoni, Nilsson, Ormel (since 1.11.), Pasetto, Pasquali, Pavlyuchenkov (until 31.10.), Rodler (until 30.4.), Sicilia Aguilar (until 31.8.), Skibba, Tamburro (until 30.9.), Thalmann (since 1.7.), Tremonti (since 15.9.), Tubbs (until 15.1.), van Boekel (until 15.1.), van der Wel (since 15.9.), Wang Wei (since 1.9.), Weldrake (until 31.3.) Zatloukal (since 22.10.), Zibetti

Interns: Benesch (until 29.2.), Euler (until 29.2.), Finzer (until 15.8.), Franke, Herbrandt (1.3. – 31.8.), Lechner (since 1.9.), Merx, Neidig, Schewtschenko (until 18.1.), Törl (1.3. – 31.8.), Wipfler (since 1.9.), J. Zimmermann

MPIA Observatories: Gredel

Technical Departments: Kürster (Head)

Mechanics Design: Rohloff, Baumeister; Blümchen (since 1.12.), Ebert, Huber, Münch, Schewtschenko (19.1. – 26.3.); trainees, interns, student assistants Schewtschenko (until 18.1.)

Precision Mechanics Workshop: Böhm, W. Sauer; Euler (since 1.3.), Heitz, Hirt (until 30.6.), Maurer, Meister, Meixner, Stadler; trainees, interns, student assistants Ehret (since 1.9.), Euler (until 28.2.), Finzer (until 15.8.), Franke, Merx, Neidig, Wipfler (since 1.9.)

Electronics: Wagner, Mohr; Adler, Alter, Ehret, Klein, Lehmitz, Mall, Mohr, Ramos, Ridinger, Westermann, Wrhel; trainees, interns, student assistants Benesch (until 28.2.) Herbrandt, (1.3. – 31.8.), Keilbach (since 1.9.), Pfannschmidt (since 1.9.), Törl (1.3. – 31.8.)

Instrumentation Software: Briegel, Storz; Berwein, Borelli, Kittmann (Guest Univ. Köln), Leibold, Möller-Nilsson (since 1.3.) Neumann, Pavlov, Trowitzsch; trainees, interns, student assistants: Fischer

Engineering and Project Management: Marien, Bizenberger; Bertram (1.9.), Brix, De Bonis (Gast Univ. Köln), Egner (until 15.4.), Gässler (since 1.7.), Graser, Laun, Meschke, Naranjo, Peter (since 1.8.)

Administrative and Technical Service Departments:

Administration: Voss; Apfel, Anders, Baier, Beckmann, Heißler, Hölscher, Schleich, S. Schmidt, Trenkler (until 18.6.), Zähringer; trainees: Lechner (since 1.9.), J. Zimmermann

Library: Dueck

Data Processing: Richter, Piroth; Hiller; Student Assistant: Bestenlehner

Photographic Lab: Anders

Graphic Artwork: Quetz; Meißner, Müllerthann

Secretaries: Bohm, Janssen-Bennynck, Koltes-Al-Zoubi, Seifert

Technical Services: Zergiebel, F. Witzel; Behnke, Drescher, Jung, Lang, Nauss, B. Witzel, E. Zimmermann

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

Freelance Science Writer: Thomas Bührke

Guests: Kerstin Meyer-Ross, TU Dresden, 17. – 19. Jan.; Pierluigi Monaco, Univ. Trieste, 22. – 25. Jan.; Nikoletta Sipos, Konkoly Univ., 28. Jan. – 19. Feb.; Laura Schreiber, Univ. Bologna, 1. Feb. – 31. May; Xianzhong Zheng, Purple Mountain Observatory, 2. – 6. Feb.; Edwin Bergin, Univ. Michigan, 3. – 9. Feb.; Gwendolyn Meeus, AIP Potsdam, 5. – 8. Feb.; Willy Benz, Univ. Bern, 6. – 7. Feb.; Tessel van der Laan, Kapteyn Inst. Groningen, 28. – 29. Feb.; Victor Debahista, Univ. Lancashire, 28. Feb. – 3. March; Angelle Tanner, JPL, 2. – 15. March; Bram Acke, Univ. Leuven, 3. – 6. March; Oskari Miettinen, 5.–14. March; Klaus-Peter Schröder, Univ. Guanajuato, 6. – 7. March; Roman Follert, Thüringer LSW, 6. March; Wie Wang, Chin. Acad. Sci, Bejing, 11. March – 9. May; Nikolai Voshchinnikov, St. Petersburg Univ., 13. March – 10. Apr.; Andrey Zhilkin, Russ.Acad.Sci. Moscow, 16. – 31. March; Daniel Schaerer, Obs. Genève, 17. – 18. March; Olja Panic, Leiden Observatory, 30. March. – 4. Apr.; Nikoletta Sipos, Konkoly Observatory; 31. Mar – 15 Apr.; Cristian Beaugé, Observatory of Cordoba, 5. – 18. Apr.; Thorsten Ratzka, AIP Potsdam, 7. – 11. Apr.; S. di Serego Alighieri, Oss. Astro. Arcetri, 7. – 11. Apr.; Cuynet, Stéphane, Obs. Besanon, 7. – 10. Apr.; Marco Spaans, Univ. Groningen, 8. – 11. Apr.; Chris Ormel, Univ. Groningen, 8. – 11. Apr.; Miguel Garcia Torres, Univ. La Laguna, 9. – 11. Apr.; Clement Baruteau, Service d'Astrophysique, 13. – 15. Apr.; Balazs Csak, Univ. Szeged, 20. – 22. Apr.; Christoph Mordasini, Univ. Bern, 22. – 24. Apr.; Eric Murphy, CalTech, 4. – 15. May; Sean Andrews, Harvard Univ., 4. – 7. May; Luciano Casarini, Univ. Milano-Bicocca, 7. May – 6. June; Elena Puga, Univ. Madrid, 8. – 24. May; Zsolt Regaly, Konkoly Obs., 13. – 25. May; Kasper B.Schmidt, Copenhagen Univ., 14. – 16. May; Jürgen Sauter, Univ. Kiel, 16. – 25. May; Robin Garrod, MPIfR, Bonn; 19. – 21. May; Baruch Barzel, Racah Inst. Tel-Aviv, 19. – 23. May; Kleomenis Tsiganis, Univ. Thessaloniki, 20. – 25. May; Kelsey Johnson, Univ. Virginia, 1. – 4. June; Dustin Lang, Univ. Toronto; 3. – 24. June; David Hogg, NY Univ., 3 Jun. – 30. Aug.; Beate Stelzer, INAF, Palermo, 4. – 5. June; René Plume, Univ. Calgary, 4 Jun. – 15. Sep.; Mordecai-Mark Mac Low, American Mus. Nat. History, NY, 6 Jun. – 22. July; James Rhoads, ASU, 9. – 27. June; Sangeeta Malhotra, ASU, 9. – 27. June; Dominik Riechers, CalTech, Jun 15. – 18.; Vernesa Smolcic, 15. – 22. June; Gang Zhao, Purple Mountain Obs., 16. – 20. June; Doug Looze, Univ. of Mass., 16. – 20. June; Agnes Kospal, Leiden Obs., Jun 17. – 21.; Peter Abraham, Konkoly Obs., 17. – 24. June; Buell Januzzi, NOAO/Kitt Peak, 19. – 23. June; Katherine Kretke, UCSC, 19. – 29. June; David Wilner, CfA, 22. – 25. June; David Weinberg, Ohio State Univ., 24. – 25. June; Jürgen Ott, CalTech, 25. – 27. June; Monika Petr-Gotzens, ESO Garching, 25. – 27. June; Boris Häussler, Univ. Nottingham, 25. – 30. June; Bram Acke, Univ. Leuven, 25 Jun. – 25. July; Aaron Dutton, UC Santa Cruz, 25 Jun. – 9. July; Zsuzsanna Gyory, Univ. Budapest, 29 Jun. – 5. July; David Martinez-Delgado, IAC, 1 Jul. – 3. Sep.; Arjen van der Wel, Johns Hopkins Univ., 7. – 11. July; Paul Schechter, MIT, 7. – 15. July; Alexander Bridi, UCL London, 7. – 31. July; Ronin Wu, NY Univ., 7. July – 17. Aug.; Simone Weinmann, MPI Astrophysik, 14. – 25. July; Christian Wolf, Univ. Oxford, July 14. – 18.; Pucci, A., Univ. Heidelberg, 17. – 18. July; Markus Klevenz, Univ. Heidelberg, 17. – 18. July; Christy Tremonti, Steward Obs., 18. – 14. July; Rachel Somerville, STScI, 21. – 25 July; Agnes Kospal, Leiden Observatory, 21. – 26. July; Doug Johnstone, Ntl. Res. Council Can., 23. – 28. July; Eyal Neistein, Hebrew Univ., 24. – 25. July; Peter Abraham, Konkoly Observatory, 21. Jul. – 6. Aug.; Nikoletta Sipos, Konkoly Observatory, 21. Jul. – 12. Aug.; Blair Conn, ESO Chile, 25. Jul. – 1. Aug.; Stephanie Gogarten, Univ. Washington, 30. Jul. – 20 Aug.; Julyanne Dalcanton, Univ. Washington, 1. – 30. Aug.; José Garcia, Dublin Inst., 6. – 7. Aug.; Joe Shields, Ohio Univ., 6. – 8. Aug.; Kenichi Nomoto, Univ. Tokyo, 17. – 18. Aug.; Serge Chastel, CNES Toulouse, 18. – 22. Aug.; Thorsten Ratzka, AIP, 18. – 22. Aug.; Dick Durisen, 26. Aug.; Jürgen Sauter, Kiel Univ., 29 Aug. – Sep. 14; Mohsen Ramenzapoor, Sharif Univ., Iran, 1. – 19. Sep.; Jacques Beckers, Univ. Chicago, 2. – 6. Sep.; Shantanu Rastogi, Gorakhpur Univ, India, 5. – 16. Sep.; Nikolai Voshchinnikov, St. Petersburg Univ., 8. – 18. Sep.; David Bonfield, NASA, 8. – 18. Sep.; Anupreeta More, MPIfR, 11. – 19. Sep.; Andreas Seifahrt, Univ. Göttingen, 18 Sep.; Yan-Mei Chen, MPA Garching, 8. – 22. Oct.; Tigran Movsisyan, Byurakan Obs., 13. Oct. – 17. Dec.; Hongchi Wang, Purple Mountain Obs., 15. Oct. – 14 Dec.; Laura Schreiber, Univ. Bologna, 25. – 31. Oct.; Massimo Robberto, STScI, 3. – 6. Nov.; Linda Watson, Ohio Univ., Nov 3. – 14.; Carmelo Arcidiacono, INAF, 5. – 8. Nov.; Herma Cuppen, Leiden Obs., 10. – 12. Nov.; Paul Boley, Ural State Univ., 19. Nov. – 19. Dec.; Warrick Lawson, Univ. New South Wales, 21. Nov. – 13. Dec.; Eric Feigelson, Penn State Univ., 23. – 25. Nov.; Xiang-Xiang Xue, Purple Mountain Obs., 23. – 28. Nov.; Henry Lee, Gemini, La Serena, 24. Nov. – 3. Dec.; Carsten Dominik, Univ. Amsterdam, 27 Nov. – 4. Dec.; Wlad Lyra, Uppsala Astron. Obs., 1. – 12. Dec.; Subo Dong, Ohio State Univ., 3. – 6. Dec.; Daniel Harbeck, NOAO, 8. – 9. Dec.; Stefanie Phleps, MPE Garching, 8. – 11 Dec.; Andrea Stolte, Univ. Köln, 11. – 12. Dec.; Benjamin Hussmann, Univ. Köln, 11. – 12. Dec.; Markus Janson, Univ. Toronto, 15. – 18. Dec.; Dominik Riechers, CalTech, 20. – 23. Dec.

Due to our regular international meetings and workshops further guests came to the Institute, who are not listed here individually.

Calar Alto Observatory
Almeria, Spanien

Astronomy Coordination: Thiele (Deputy, since 1.6.)
Teleskope Technology and Data Processing: W. Müller

Departments

Department: Planet and Star Formation
Director: Thomas Henning

Infrared Space Astronomy: Oliver Krause, Marc-André Besel, Stephan Birkmann, Thomas Blümchen, Jeroen Bouwman, Helmut Dannerbauer, Örs Hunor Detre, Ulrich Grözinger, Martin Hennemann, Ralph Hofferbert, Rory Holmes, Armin Huber, Serena Kim, Ulrich Klaas, Hendrik Linz, Friedrich Müller, Markus Nielbock, Jan Pitann, Silvia Scheithauer, Jürgen Schreiber, Jutta Stegmaier

Star Formation: Thomas Henning, Aurora Aguilar Sicilia, Adrianus Bik, Xuepeng Chen, Min Fang, Davide Fedele, Markus Feldt, Mario Gennaro, Dimtrios Gouliermis, Miwa Goto, Attila Juhász, Ralf Launhardt, Rainer Lenzen, Hendrik Linz, Owen Matthews, Laszlo Mosoni, André Müller, Christiaan Ormel, Yaroslav Pavlyuchenkov, Diethard Peter, Veronica Roccatagliata, Markus Schmalzl, Dmitri Semenov, Bernhard Sturm, Robert Tubbs, Roy van Boekel, Antonin Vasyunin, Tatiana Vasyunina, Wei Wang

Brown Dwarfs/Exoplanets: Reinhard Mundt, Carolina Bergfors, Wolfgang Brandner, Joseph Carson, Kerstin Geißler, Bertrand Goldmann, Felix Hormuth, Markus Janson, Viki Joergens, Boyke Rochau, Florian Rodler, Victoria Rodriguez Ledesma, Johny Setiawan, Christian Thalmann, Patrick Weise, David Weldrake

Theory (SP): Hubertus Klahr, Andrej Bicanski, Frithjof Brauer, Frank Dettenrieder, Natalia Dziourkevitch, David Foltin, Artur Gawryszczak, Anders Johansen, Rolf Kuiper, Christoph Mordasini, Ana Uribe

Laboratory Astrophysics: Friedrich Huisken, Marco Arold, Cornelia Jäger, Sergey Krasnokutskiy, Libo Ma, Gael Rouillé, Torsten Schmidt, Mathias Steglich

Frontiers of Interferometry in Germany (FRINGE): Thomas Henning, Uwe Graser, Ralf Launhardt, Jürgen Steinacker

AO Laboratory: Wolfgang Brandner, Nicola Da Rio, Joseph Carson, Fulvio De Bonis, Markus Feldt, Dimitrios Gouliermis, Stefan Hippler, Felix Hormuth, Micaela Stumpf, Christian Thalmann

Emmy-Noether-Group I, “The Formation of Massive Stars”: Henrik Beuther, Cassandra Fallscheer, Javier Rodon

MPG Junior Research Group: Cornelis Dullemond, Tilmann Birnstiel, Mario Flock, Zsolt Sandor, Andras Zsom

MPG Minerva Group: Cristina Afonso, Balasz Csak, Maximiliano Moyano, Nikolai Nikolov

Department: Galaxies and Cosmology
Director: Hans-Walter Rix

Structure and Dynamics of Galaxies: Hans-Walter Rix, Josef Fried, Jelte De Jong, Matthews Coleman, Anna Pasquali, Nicolas Martin, Christy Tremonti, Stefano Zibetti, Kelly Foyle, Rainer Klement, Domenico Tamburro, Arjen van der Wel, Sergey Koposov, Xiang-Xiang Xue; Kasper Borello Schmidt

Stellar Populations and Star Formation: Fabian Walter, Sebastian Jester, Thomas Greve, Adam Leroy, Frank Bigiel, Gisella de Rosa, Dominik Riechers, Andreas Schruba; Thomas Herbst, Wolfgang Gäßler, Maiken Gustafsson, Lucas Labadie, Fulvio de Bonis, Frank Kittmann, Johannes Schmidt

Evolution of Galaxies and Cosmology: Klaus Meisenheimer, Hermann-Josef Röser, Hans Hippelein, Kim Nilsson, Irini Sakelliou, Kris Blindert, Leonard Burtscher, Isabel Franco, Hélène Nicol, Konrad Tristram, Michael Zatloukal

Active Galactic Nuclei: Klaus Meisenheimer, Christi-an Fendt, Sebastian Jester, Marc Schartmann, Konrad Tristram; Xiaohui Fan (sabbatical)

Theory: Formation of Galaxies and Large Scale Structure: Rachel Somerville, Fabio Fontanot, Andrea Macciò, Christian Maulbetsch, Ben Moster, Hsiang-Hsu Wang; Christian Fendt (also IMPRS Coordinator), Oliver Porth und Bhargav Vaidya

Instrumental Developments: Thomas Herbst, Hermann-Josef Röser, Josef Fried, Wolfgang Gäßler, Sebastian Egner, Maiken Gustaffson, Lucas Labadie, Roman Follert, Eva Meyer

Emmy Noether Group II, "Stellar Populations and Star Formation": Coryn Bailer-Jones, Paraskevi Tsalmantza, Steve Boudreault

Emmy Noether Group III, "Evolution of Galaxies and Cosmology": Eric Bell, Anna Gallazzi, Xianzhong Zheng, Aday Robaina, Christine Ruhland, Rosalind Skelton

Emmy Noether Group IV, "Active Galactic Nuclei": Knud Jahnke, Katherine Inskip, Mauricio Cisternas, Dading Hadi Nugrohu

MPG Junior Research Group, "Formation of Galaxies and Large Scale Structure": Frank van den Bosch, Marcello Cacciato, Xi Kang, Surhud More, Ramin Skibba, Jianling Gan

MPG Minerva Group, "Active Galactic Nuclei": Eva Schinnerer, Gael Dumas, Mark Sargent, Alejo Martinez Sansigre, Sebastian Haan, Alexander Karim

GAIA Project Group: Coryn Bailer-Jones, Christian Elting, Rainer Klement, Kester Smith, Carola Tiede

Teaching Activities

Winter Term 2007 / 2008

E. Bell: Observing the Big Bang (Lecture)
Ch. Fendt: Current Research Topics in Astrophysics (IMPRS Course, with J. Wambsganss, ZAH)
Th. Henning: Physics of Star Formation (Seminar)
K. Meisenheimer: Sources of High Energy Radiation (Seminar, with J. Kirk, MPIK and S. Wagner, ZAH)
K. Meisenheimer: Current Research Topics in Astrophysics (IMPRS Seminar, with B. Fuchs and J. Wambsganss, ZAH)
K. Meisenheimer: Colloquium at MPIA and LSW (with M. Camenzind, ZAH)
H.-J. Röser: Introduction to Astronomy and Astrophysics, III (Seminar, with E. Grebel and J. Heidt, ZAH)
S. Wolf: Introduction to Astronomy and Astrophysics I, with Exercises (with M. Camenzind, ZAH)

Summer Term 2008

Coryn Bailer-Jones: Machine Learning, Pattern Recognition and Statistical Data Mining (Lecture)
E. Bell, H.-W. Rix: Galaxies (IMPRS Course)
C. Dullemond, Ch. Fendt: Current Research Topics in Astrophysics (IMPRS Seminar, with E. Grebel, ZAH)
Th. Henning: Physics of Star Formation (Seminar)
F. Huisken: Nanophysik II: Nanoparticles (Lecture, FSU Jena)
K. Meisenheimer: Sources of High Energy Radiation (Seminar, mit S. Wagner, ZAH)
K. Meisenheimer: Colloquium at MPIA and LSW (with M. Camenzind, ZAH)
H.-W. Rix: Galaxies (IMPRS Course, with E. Bell)
H.-W. Rix: Physics II, Exercises

Winter Term 2008/2009

E. Bell: Observing the Big Bang (Lecture)
Beuther, H., Ch. Fendt: Outflows and Jets: Theory and Observations
Ch. Fendt: Current Research Topics in Astrophysics (IMPRS Seminar, with M. Camenzind, ZAH)
Ch. Fendt, K. Meisenheimer, H.-W. Rix: Current Research Topics in Astrophysics (IMPRS Seminar)
Th. Henning: Physics of Star Formation (Seminar)
K. Meisenheimer: Sources of High Energy Radiation (Seminar, with J. Kirk, MPIK and S. Wagner, ZAH)
K. Meisenheimer: Colloquium at MPIA and LSW (with M. Camenzind, ZAH)

Service in Committees

Cristina Afonso: Member of the Science Consortium of the PLATO (PLAnetary Transits and Oscillations of stars) Space Mission; Member of the Strategy Survey Working Group of Pan-STARRS1; Member of the working group "Photometric Searches of Extra-solar Planets" of the ARENA Network on Antarctica Research in Astronomy
Coryn Bailer-Jones: Member of the GAIA Data Processing and Analysis Consortium Executive; Head of the Subconsortium "Astrophysical Parameters" in the GAIA Data Processing and Analysis Consortium (DPAC); Member of the Scientific Organizing Committee of IAU Commission 45 (Stellar Classification); Head of the SOC of the international Conference "Classification and Discovery in Large Astronomical Surveys"; UKIRT TAC Support
Eric Bell: TAC Member for SPITZER Cycle 4
Henrik Beuther: Member of the ESO OPC; TAC Member for APEX

Wolfgang Brandner: Member of the FP7 E-ELT Preparation Group (ESO); CoPI GRAVITY (2nd generation VLTI instrumentation); Member of the METIS Science Team for the E-ELT Instruments; CoPI of AstraLux Sur (Guest instrument for ESO/NTT); Member of the Calar Alto Scientific Advisory Committee; Member of the PhD Advisory Committee (PAC) at MPIA; Member of the IMPRS PhD Committee; Member of the Selection Committee for the Heidelberg Astronomcal Colloquium

Leonard Burtscher: Speaker of PhDnet (the PhD Students Network of the MPG)

Marcello Cacciato: Students representative in the Patzer Prize Commitee and IMPRS

Cornelis Dullemond: Member of the PAC Committee

Kelly Foyle: IMPRS Representative

Wolfgang Gässler: Member of the IAU working group on optical Interferometry data standards; AO speaker at the LBT Board

Roland Gredel: Member of the following Committees: Opticon board; MPIA STAC; Ice-T Review; ARENA NA2 (Site Characterization of Dome C, Head); ESE (ELT Science & Engineering Group); SSAC (ELT Site Selection Advisory Committee); ESO OPC (Head); Panel C3; PanSTARRS PS1 review PORDIG (Head)

Martin Hennemann: Students representative in the years 2007-2008

Thomas Henning: Member of the following Committees: Visiting Committee, Strasburg Observatory; Appointment Committee, Professorship for Planets and Star Formation, ETH Zürich; Search Committee, ALMA Director; ESO Council (Vice President), Advisory Council of the Kiepenheuer Institute for Solar Physics, Freiburg and of the Thüringen State Observatory, Tautenburg; PS1 Board of Directors; European Research Council, Panel Chair, Advanced Research Grants; Member of the SOFIA Science Council; Head of the German Interferometry Centre FRINGE; President of the Science Council of the European Interferometry Initiative; Co-I of the IR Instruments FIFI-LS (SOFIA), PACS (HERSCHEL), MIRI (JWST), SPHERE (VLT), PRIMA-DDL (VLTI), MATISSE (VLTI); Member of the Astronomische Gesellschaft and of the DPG; Member of the Deutsche Akademie der Naturforscher Leopoldina (Chairman for Astrophysics)

Tom Herbst: Princial Investigator for LINC-NIRVANA, Member of the Science and Technical Committee for LBT, of the ESO Science Strategy Working Group and Science and Technical Committee, Chairman of the E-ELT Science and Engineering Committee, Supervisor of the Differential Image Motion Monitor Project for LBT, Co-Investigator of the LBT AO Test Kamera, Member of the Science Team for DARWIN, responsible for the Phase-A Study for MICADO (E-ELT)

Klaus Jäger: Collaborator of the Rat Deutscher Sternwarten (RDS) and the LBT- Beteiligungsgesellschaft (LBTB), Member of the Scientific Advisory Board of the International Summer Science School Heidelberg (ISH), Member of the Atronomische Gesellschaft

Knud Jahnke: Member of the Phase A Working group for the E-ELT Instrument study MICADO

Sebastian Jester: Member of the CHANDRA X-ray Observatory Time Allocation Committee

Ulrich Klaas: Member of the HERSCHEL Calibration Steering Group as representative of the PACS Instrument Control Centre Calibration Working Group

Oliver Krause: Member of the European SPICA Instrument Steering Committee

Martin Kürster: Member of the Organizing Committee for the Creation of IAU Commission 53,“Extrasolar Planets”

Jaron Kurk: TAC Member for SUBARU in the sections “High-*z* Galaxies” and “Large Scale Structure”

Ralf Launhardt: Jury Member for the Scientific Ernst Patzer Prize

Christoph Leinert: Member of the VLTI subpanel in the ESO Science and Technical Committee

Alejo Martinez: Member of the Additional Science Working Group for EUCLID; Member of the Science Advisory Board for the EUCLID near-infrared spectrograph

Klaus Meisenheimer: Member des ESO OPC; Head of the “Strategic TAC” at the MPIA

Reinhardt Mundt: Member of the MPIA Time Allocation Committee

Anna Pasquali: Member of the ESO OPC

Hans-Walter Rix: Head of the Scentific Advisory Board of the Astrophysical Institute, Potsdam; Board Member of the Large Binocular Telescope Corporation and of the Large Binocular Telescope Beteiligungsgesellschaft; Member of the NIRSPEC Science Team; Member of the BMBF Referees Committee “Astrophysics and Astroparticle Physics”; Member der DFG Fachkollegien; Member “at large” of the ASTRONET Infrastructure Roadmap Working Group

Hermann-Josef Röser: PAC Member at the MPIA; Head of the Computer Committee at the MPIA; ESO OPC: Advisor for Panel A1, Panel Representative at the OPC for Discussion of the Large Programs

Eva Schinnerer: Member of the Selection Committee for the Scientific Ernst Patzer Preise

Jakob Staude: Member of the National Selection Committee for the Contest “Jugend forscht”

Fabian Walter: Member of the IRAM Program Committee and of NRAO User’s Committee

Further Activities

Girls Day on April 24 at the MPIA was organized by Stephan Birkmann, Helmut Dannerbauer, and Silvia Scheithauer.

The series of nine public talks “Astronomy on Sunday Morning” in May – June was organized by Klaus Jäger, Jakob Staude, Boyke Rochau and others.

The BOGy internship for school students on October 20. – 24. Was organized by Leonard Burtscher, Klaus Meisenheimer, Klaus Jäger, and Jutta Stegmaier.

The Board of Trustees of the MPIA met on February 22 and December 11.

At a press conference held on December 10, 2008 in the domicile of the Klaus Tschira Foundation it was announced that this Foundation will build a "Haus der Astronomie" (House of Astronomy) on the grounds of the MPIA. In this facility, the educational and public outreach activities of all astronomers in Heidelberg will be concentrated and developed further. Besides the information of the media and the general public, the development of didactic material and the training of university students and teachers of physics, astronomy and natural sciences will play a major role. The Klaus Tschira Foundation will finance the building and its technical equipment, and the Max Planck Society will operate the facility. Besides these Institutions, also the City of Heidelberg, the State of Baden-Württemberg, and the University of Heidelberg will contribute to the personnel costs. In addition, the University of Heidelberg with its Center for Astronomy will bring in activities related to public and educational outreach. Thomas Henning, Klaus Jäger, Hans-Walter Rix, Jakob Staude and Mathias Voss contributed to the planning and development of the "Haus der Astronomie".

In the course of the year, 30 groups with a total of 760 visitors were guided through the Institute (Axel M. Quetz, Patrick Weise, Cassandra Fallscheer and others). Klaus Jäger organized special tours with talks about the Institute for the Gesprächskreis Rhein-Neckar, the Freundeskreis des Planetariums Mannheim, for staff and readers of the local newspaper Rhein-Neckar-Zeitung, for the International Max Planck Research School, as well as an one hour feature on astronomy for Radio Darmstadt.

Fifteen press releases were published and numerous radio and TV interviews were given (Klaus Jäger, Axel Quetz, Jakob Staude, and others).

Within the Advanced Practical Course in Physics at the University of Heidelberg, Josef Fried was responsible for the experoment "CCD-Photometry" and Stefan Hippler for the experiment "Wavefrint analysis with a Shack-Hartmann sensor".

Ulrich Klaas was head of the MPIA Library Committee

As a Guest Editor, Sebastian Jester edited a special issue of the IEEE-Journal "Computing in Science and Engineering" (January/February 2008, Vol. 10, No. 1).

Markus Nielbock assisted during the Course of Practical Astronomy of the Kantonsschule Luzern at the "Hoher List" Observatory, as well as in the Society for Horizon Astronomy in the Ruhr Basin and in the "Astronomieschule e.V." at the Landessternwarte Königstuhl.

Jakob Staude, assisted by Axel Quetz, contributed to editing the 47. Annual volume of the monthly astronomical magazine "Sterne und Weltraum".

Awards

The Otto Hahn Medail of the Max Planck Society for outstanding acievements of young scientists was awarded to *Anders Johansen* for his work on "Gravoturbulent Formation of Planetesimals in the turbulent gaseous Disks around Young Stars", and to *Nadine Neumayer* for her "Mass Determination of the Central Black Hole in the Active Galaxy Centaurus A" and the observational proof that also in this case the mass of the Black Hole satisfies the general correlation between the central Black Hole's mass an the much greater mass of the surrounding stellar bulge.

Frithjof Brauer obtained a Reimar Lüst Stipendium of the Max Planck Society.

This year's prizes of the Scientific Ernst Patzer Foundation were won by the PhD students *Frithiof Brauer* for his work on coagulation, fragmentation and radial motion of solid particles in protoplanetry disks", *Dominik A. Riechers* for his work on the formation of a quasar galaxy by merging of two galaxies 1.4 billion years after the Big Bang, and *Xiang-Xiang Xue* for her determination of the galactic rotation courve up to 60 kiloparsecs, and of the mass of the dark galactic halo from the kinematics of 2400 Blue Giants in the SDSS catalogue.

Micaela Stumpf obtained the "Chamberliss Astronomy Achievement Student Award" of the Amercian Astronomical Society for one of the best posters at the 211. AAS Meeting in Austin, USA.

Compatibility of Science, Work, and Family

In the course of the year, further measures were implemented at the MPIA to improve the compatibility of work and family. Besides the already existing "baby offices" for young scientists and researchers, the creation of opportunities for family-related telework, work-at-home, and the improvement of the information exchange on the issue of compatibility of work and family, the institute's own daycare room was set up. The institute now also shares entitlement to a total of 15 day nursery and kindergarten places with the other Max-Planck Institutes in Heidelberg. MPIA also offers a childcare service for meetings and other major scientific events. Together with a number of other major research facilities and business enterprises in the region, the institute is a member of the Heidelberg Action Alliance for Families. The aim of these networked research facilities and business enterprises is to increase the attractiveness of Heidelberg as a city of science and of business by offering family-friendly organizational schemes. The measures to improve compatibility of work and family at the institute are permanently upgraded in order to further improve the boundary conditions for research at the Institute.

Cooperation with Industrial Companies

4D electronic GmbH, Bretten
Aachener Quarz-Glas, Aachen
Abacus Deltron, München
ABB (Hartmann + Braun), Alzenau
Additive GmbH, Friedrichsdorf
ADR, Paris
Agilent Technologie, Böblingen
Ahlers EDV-Systeme GmbH, Wildburg-Sulz
Air Liquide GmbH, Pfungstadt
alimex GmbH, Willich
Allectra GmbH, Schönfließ
Almet-AMB, Mannheim
Alternate Computer Versand, Linden
America II, Mönchengladbach
Ametek GmbH, Meerbusch
Amphenol AIR LB GmbH, Saarlouis
Amphenol-Tuchel Electronics, Heilbronn
Andus Electronic GMBH, Berlin
Angst+Pfister, Mörfelden
Ansonic GmbH, Essen
APE Elektronik, Kuppenheim
Argenta Elektronik, Solingen
Arnold Magnetic Technologies, Hanau
Arrow Central Europe GmbH, Dreieich
Arthur Henninger, Karlsruhe
Arrow Central Europe GmbH, Dreieich
Asahi Spectra Co., Ltd., Kita-ku, Tokyo
Asco Joucomatic GmbH & Co., Ölbronn-Dürrn
Asknet AG, Karlsruhe
AST Leistungselektronik Gmb, Berlin
Auer Paul GmbH, Mannheim
AVNET EMG, Bad Camberg
AXSYS Technologies, Rocherster Hills, USA
B+A Montana Networks GmbH, Karlsruhe
Bacuplast GmbH, Remscheid-Lüttringhausen
Baier Digitaldruck, Heidelberg
Barr Associates Inc., Westford, USA
Barth, Leimen
Bechtle GmbH & Co.KG, Mannheim
Bectronic GmbH, Derschen
Belling GmbH, Mannheim
Best Power Technology, Erlangen
Beta Layout, Arbergen
Bikar-Metalle GmbH, Bad Berleburg
Binder Elektronik GmbH, Sinsheim
Blässinger, Stuttgart
Böllhoff GmbH, Winnenden
Börsig, Neckarsulm
Bohnenstiel, Heidelberg
Bubenzer Bremsen, Kirchen-Wehrbach
Bürger-Electronic, Reutlingen
Bürklin OHG, München
Bremer und Leguil GmbH, Duisburg
C & K Components, Neuried b. München
CAB, Karlsruhe
Cadence Design Systems GmbH, Feldkirchen
CADFEM GmbH, Grafing
Cadillac-Plastic, Viernheim
CAMCenter GmbH, Nidderau
CAP CNC+Coating Technik, Zell. a. H.
Cargopack mbH, Mannheim
Carl Roth, Karlsruhe
Carl Zeiss 3D Automation GmbH, Essingen
Carl Zeiss MicroImaging GmbH, Göttingen
Carl Zeiss Optronics GmbH, Oberkochen
Caspar Gleidlager GmbH
Chemsearch, Mörfelden-Walldorf
Cherry Mikroschalter, Auerbach
Christiani, Konstanz
Chroma Technology Corporation, Rockingham, USA
Cision Deutschland GmbH, Kornwestheim
Coating-Plast, Schriesheim
Com Pro, Stuttgart
Comtronic GmbH, Heiligkreuzsteinach
Compumess Electronik, Unterschleissheim
Conrad Electronic GmbH, Hirschau
Contag GmbH, Berlin
Cook Kem H., San Ramon, USA
Cryophysics GmbH, Darmstadt
Cryotherm GmbH & Co. KG, Euteneuen
Cryovac, Troisdorf
CST GmbH, Darmstadt
Cunz GmbH & Co.KG., Frankfurt
D.H. Frank GmbH, Nussloch
D+C-Airparts Battery, Mörfelden-Walldorf
Dannewitz, Linsengericht
Dastex GmbH & Co. KG, Muggensturm
dataTec GmbH, Reutlingen
db electronic Daniel Böck GmbH, Ehringshausen
Dell-Computer GmbH
Delta-V, Wuppertal
Deltron Components GmbH, Neuried b. München
Deti, Meckesheim
Digi-Key, Enschede
Dicronite UTE Pohl GmbH, Iserlohn
Distrelec Schuricht GmbH, Bremen
DMG-Service, Pfronten
DMG Stuttgart Vertriebs+Service, Leonberg
DPS Vakuum, Großrinderfeld
DPV Elektronik Service GmbH, Eppingen
Dürkes & Obermayer, Heidelberg
Dyna Systems NCH, Mörfelden-Walldorf
Easy-Tecs GmbH, Karlsfeld
Ebara Pumpen, Dietzenbach
EBJ, Ladenburg
EBV-Electronik, Leonberg
EC Motion, Mönchengladbac
Edico-Equipment GmbH, Nürnberg
Edmund Optics GmbH, Karlsruhe
Edsyn Europa, Kreuzwertheim
EFH, Neidenstein
Elblinger Elektronik GmbH, Salzgitter
Electronic Product Services Lt, Kinsealy Co., Dublin
Electronic sensor+resistor GmbH, Ottobrunn
Elektrometall Schwanenmühle
Elektro-Steidl, Weinheim
Elna Transformatoren, Sandhausen
Elspec, Geretsried
ELV Elektronik, Leer
EMS-Elektro Metall Schwanenmühle
Eriks NordOst GmbH, Blankenburg
ERNI, Adelberg
Essential Systems GmbH, Havixbeck
Eurodis Enatechnik, Quickborn
Euromicron GmbH, Mittenaar
Europa-Lehrmittel, Verlag
European IT Storage Ltd., Filderstadt
EWF, Eppingen
Excel Technology Europe GmbH, Darmstadt
eXpansys SAS, Montpellier Cedex 2
Faber Industrietechnik GmbH, Mannheim

factronix GmbH, Alling
Fairchild Imaging Inc., Milpitas, CA, USA
Farben Specht, Bammental
Farnell Electronic Services, Möglingen
Farnell GmbH, Oberhaching
Farnell in One, Deisenhofen
FAST ComTec Communication, Oberhaching
Faulhaber GmbH & Co KG, Schönaich
FCT Electronic, München
FED-Fachverband Elektronik-Design, Berlin
Fiberoptic Systems Inc., Simi Valley, USA
Filtrop AG, Balzers
Fischer Elektronik GmbH & Co., Lüdenscheid
Fisba Optik, St. Gallen
Fischer Elektronik, Lüdenscheid
Flexa GmbH & Co.KG, Hanau
FlowCAD EDA-Software Vertrieb, Feldkirchen
Fotemia KG, Wiesbaden
FPS-Werkzeugmaschinen GmbH, Warngau
Frank GmbH, Mörfelden-Walldorf
Franke, Aalen
Fresemann Andreas, Dörpen
Future Electronics Deutschland, Unterföhring
F.X. Stöhr GmbH & Co. Armaturenwerke, Königsbrunn
GAD GmbH, Plankstadt
Ganter GmbH, Walldorf
Gehrckens C. Otto GmbH, Pinneberg
Geier Metall-u. Stahlhandel, Mannheim
Genoma Normteile, Hameln
Gerwah Präzision GmbH, Grosswallstadt
GFI Elektro GmbH, Heidelberg
Gläser Automatendreherei,Olbernhau
Glenair Electric GmbH, Oberursel
Glenair Electronic GmbH, Steinbach
GLT, Pforzheim
Goodfellow, Bad Nauheim
Goecke GmbH & Co KG, Schwelm
Gravograph GmbH, Umkirch
Gould Nicolet Meßtechnik, Dietzenbach
Grandpair, Heidelberg
Grothues Elektrotechnische Geräte, Leimen
Grulms-Pneumatik, Grünstadt
GRW, Würzburg
Gummi Körner, Eppelheim
Gummi-Plast Schild, Gerns
Günter Jacobi GmbH, Griesheim
Gutekunst & Co. Federnfabrik, Metzingen
Gutekunst, Pfalzgrafenweiler
Guttroff Friedrich GmbH, Wertheim
Häcker, Weinsberg
Häfele Leiterplattentechnik, Schriesheim
Hagemeyer Deutschland GmbH &Co, Heidelberg
Hahn & Kolb GmbH & Co., Stuttgart
Hans E. Winkelmann GmbH, Rödermark/Ober-Roden
Harmonic Drive AG, Heidenheim
Heidenhain Dr. Johannes GmbH, Traunreut
Heinrich Baum GmbH, Flörsheim
Heinzinger electronic GmbH, Rosenheim
Helukabel, Hemmingen
Hema, Mannheim
Heinrich Wietholt GmbH, Coesfeld
HM Industrieservice, Waghäusel
Henri Electronic GmbH, Bopfingen
Hera Hermann Rapp GmbH, Blaufelden
Herz, Leister Geräte, Neuwied
Hewlett-Packard Direkt, Böblingen
Hilger und Kern, Mannheim
Hilma-Römheld GmbH, Hilchenbach
HKI GmbH, Weinheim
Hoffmann Nürnberg GmbH, Nürnberg
Hommel-Hercules Werkzeughandel, Viernheim
Hormuth, Heidelberg
Horst Göbel, Ludwigshafen
Horst Pfau, Mannheim
HOT Electronic, Taufkirchen
HTF Elektro, Mannheim
Huber + Suhner, Taufkirchen
Hummer + Rieß, Nürnberg
IBF Mikroelektronik, Oldenburg
IBIS-Ingenieurbüro, Mainburg
IBT Dr. Johannes Tille, Groß-Zimmern
IDS GmbH, Obersulm
IDS Innomic GmbH, Salzwedel
II-VI Deutschland GmbH, Darmstadt
Ilfa Feinstleitertechnik GmbH, Hannover
Industriebedarf Oberhausen, Ketsch
Infrared Labs, Tucson
Ing.-Büro Loss Rolf-Dieter, Wutöschingen
Ing. H. Tafelmaier, Rosenheim
Ingenieurbüro M. Steinbach, Jena
Ingenieurbüro Schlossmacher, Unterschleißheim
Inneo Solutions GmbH, Ellwangen
Inotec electronics GmbH, Lauffen a.N.
Institut für Mikrotechnik, Mainz
iSystem, Dachau
item Industrietechnik, Ulm
Jacobi Eloxal GmbH, Altlussheim
Japan Aviation Electronics Ind, Tokyo
Jarmyn, Limburg
Joisten+Kettenbaum, Bergisch Gladbach
Jasco, Groß-Umstadt
Jehier S.A., Chemille, F
Kälte Wärme Klima, Lauffen a.N.
Kaiser + Kraft GmbH
Kaufmann, Horst W., Crailsheim-Wittau
Keil Electronic GmbH, Grasbrunn
Keithley Instruments GmbH, Germering
Kerb-Konus-Vertriebs-GmbH, Amberg
Kern Micro-und Feinwerktechnik, Murnau-Westried
KFK Verzinkerei GmbH, Sinsheim
KG Hinrich Karp, Bleckede
KGW-Isotherm GmbH, Karlsruhe
Kim-Vy Tran, Zürich
Klevenz, Markus, Heidelberg
Kniel GmbH, Karlsruhe
Knürr AG, Arnstorf
Koch + Schröder GmbH, Neuss
Koco Motions GmbH, Dauchingen
König GmbH, Büttelborn
Kühne + Nagel, Halger
Kurt Norr & Co, Viernheim
KVT Canespa, Langenhagen
L.Meili &.Co.GmbH/Hebezone, Hanau
Laflow Reinraumtechnik GmbH + Co, Blaubeuren
Lambda Electronics, Achern
Lang-Werkzeugtechnik GmbH, Neuhausen
Laser 2000 GmbH, Wessling
Laser Components, Olching
Lauterbach Verfahrenstechnik, Eggenstein
Lava Vakuumverpackung, Bad Saulgau/Lampertsweiler
LCK Vertriebs-GmbH, Ubstadt-Weiher
LDS Test and Measurement GmbH, Ismaning

Lemo Elektronik GmbH, München
Leuze electronic GmbH + Co., Owen-Teck
Lineartechnik Korb
LinuxLand International GmbH, München
Lista GmbH, Bergneustadt
LOT Oriel GmbH, Darmstadt
Löttechnik 24 , Dortmund
LPKF CAD/CAM Systeme, Garbsen
LTN Servotechnik GmbH, Otterfing
LWS-Technik GmbH & Co., Heilbronn
M & L Montagetechnik Luck GmbH, Wasungen
Maas International GmbH, Bruchsal
Macrotron, München
Mädler, Stuttgart
Magna C GmbH + Co, Wendlingen
Mankiewicz Gebr. & Co, Hamburg
Maschinenbau Pelzer, Jena
Matsuo Electronics Europe, Eschborn
Matsushita Automation, Holzkirchen
Max Computer GmbH, Schönberg
Maxim GmbH, Planegg
Meilhaus Electronic, Puchheim
Meister Strömungstechnik, Wiesen
Melles Griot, Bensheim
Memmert GmbH + Co. KG, Schwabach
Menges electronic, Dortmund
Mensch und Maschine Akademie, Kircheim/Teck
Mentor, Erkrath
Messer Cutting+Welding, Frankfurt
Metallbau Glawion GmbH, Eberswalde
Metrofunkkabel-Union GmbH, Berlin
Micos, Eschbach
Micro Warehouse, Mainz-Kastel
Microgate Srl-GmbH, Bolzano
Micronclean, Reutlingen
Microstaxx GmbH, München
Mikropack GmbH, Ostfildern
Minera Kraftstoffe
Misco Germany Inc.
Mitsubishi-Electric, Weiterstadt
MK Computer Electronic GmbH
MKS Instruments Deutschland Gm
Modia GmbH, Neckargemünd
Modulor, Berlin
Möller-Wedel Optical GmbH, Wedel
Mönninghoff, Bochum
Moll, Bleche und Verarbeitung, Hirschberg
MSC Vertriebs GmbH, Stutensee
MST Aerospace GmbH, Köln
MTG-Bayer GmbH, Mannheim
MTI, Baden-Baden
MTS Systemtechnik GmbH, Mertingen
Munz, Lohmar
Mura, Metallbau, Viernheim
Murrplastik-System-Technik, Oppenweiler
Mutanox GmbH, Berlin
MWR/Christian Wirth, Rimbach
Nanotec-Electronic GmbH, Finsing
National Instruments GmbH, München
Neolab Laborbedarf – Vertriebs GmbH, Heidelberg
Neopost GmbH, München
Newport Spectra-Physics GmbH, Darmstadt
NH Heidelberg
Nibler W. GmbH, Walldorf
Nickel Schalt- und Meßgeräte, Villingen-Schwenningen
Niedergesess, Sandhausen
Nies Elektronic GmbH, Frankfurt
Nösse Datentechnik, Leverkusen
Nova Electronik, Pulheim
NU Horizons Electronics GmbH, München
Oberhausen, Ketsch
Oerlikon, Köln
officeb2b GmbH, Aysetten
Officio, Bremen
Omnilab GmbH, Berlin
Ooms, Ittner & Verfürth, Limburgerhof
Open Storage AG, Murnau / Staffelsee
Optima Research Ltd, Stansted
Orbiteam SW-GmbH, Bonn
Otto Faber, Mannheim
Otto Ganter GmbH, Furtwangen
Orglmeister, Walluf
Otto Office GmbH, Hamburg
OWIS GmbH, Staufen
Oxford Instruments GmbH, Wiesbaden
OZB Computerzubehör, Gaggenau
P. Lapport & Sohn GmbH, Enkenbach-Alsenborn
Parametric Technology, München
Parcom, CH-Flurlingen
Partool GmbH, Nürnberg
pbe Electronic, Elmshorn
PC-Ware, Bad Homburg
PC-Ware AG, Leipzig
PC-Ware Information Technologie, Frankfurt a. M.
PCE Group oHG, Meschede
Penninger GmbH, Heidelberg
pf Electronic GmbH, gerlingen
Pfeiffer Adolf GmbH, Mannheim
Pfeiffer & May, Heidelberg
Pfeiffer Vacuum GmbH, Asslar
Philipp Lahres GmbH, Weinheim
Phoenix Contact GmbH & Co., Blomberg
Physik Instrumente GmbH & Co. KG, Karlsruhe
Physik Instrumente, Waldbronn
Phytec Messtechnik, Mainz
Phytron-Elektronik GmbH, Gröbenzell
Plano GmbH, Wetzlar
Plastipol, Runkel
Plusminus Batterietechnik GmbH, Überlingen
PMK Mess- und Kommunikationstechnik, Heusenstamm
Pneu-Therm Ltd., Newark
POG Präzisionsoptik GmbH, Gera
Polytec GmbH, Waldbronn
Polytron-Kunststofftechnik, Bergisch Gladbach
Pro Betriebsratswissen e.V., Bonn
Pro-Com Datensysteme GmbH, Eislingen
Promostore Merchandising, Essen
Prout Services+Hardware GmbH, Wandlitz
PSC Portable System Center, Saarbrücken
PSI Tronix, Tulare, California, USA
PTR Präzisionstechnik GmbH, Maintal
Pühl A. GmbH, Plettenberg
Püschel Electronik, Mannheim
Quick-Ohm Küpper & Co. GmbH, Wuppertal
R.A. Zimmermann KG, Dietzenbach
Radiall, Rödermark
Räder Gangl, München
Rahm GmbH, Heidelberg
RALA, Ludwigshafen
Rau-Messtechnik, Kelkheim
RAZ R.A. Zimmermann KG, Dietzenbach
RCF-comtronics, Neenstetten
Redcoon GmbH, Aschaffenburg
Redlich-EDV, Jena
REEG GmbH, Wiesloch
Regional Electronic Distribution, Rodgau-Jügesheim
REFA Construction Management, Windhoek

Reichelt Elektronik, Sande
Reimund Oberflächentechnik, Sinsheim
Reinhold Halbeck, Offenhausen
Reith, Mannheim
Retronic, Ronneburg
Rexim, Maulbronn
Rexroth Bosch, Lohr am Main
Riekert & Sprenger, Wertheim
Rinnert GmbH, Kaast
Rittal GmbH + Co. KG, Herborn
Roland Häfele Leiterplattentechnik, Schriesheim
Rossaro Ausbau GmbH, Aalen
Roth Carl GmbH, Karlsruhe
Rotronik GbR, Bruckmühl
RS Components GmbH, Mörfelden-Walldorf
RS Elektroniksystem GmbH, Grassau
RSP-GmbH, Mannheim
Rudolf, Heidelberg
Rütgers, Mannheim
RUF Elektrohandel, Mannheim
Rufenach Vertriebs-GmbH, Heidelberg
Rufflar, Laudenbach
Rutronik, Ispringen
Samasoffice GmbH, Mannheim
Sartorius, Ratingen
Sasco Holz Gmbh, Putzbrunn
Sauter-Cumulus GmbH, freiburg i.Br.
Scantec, Planegg
Schaeffer AG, Berlin
Schäfer-Shop GmbH, Mannheim
Schäfter+Kirchhoff GmbH, Hamburg
Schaffner Elektronik, Karlsruhe
Schenker Deutschland AG, Mannheim
Schenker Deutschland AG, Osnabrück
Schneider Günther GmbH, Sandhausen
Schrauben-Jäger AG, Viernheim
Schraubenladen, Villingen-Schwenningen
Schroff GmbH, Straubenhardt
Schulenburg W. Nachf. Gmbh & Co.KG, Wuppertal
Schulz H.u.G. Ingenieure, Heidelberg
Schupa Schumacher GmbH, Walldorf
Schuricht, Fellbach-Schmiden
Schweizer Elektroisolierungsstoffe, Mannheim
SCT Servo Control Technology, Taunusstein
SE Spezial-Electronic, Bückeburg
Secutrada GbR, Stuttgart
Seifert mtm Systems, Ennepetal
Servo Halbeck GmbH, Offenhausen
Sicon Socomec GmbH, Mannheim
Siemens AG, Mannheim
Sky Blue Microsystems, München
SMS System-Managment, Aachen
Softwarebox GmbH, Schönaich
SolidLine AG, Walluf
Spaeter, Viernheim
Sphinx GmbH, Laudenbach
Spindler & Hoyer, Göttingen
Spoerle Electronic, Dreieich
Stemmer PC-Systeme GmbH, Puchheim
Stenzel GmbH, Frankfurt/Oder
StoCretec, Kriftel
Straschu Leiterplatten, Oldenburg
Studio 1 Solutions, Berlin
Suarez International, Tucson
SUCO-Scheuffele, Bietigheim-Bissingen
Sulzer GmbH, Freiburg i. Br.
SWS Edelstahl GmbH, Emmingen
Sumitomo SHI Cryogenics, Darmstadt
Sun Microsystems GmbH, Kirchheim-Heimstetten
Swedex GmbH+Co.KG, Essen
Swets Information Services, Frankfurt a.M.
Synatron, Hallbergmoos
SynoTech, Linnich
Tandler, Brauen
Tautz Druckluft+Sandstrahltechnik, Mannheim
Tafelmaier, Rosenheim
TBK, Meinerzhagen
Techem Energy Services, Eschborn
Technik Direkt, Würzburg
Technische Antriebselemente GmbH, Hamburg
TecService Europe AG, Nufringen
Tekdata Interconnections Ltd., Staffordshire
Teldix GmbH, Heidelberg
Teledyne Scientific & Imaging, LLC, Camarillo, USA
Telemeter Electronic GmbH, Donauwörth
Telko GmbH, Saalfeld
Teseq GmbH, Berlin
Testo GmbH & Co, Lenzkirch
Teuber Vermessungsgeräte, Freigericht
tfi Ingenieure Elektrotechnik, Mannheim
The MathWorks GmbH, Aachen
The MathWorks GmbH, Ismaningen
Thermodyne GmbH, Osnabrück
THK, Düsseldorf
Thorlabs GmbH, Grünberg
ThyssenKrupp Schulte, mannheim
TNT Express GmbH, Mannheim
TNT Express GmbH, Troisdorf
TMS Test- und Meßsysteme, Herxheim/Hayna
Tomerelli s.r.l., Villafranca
Topcart International GmbH, Erzhausen
Total Walther GmbH, Ratingen
Tower Electronic Components, Schriesheim
Transmit-Deutschland GmbH, Hollenstedt
Transtec AG, Tübingen
Trenz Electronic GmbH, Bünde
Trinos Vakuum-Systeme, Göttingen
TS-Optoelectronic, München
TuTech Innovation GmbH, Hamburg
TWK-Elektronik, Karlsruhe
Tydex J.S.Co, St. Petersburg
UKP GmbH, Mainz
Unger GmbH, Kirchheim/Teck
UTI Deutschland GmbH, Mannheim
v. Bezold & Partner, München
Vacom GmbH, Jena
Vacuumschmelze, Hanau
VBE Baustoff+Eisen, Heidelberg
Vero Electronics, Bremen
Vigot GmbH, Bremen
Vision Engineering, Emmering
Visitech, Marxzell-Pfaffenrot
VWR International GmbH, Dresden
Walter Bautz GmbH, Griesheim
W. & W. Schenk, Maulbronn
W. Sell Computer-Dienst, Wiesbaden
W.L. Gore & Associates GmbH, Pleinfeld
W. Niedergesess Holz, Sandhausen
Walter Bautz GmbH, Griesheim
Watlow GmbH, Kronau
Wiegandt GmbH, Krefeld
Wiesemann u. Theis GmbH, Wuppertal
Wikotec, Bramsche
Willi Stober GmbH & Co., Karlsruhe
WIKA, Klingenberg
WilTec Wildanger Technik GmbH, Eschweiler
Witter GmbH, Heidelberg
Witzenmann Rhein-Ruhr GmbH, Xanten
Wiwasoft GmbH, Hannover
WS CAD Electronik, Berk Kirchen
Würth Elektronik GmbH & CO.KG, Künzelsau
Yokogawa-nbn GmbH, Herrsching
Zemax Corporation, Bellevue, USA

Conferences, Scientific, and Popular Talks

Conferences Organized

Conferences Organized at the Institute

Gesprächskreis Rhein-Neckar, "Physical Research in Industry and Universities in the Rhein-Neckar area", MPIA, 31. Jan. (Klaus Jäger)

Meeting of the Board of Trustees, Heidelberg, MPIA, 22. Feb. (Klaus Jäger)

Conference "Nuclear Clusters Across the Hubble Sequence", Heidelberg, 25. – 27. Feb. (E. Schinnerer, S. Koltes-Al-Zoubi, S. Haan, H.-W. Rix)

Internal Meeting of the IMPRS Students, Innsbruck, 4.–7. March (S. Boudreault)

First PanSTARRS1 Science Consortium Meeting, Heidelberg, 14. – 18. Apr. (E. Bell, S. Jester)

LINC-NIRVANA Science Team Meeting, Heidelberg, 8. May (Eva Schinnerer)

Seminar on Personnel Management for Young Group Leaders, Heidelberg, 5. – 7. May (Eva Schinnerer)

Second Generation Science with the Large Binocular Telescope, Ringberg Castle, 13. – 19. July (Tom Herbst, Eva Schinnerer)

Conference "EPoS 2008 – The Early Phase of Star Formation", Ringberg Castle, 28. July – 1. Aug. (Th.Henning, H. Beuther, H. Linz, M. Nielbock, D. Semenov, J. Steinacker)

IMPRS Summer School "The Art and Craft of Astronomical Instrumentation", Heidelberg, 1. – 5. Sept. (Ch. Fendt, A. Quirrenbach (ZAH/LSW))

Conference "Cosmic Dust – Near and Far", Heidelberg, 8. – 12. Sep. (Th. Henning, F. Huisken, J. Steinacker, M. Jannssen-Bennynck, O. Krause, M. Piroth)

Workshop "Cosmic Dust and Radiative Transfer", MPIA, 15. – 17. Sep. (Th. Henning, J. Steinacker)

5. MPIA Student Workshop, Munchhausen, Frankreich, 21. – 27. Sep. (Eva Meyer, Boyke Rochau)

Workshop with LBTO representatives on LINC-NIRVANA, Heidelberg, 23. – 24. Sep. (Kürster)

Conference "Understanding Lyman-alpha Emitters", Heidelberg, 6. – 10. Oct. (K. Nilsson, K. Meisenheimer, H. Dannerbauer, J. Kurk, H. Seifert, Ch. Tapken)

External Retreat of the PSF department, Maulbronn, 8. – 10. Oct. (H. Beuther)

Workshop of the Works Councils from all Max Planck Institutes in Heidelberg, 10. Oct. (K.-H. Marien)

Workshop "Classification and Discovery with Large Astronomical Surveys", Ringberg Castle, 14. – 17. Oct. (C. Bailer-Jones, C. Elting, S. Koltes-Al-Zoubi, K. Smith, C. Tiede, P. Tsalmantza)

Meeting of the LINC-NIRVANA Consortium, MPIA, 23. – 24. Oct. (Kürster)

Workshop "The High-energy Astrophysics of Outflows from Compact Objects", Ringberg Castle, 7. – 13. Dec. (Ch. Fendt, J. Kirk, MPI for Nuclear Physics)

Meeting of the Board of Trustees, Heidelberg, MPIA, 11. Dec. (Klaus Jäger)

Other Conferences Organized:

Coryn Bailer-Jones: GAIA DPAC CU8 Meeting No. 5, Bologna, 27. – 29. May; GAIA DPAC CU8 Meeting No. 6, Brussels, 24. – 26. Nov.

Cornelis Dullemond: Winter School "The First Stages of Planet Formation", Bad Honnef, 18. – 22. Feb. (SOC)

Thomas Henning: IAU Symposium 251 "Organic Matter in Space", Hong Kong, 18. – 22. Feb. (SOC); First Chinese-German Workshop on Star and Planet Formation, Nanjing, 31. March – 4. Apr. (SOC); CAHA Workshop on Instrumentation, Granada, 11. – 13. June (SOC); ETH Conference "Origin and Evolution of Planets", Ascona, 29. June – 4. July (SOC)

Tom Herbst: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (SOC)

Martin Kürster: Meeting of the LINC-NIRVANA Consortium, MPIfR Bonn, 19. – 20. Feb.; LINC-NIRVANA meeting on internal procedures, MPIfR Bonn, 20. – 22. Feb.

Ralf Launhardt: VLTI Training School "Astrometry and Imaging with the Very Large Telescope Interferometer", Keszthely (Lake Balaton), 2. – 13. June

Dietrich Lemke: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Chairman, proceedings Editor)

Fabian Walter: Conference "Gas and Stars in Galaxies – A Multi-Wavelength 3D Perspective", ESO, Garching, July (SOC)

Conferences and Meetings Attended, Scientific Talks and Poster Contributions

Cristina Afonso: PLATO (PLAnetary Transits and Oscillations of stars) Space Mission Meeting, DLR, Berlin, April (Talk); Pan-STARRS1 Consortium Meeting, Heidelberg, 14. – 18. Apr. (Talk); IAU Symposium no. 253, "Transiting Planets", Boston, 19. – 23. May (Talk);

Coryn Bailer-Jones: GAIA DPACE Meeting No. 5., Cambridge, 15. – 16. Jan.; Pan-Starrs Workshop, MPIA, April; GAIA DPACE Meeting No. 6., Heideberg, 22. – 23. May; GAIA DPAC CU8 Meeting No. 5, Bologna, 27. – 29. May; IAU Symposium 254, "The Galaxy disk in comsological context", Copenhagen, June; GAIA DPACE Meeting No. 7, ESAC/Madrid 25. – 26. Sep.; Classification and Discovery in Large Astronomical

Surveys, Ringberg Castle, 14. – 17. Oct. (Poster); ESLAB 2008 – Cosmic Cataclysms and Life, Esrin/Frascati, Nov. (Talk); GAIA DPAC CU8 Meeting No. 6, Brussels, 24. – 26. Nov.

Eric Bell: Pan-STARRS1 Consortium Meeting, Heidelberg, 14. – 18. Apr.; Conference "German-American Frontiers of Science", Humboldt-Stiftung, Potsdam, June; Space Telescope A901/902 Galaxy Evolution Survey Meeting, Edinburgh, Nov.

Arian Bik: ESO Workshop "Star Formation Across The Milky Way Galaxy", Santiago de Chile, 3. – 6. March (Talk);

Stephan Birkmann: MIRI European Consortium Meeting CD Nr.12, Swedish National Space Board, Onsala, 28. – 30. May; SPIE – Astronomical Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk); Conference "Cosmic Dust – Near and Far", Heidelberg, 8. – 12. Sep.

Steve Boudreault: 15th. Cool Star Meeting, St. Andrews, Scotland, 21. – 25. July (Poster, with C. A. L. Bailer-Jones)

Jeroen Bouwman: PACS Consortium Meeting Nr. 30, MPE, Garching, 24. – 25. Jan.; Conference "Planet Formation Processes and the Development of Prebiotic Conditions", JPL (NASA), Pasadena, 18. – 21. March (Talk); IAU Symposium No. 253 "Transiting Planets" Cambridge, MA, 19. – 23. May (Poster); MIRI European Consortium Meeting CD Nr. 12, Swedish National Space Board, Onsala, Sweden, 28. – 30. May; Conference "Cosmic Dust – Near and Far", Heidelberg, 8. – 12. Sep.; MIRI European Consortium Meeting CD Nr. 13, Trinity College, Dublin/Irland, 17. – 19. Sep.; SPITZER Conference, SSC, Pasadena, USA, 27. – 30. Oct.

Wolfgang Brandner: PanSTARRS1 Consortium Meeting, Heidelberg, 14. – 18. Apr.; Conference "Astronomy at High Angular Resolution", 21. – 25. Apr. (Poster); CAHA Instrumentation Workshop, 11. – 13. June

Mario Brix: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Poster, Talk)

Leonard Burtscher: DPG-FrühjahrsConference, Freiburg, 3. – 7. March (Talk); VLTI Training School, Keszthely, Ungarn (2. – 13. June); IMPRS Summer School "The Art & Craft of Astronomical Instrumentation", Heidelberg, 1. – 5. Sep.

Marcello Cacciato: Conference "Galactic Structure and Structure of Galaxies", Ensenada, Mexiko, 17. – 21. March (Poster)

Joseph Carson: SUBARU SEEDS Workshop, 1. Feb. (Talk), IAU Symposium 253 "Transiting Planets", Cambridge, MA, 19. – 23. May (Poster); SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Poster)

Helmut Dannerbauer: PACS Consortium Meeting Nr. 30, MPE, Garching, 24. – 25. Jan.; Conference "Gas and Stars in Galaxies", ESO, Garching, 10. – 13. June (Talk); Conference "Cosmic Dust – Near and Far", Heidelberg, 8. – 12. Sep. (Talk); Conference "Understanding Lyman-alpha Emitters", Heidelberg, 6. – 10. Oct. (Talk)

Cornelis Dullemond: Winter school, Lecture on protoplanetary disks, 18. – 22. Feb.; Conference "Astronomy at high angular resolution"

Jelte de Jong: IAU Symposium 254: "The Milky Way Disk in Cosmological Context", 9. – 13. June, Copenhagen (Talk); Conference "Chemical Evolution of Dwarf Galaxies and Stellar Clusters", 21. – 25. July, Garching (Talk)

Örs H. Detre: Miri European Consortium Meeting CD Nr. 13, Trinity College, Dublin, Ireland, 17. – 19. Sep.; JWST US/European Partners Workshop, München, 13. Oct.

Gaelle Dumas: Conference "Galaxy and Stellar Dynamics 2008", Straßburg, 16. – 20. March (Talk); "Gas and stars in galaxies. A multi-wavelength 3D perspective", Eso Garching, 10. – 13. June (Talk)

Markus Feldt: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk)

Christian Fendt: Conference "Protostellar Jets in Context", Rhodos, 7. – 12. July (Talk); Jetset-TLS Workshop "Comparing Jet Observations and Simulations", Tautenburg, 26. – 28. Jan.

Fabio Fontanot: Eight Italian Conference "Active Galactic Nuclei", Torino, 19. – 22. May (Talk); XXIV IAP Colloquium "Far Away – Light in the Young Universe at Redshift Beyond 3", Paris, 7. – 11. July (Poster); KITP Workshop "Building the Milky Way", Santa Barbara (California), 6. – 14. Nov.

Kelly Foyle: IAU Symposium 254 "The Galaxy in the Cosmological Context", Copenhagen, June (Poster)

Wolfgang Gässler: LBT-LGS Phase A Study Preparation Meeting, Tuscon, 22. – 23. Jan. (Talk); LINC-NIRVANA consortium meeting, Bonn, 19. – 22. Feb. (Talk); LBTLGS Phase A Review, Tuscon, 17. – 18. March (Talk); ARGOS (LBT-LGS) Kick-off Meeting, Florenz, 26. – 17. May (Talk); CAHA InstrumentationWorkshop, Granada, 11. – 13. June (Talk); SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (several talks and Posters with Co-authors); FP6-OPTICON JRA1-General Meeting, Garching, 25. – 26. Sep. (Talk); LINC-NIRVANA Consortium Meeting, Heidelberg, 23. – 24. Oct. (Talk); ARGOS Meeting, Potsdam, 21. – 22. Nov. (Talk)

Anna Gallazzi: EARA Workshop "HERSCHEL Promises for Galaxy Evolution Studies", Paris, 18. – 19. Feb.

Bertrand Goldman: Conference on Cool Stars No. 15, St. Andrews, Scotland, 21. – 25. July (Poster); Conference "Cosmic Dust – Near And Far", Heidelberg, 8. – 12. Sep. (Poster); Conference "Science from UKIDSS II", RAS London 15. – 17. Dec. (Talk)

Dimitrios Gouliermis: IAU Symposium No 255 "Low Metallicity Star Formation: From the First Stars to Dwarf Galaxies" Rapallo, 16. – 20. June (Poster); IAU Symposium No 256 "The Magellanic System: Stars, Gas, and Galaxies", Keele University, UK, 28. July – 1. Aug. (Talk); International Conference "Cosmic Dust – Near & Far", Heidelberg, 8. – 12. Sep.; International Workshop "Star-forming Dwarf Galaxies", Creta, 29. Sep. – 3. Oct. (Talk); MPIA Planet and Star Formation Group Workshop, Maulbronn, 8. – 10. Oct. (Talk)

Roland Gredel: CAHA Instrumentation Workshop, Granada; 10. – 13. June; Translucent Molecular Clouds, SAO, Russland, 4. – 8. Aug.; ESO Workshop Large Programmes, ESO Garching, 13. – 15. Oct.

Ulrich Grözinger: SPICA Consortium Meeting, RAL, Didcot/UK, 30. – 31. Jan.; MIRI European Consortium Meeting CD Nr. 11, PSI, Villigen/CH, 26. – 28. Feb.; MIRI European Consortium Meeting CD Nr. 12, Swedish National Space Board, Onsala, 28. – 30. May; JWST US/European Partners Workshop, München, 13. Oct.

Martin Hennemann: MIRI European Consortium Meeting CD Nr. 11, PSI, Villigen/CH, 26. – 28. Feb.; MIRI European Consortium Meeting CD Nr. 12, Swedish National Space Board, Onsala, 28. – 30. May; Conference "The Early Phase of Star Formation" (EPoS), Ringberg, 28 July – 1. Aug. (Poster); MIRI European Consortium Meeting CD Nr. 13, Trinity College, Dublin/Ireland, 17. – 19. Sep.

Tom Herbst: MICADO Team Meeting, Garching, 8. Jan. (Talk); LIINUS/SERPIL Meeting, Köln, 16. Jan. (Talk); LN Consortium Meeting, Bonn, 19. Feb. (Talk); LN Consortium Meeting, 20. Feb. (Talk); MPIA Kuratorium, 22. Feb. (Talk); "European ELT Re-Baselining", Garching, 29. Feb. – 4. March; ESO STC Meeting, Garching, 16. April (Talk); LBTB Meeting, MPIA, 29. April (Talk); LN Science Meeting, 8. May (Talk); LIINUS/SERPIL Meeting, 29 May (Talk); Summer School on Astrophysics, Tarquinia, 8. – 11. June; SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June; Second Generation Science with the LBT Ringberg, 13. – 19. July; JENAM 2008, Wien, 8. – 10. Sep.; Future Ground-Based Solar System Research, Elba, 10. – 12. Sep.; LBT Board Meeting, Potsdam, 26 September (Talk); MICADO Team Meeting, Garching, 6. Oct. (Talk); ESO STC Meeting, Garching, 22. Oct. (Talk); LN Team Meeting, MPIA, 23. Oct. (Talk)

Stefan Hippler: METIS Science meeting, Heidelberg, 13. – 14. Feb.; METIS team meeting, Sterrewacht, Leiden, 9. – 10. June; METIS progress meeting, MPIA, Heidelberg, 8. Sep.; METIS AO meeting, MPIA, Heidelberg, 9. Sep.; E-ELT AO control strategy workshop, ESO, Garching, 22. Sep.; METIS AO working plan meeting, Sterrewacht, Leiden, 16. Oct.; ATLAS (Laser Tomography Adaptive Optics) – METIS first joint meeting, ONERA, Paris, 27. Nov.; GRAVITY AO meeting, MPIA, Heidelberg, 28. Jan.; GRAVITY Kick-off meeting, MPE, Garching, 8. July; GRAVITY AO meeting, MPE, Garching, 10. July

Ralph Hofferbert: MIRI European Consortium Meeting CD Nr. 12, Swedish National Space Board, Onsala, 28. – 30. May; MIRI European Consortium Meeting CD Nr. 13, Trinity College, Dublin, 17. – 19. Sep.

Rory Holmes: JWST US/European Partners Workshop, München, 13. October

Felix Hormuth: Conference "Star Formation Across the Milky Way Galaxy", ESO, Vitacura, Chile, 3. – 6. March (Poster); Conference "The Universe under the Microscope – Astrophysics at High Angular Resolution", Bad Honnef, 21. – 25. April (Poster); SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumenta-tion, Marseille, 23. – 28. June (zwei Poster); 15th. Cool Star Meeting, St. Andrews, Scotland, 21. – 25. July (Poster)

Friedrich Huisken: 2nd International Conference on New Diamond and Nano Carbons (NDNC2008), Taipei, May 26. – 29. (Poster); Conference "Cosmic Dust Near and Far", Heidelberg, September 8. – 12. (Poster);

Klaus Jäger: Conference zur Verleihung des Jugendsoftwarepreises der Klaus Tschira Stiftung gGmbH, Villa Bosch, Heidelberg, 25. Jan.; Heidelberg Astronomers' Convention, Kirchhoff-Institut für Physik, Heidelberg, 26. March; Treffen des Rats Deutscher Sternwarten, Argelander-Institut für Astronomie, Bonn, 28. March; Meeting der LBT Beteiligungsgesellschaft, Heidelberg, MPIA, 29. Apr.; Conference und Festveranstaltung "50 Jahre Max-Planck-Institut für Kernphysik" (MPIK), Heidelberg Convention Center und MPIK, 1. Oct.; Explore Science, Mannheim, 9. – 11. June; Treffen des Rats Deutscher Sternwarten, Universitäts-Sternwarte München (6. Oct.); Interdisziplinäres Wissenschaftssymposium der Klaus Tschira Stiftung "Einschläge von Asteroiden und Kometen – Gefahr für die Erde?", Villa Bosch, Heidelberg (13. Nov.); Festveranstaltung "30 Jahre Spektrum-Verlag", Technikmuseum Mannheim (21. Nov.)

Knud Jahnke: STAGES Collaboration Workshop, Obergurgl, Austria, 8. – 12. Apr.; First PanSTARRS1 Science Consortium Meeting, Heidelberg, 14. – 18. Apr.; COSMOS Collaboration Workshop, IAP Paris, 9. – 13. June; Aspen Center for Physics, Workshop on Active Galactic Nuclei: The Interplay Between Supermassive Black Holes, Star Formation, and Galaxy Evolution, Aspen, USA, 14. – 20. July.

Sebastian Jester: "XEUS: Physics of the hot evolving Universe", ESA-ESTEC Noordwijk, March (Poster); Conference "The X-ray Universe", Granada, May (Talk); Workshop on Cosmic Reionization, Kavli Institute for Astronomy and Astrophysics/Beijing University, June (Talk)

Viki Joergens: Conference "Cool Stars No. 15", St Andrews, Scotland, 21. – 25. July (Poster), Conference "Origin and Evolution of Planets 2008", Ascona, 29. June – 4. July (Poster)

Attila Juhász: Conference "The Early Phase of Planet Formation – Wilhelm and Else Heraeus Physics Shool", Bad Honnef, 18. – 22. Feb. (Poster); Conference “Planet Formation Processes and the Developement of Prebiotic Conditions”, Pasadena, 17. – 21. March (Talk); PSF External Retreat, Maulbronn, 8. – 10. Oct. (Talk); Conference “Cosmic Dust Near and Far, Heidelberg, 8. – 12. Sep.“ (Poster); 5th SPITZER Conference “New Light on Young Stars”, Pasadena, 26. – 30. Oct. (Poster);

Ulrich Klaas: PACS Consortium Meeting Nr. 30, MPE, Garching, 24. – 25. Jan.

Hubert Klahr: Conference “Planet Formation Processes and the Development of Prebiotic Environment”, Caltech Pasadena, 17. – 21. March (Talk)

Rainer Klement: IAU Symposium 254 “The Galaxy Disk in Cosmological Context”, Copenhagen, 9. – 13. June (Poster); Conference “Back to the Galaxy II”, UC Santa Barbara, 29. Sep. – 3. Oct. (Poster); GAIA CU8 Meeting No. 6, Brüssel, 25. – 26. Nov.

Sergey Koposov: Conference “Dark Matter on Small Scales”, Paris, 13. – 15. Feb., (Talk); Conference “Building the Milky Way”, Santa Barbara, US, Oct. (Poster, Talk); Conference “Classification and Discovery in Large Astronomical Surveys”, Ringberg, Oct. (Poster)

Oliver Krause: SPICA Consortium Meeting, RAL, Didcot/UK, 30. – 31. Jan.; MIRI European Consortium Meeting CD Nr. 11, PSI, Villigen/CH, 26. – 28. Feb.; MIRI European Consortium Meeting CD Nr. 12, Swedish National Space Board, Onsala, 28. – 30. May; SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk); Conference “Cosmic Dust – Near and Far”, Heidelberg, 8. – 12. Sep. (Poster); MIRI European Consortium Meeting CD Nr. 13, Trinity College, Dublin/Ireland, 17. – 19. Sep.; JWST US / European Partners Workshop, München, 13. Oct.

Martin Kürster: Cool Stars 15, St. Andrews, Scotland, 21. – 25. July (Poster)

Jaron Kurk: Conference “Gas and Stars in Galaxies: A Multi-Wavelength 3D Perspective”, ESO, Garching, 10. – 13. June (Talk); KIAA-PKU Summer School and Workshop 2008, “Cosmic Reionization – the Formation and Evolution of Stars, Galaxies and Black Holes”, 1. – 11. July (Talk)

Ralf Launhardt: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk und Poster)

Dietrich Lemke: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June; JENAM, Wien, 12. September (Talk); Conference “400 Years of Astronomical Telescopes”, ESA, Noordwijk, 29. Sep. – 2. Oct.

Rainer Lenzen: METIS Science meeting, Heidelberg, 13. – 14. Feb.; ARENA-Workshop “Wide field telescopes in Antarctica”, Exeter 25. – 27. March; METIS team meeting, Sterrewacht, Leiden, 9. – 10. June; METIS progress meeting, MPIA, Heidelberg, 8. Sep.; METIS team meeting, Garching, 15. Oct.; METIS first joint meeting, ONERA, Paris, 27. Nov.; GRAVITY Kick-off meeting, MPE, Garching, 8. July

Hendrik Linz: Conference “The Universe under the Microscope – Astronomy at High Angular Resolution”, Bad Honnef, 21. – 25. Apr. (Poster); Conference “Early Phases of Star Formation”, Ringberg (Talk)

L. Ma: 2. International Workshop on Semiconducting Nanoparticles – Photovoltaics and Optoelectronics, Duisburg, 10. – 12. Dec. (Talk)

Andrea Macciò: “Frontiers in Computational Astrophysics: The Origin of Stars, Planets and Galaxies”, Ascona (Switzerland) 13. – 18. July (Poster)

Nicolas Martin: Conference “Galactic Structure and the Structure of Galaxies”, Ensenada, Baja California, Mexico, 17. – 21. March (Talk); Conference “Chemical Evolution of Dwarf Galaxies and Stellar Clusters”, Garching, 21. – 25. July (Talk); Conference “Back to the Galaxy II”, Kavli Institute for Theoretical Physics, Santa Barbara, California, USA, 29. Sep. – 3. Oct.

Alejo Martinez: COSMOS collaboration meeting, Institut d’Astrophysique, Paris (Talk); EUCLID meeting, Institut d’Astrophysique, Paris (Talk); Conference “The central kiloparsec, AGN and their hosts”, Ierapetra (Talk)

Klaus Meisenheimer: Workshop “HERSCHEL Key Project Coordination and Science Exploitation”, Nordwijk 1. – 2. July; XMS Kick-off Meeting, Durham 30 Sep. – 1. Oct.; STAGES Science Meeting, Edinburgh 26. – 28. Nov.

Eva Meyer: Conference “Cool Stars XV”, St. Andrews, Scotland 20. – 25. July (Poster); 5. MPIA Studenten Workshop, Munchhausen, 21. – 27. Sep. (Talk); PSF Workshop, Maulbronn, 8. – 10. Oct. (Talk)

Surhud More: Workshop “Probes of Large Scale Structure”, IUCAA, Pune, India, 15. – 17. Aug. (Talk); MPIA/LSW HausColloquium, Heidelberg, 27. June (Talk)

Maximiliano Moyano: PanSTARRS1 Science Consortium Meeting, Heidelberg, April; IAU Symposium No 253 “Transiting Planets”, Cambridge, MA, 19. – 23. May; International Young Astronomers School “The Star and its Planetary System in the wake of Corot Advances”, Paris, 6. – 10. Oct.

Friedrich Müller: SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23.–28. June; MIRI European ConsortiumMeeting CD Nr. 13, Trinity College, Dublin/Ireland, 17. – 19. Sep.; JWST US/European Partners Workshop, München, 13. Oct.

Andre Müller: 8th European Symposium for the Protection of the Night Sky, Vienna (Talk)

Reinhardt Mundt: Cool Stars Workshop Nr. 15, St. Andrews, Scotland, 21. – 25. July (Talk, Poster)

Markus Nielbock: PACS Consortium Meeting Nr. 30, MPE, Garching, 24. – 25. Jan.; Conference “Star Formation Across the Milky Way galaxy”, ESO, Santiago de Chile, 3. – 6. March, (zwei Poster); Conference “The

Early Phases of Star Formation", Ringberg Castle, 28 July – 1. August (Poster); Conference der Gesellschaft für Archäoastronomie "Maß, Zahl und Geometrie in der Vor- und Frühgeschichte – Anfänge der Mathematik und der Astronomie", Berlin, 24. – 26. Oct.

Nikolay Nikolov: PanSTARRS1 Science Consortium Meeting, Heidelberg, Apr.; IAU Symposium No 253 "Transiting Planets", Cambridge, MA, 19. – 23.May; International Young Astronomers School "The Star and its Planetary System in the wake of Corot Advances", Paris, 6. – 10. Oct.

Kim Nilsson: Ultra-VISTA Survey Team Meeting, 18. – 20. March, Lorentz Center, Leiden, NL (Talk); Light in the Young Universe at Redshift beyond Three, 7. – 11. July, IAP Paris (Talk); ESO VISTA Surveys Meeting, 15. – 17. Sep., ESO Garching; Understanding Lyman-alpha Emitters, 6. – 10. Oct., MPIA (Talk)

Jan Pitann: Conference "Astronomical Polarimetry", La Malbaie, Quebec, 6. – 11. July (Talk)

Axel M. Quetz: Heidelberg Astronomers' Convention, Kirchhoff-Institut für Physik, Heidelberg, 26. March; Interdisziplinäres Wissenschaftssymposium der Klaus Tschira Stiftung "Einschläge von Asteroiden und Kometen – Gefahr für die Erde?", Villa Bosch, Heidelberg (13. Nov.)

Aday Robaina: Conference "Galaxy Evolution: Emerging Insights and Future Challenges", Austin, Texas, 11. – 14. Nov. (Talk); Conference "When the Universe Formed Stars", Martinique, Frankreich, 17. – 21. Nov. (Talk)

Boyke Rochau: Conference "Star Formation Across The Milky Way Galaxy", Santiago de Chile, 3. – 6. March (Poster); The Seventh NEON Observing School, La Palma (Spain), 23. June – 5. July; 5th MPIA Students Workshop, Munchhausen (France), 21. – 27. Sep., (Talk); PSF Retreat 2008, Maulbronn 8. – 10. Oct. (Talk und Podiumsdiskussion)

G. Rouillé: Internationale Conference "Isolated Biomolecules and Biomolecular Interactions", Valladolid, 13. – 18. Apr. (Poster); Conference "Cosmic Dust Near and Far", Heidelberg, 8. – 12. Sep. (Poster)

Christiane Ruhland: PS1SC meeting, Heidelberg, 14. – 17. Apr.; IAU Symposium Nr. 254 "The Galaxy Disk in Cosmological Context", Kopenhagen, 9. – 13. June (Poster); 3rd Heidelberg Summer School "The Art & Craft of Astronomical Instrumentation", Heidelberg, 1. – 5. Sep.; MPIA StudentsWorkshop, Munchhausen/ Frankreich, 21. – 27. Sep. (Talk); Conference "Back to the Galaxy II", KITP Santa Barbara/USA, 29. Sep. – 3. Oct.; XX Canary Island Winter School in Astrophysics "Local Group Cosmology", Teneriffa, 17. – 28. Nov. (Poster)

Zsolt Sandor: 7th Alexander von Humboldt Colloquium on Celestial Mechanics "The Chaotic Dynamics of Small Bodies and Planets", Bad Hofgastein, 30 March. – 5. April (Talk); International Conference on "The Dynamics of Celestial Bodies", Litohoro- Olympos, 23. – 26. June (Talk)

Mark Sargent: COSMOS Team Meeting, Paris, 9. – 13. June (Talk); 6th IRAM Millimeter Interferometry School, Grenoble, 6. – 10. Oct.

Silvia Scheithauer: MIRI European Consortium Meeting CD Nr. 11, PSI, Villigen/CH, 26. – 28. Feb.; GAMM Conference, University of Bremen, 31 March – 3. Apr. (Talk); SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June; MIRI European Consortium Meeting CD Nr. 13, Trinity College, Dublin / Ireland, 17. – 19. Sep.; JWST US/European Partners Workshop, München, 13. Oct.

Eva Schinnerer: Nuclear Star Clusters across the Hubble Sequence, MPIA (Talk); COSMOS team meeting, Paris (Talk); Transformational Science with ALMA: The Birth and Feedback of Massive Star Formation Within and Beyond the Galaxy, Charlottesville (Talk); LINC-NIRVANA Consortium Meeting, Heidelberg, 23. – 24. Oct.

T. Schmidt: NanoLum, European Workshop on Luminescent Nano-Objects, Les Houches, 17. – 20. March (Poster); DPG Summerschool "Functional Nanostructures", Bad Honnef, 15. – 19. Sep. (Poster); 2nd International Workshop on Semiconducting Nanoparticles – Photovoltaics and Optoelectronics, Duisburg, 10. – 12. Dec. (Poster)

Jürgen Schreiber: PACS ConsortiumMeeting Nr. 30,MPE, Garching, 24. – 25. Jan.; ADASS, Quebec, Canada, 1. – 6. Nov. (Poster)

Dmitri Semenov: Conference "Molecular Universe", Arcachon, 5. – 8. May (Poster); Workshop "Physics with cold stored ion beams", Heidelberg, 13. June (Talk); TIARA workshop "From numerical simulations to Molecular lines", Taipei, 6. – 12. July (Talk); Conference "Early Phases Of Star Formation (EPOS)", Ringberg, 28. July – 1. Aug. (Poster); Workshop "Interstellar Surfaces: from Laboratory to Models", Leiden, 6. – 10. Oct. (Talk); IAU Sympusium 251 "Organic Matter in Space", Hong Kong, 18. – 22. Feb. (Talk, mit Th. Henning)

Johny Setiawan: Interferometry Summer School, Keszthely, Ungarn 2. – 13. June (Poster); JENAM, Wien, 8. – 12. Sep. (Talk, Poster); PSF internal workshop, Maulbronn, 8. – 10. Oct. (Talk)

Aurora Sicilia-Aguilar: Conference "Cool Stars 15", St. Andrews, Scotland, 21. – 25. July (zwei Vorträge); Conference "Cosmic Dust Near and Far", Heidelberg, 8. – 12. Sep. (Poster)

Rosalind Skelton: Conference "Galaxy Evolution: Emerging Insights and Future Challenges", Austin, Texas, 11. – 14. Nov. (Talk)

Kester Smith: Workshop "Classification and Discovery with Large Astronomical Surveys", Ringberg Castle, 14. – 17. Oct. (Talk)

J. Sommerfeld: NanoLum, European Workshop on Luminescent Nano-Objects, Les Houches, 17. – 20. March (Poster)

Jutta Stegmaier: Spica Consortium Meeting, RAL, Didcot/UK, 30. – 31. Jan.; SPIE – Astronomical Telescopes and Instrumentation, Advanced Optical andMechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk)

Jürgen Steinacker: Formation Process, Fragmenation, and the Origin of the IMF, and: Circumstellar Disk Physics from Low- to High-Mass Star Formation – open discussions on Molecular Clouds and on Circumstellar Disks at Heidelberg Astronomers' Convention (26 March); Massive Star Formation Seminar MPIA Heidelberg, 2. Apr. (Talk); Workshop "Cosmic Dust and Radiative Transfer", Heidelberg, September (Talk)

Micaela Stumpf: 211th Meeting of the AAS, Austin, 6. – 11. Jan. (Poster); Conference "Cool Stars 15", St. Andrews, UK, 20. – 25. July (Poster)

Christy Tremonti: Conference "Galaxy Evolution: Emerging Insights and Future Challenges", Austin, Texas, 11. – 14. Nov.; Workshop on the Square Kilometer Array, 17. – 18. Nov. (Talk)

Paraskevi Tsalmantza: International Astronomy Meeting "Probing Stellar Populations Out to the Distant Universe", Cefalù, 7. – 19. Sep. (Talk); Workshop "Classification and Discovery in Large Astronomical Surveys", Ringberg Castle, 14. – 17. Oct. (Talk); Gaia CU8 Meeting, Brüssel, 24.–26. Nov. (Talk); Workshop "Fitting the spectral energy distributions of galaxies", Leiden, 17. – 21. Nov. (Talk)

Roy van Boekel: Conference "Cosmic Dust Near and Far", Heidelberg, Sept.; PSF group retreat, Maulbronn, 8. – 10. Oct.; Progress meeting on Visir/Midi studies of Herbig AeBe disks, Amsterdam, 7. – 9. Dec.

Fabian Walter: Aspen workshop "AGN: The Interplay Between Supermassive Black Holes, Star Formation and Galaxy Evolution", 6. – 27. July

Xi Kang: IAU Symposium 254 "The Galaxy Disk in Cosmological Context", 9. – 13. June, Kopenhagen (Poster)

Stefano Zibetti: Ultravista Kick-off Meeting, 18. – 20. March, Leiden; Conference "Fitting the Spectral Energy Distribution of Galaxies", Leiden, 17. – 21. Oct. (Talk)

Invited Talks, Colloquia

Coryn Bailer-Jones: University College London, Januar (Talk); IAU Symposium 254, Copenhagen, 9. – 13. June (Talk); Max Planck Institut für Biologische Kybernetik, Nov. (Colloquium)

Eric Bell: University of Michigan (Colloquium); Carnegie Observatories, Pasadena (Colloquium); DFG's Schwerpunkt Program Summer School "Co-evolution of Galaxies and Black Holes", Bad Honnef, 4. – 8. Aug. (Talk); Jenam 2008, Wien, 8. – 10. Sep. (Talk)

Henrik Beuther: Epos2008 "Massive Star Formation: Major Questions, Potential Answers", Ringberg Castle, 28. July – 1. Aug. (Talk); Universität Wien (Talk); Harvard-Smithsonian Center for Astrophyscis (Colloquium); Universität Köln (Talk); Universität Zürich/ETH (Talk)

Kris Blindert: Conference "Nuclear Clusters Across the Hubble Sequence", MPIA, 25. – 27. Feb. (Talk)

Steve Boudreault: University of Toronto, Graduate Student Seminars, 12. Jan. (Talk)

Jeroen Bouwman: Conference "Silicate Dust in Protostars, Astrophysical, Experimental, and Meteoretic Links", Tokyo, 25. – 26. July (Talk); Spitzer Conference, SSC, Pasadena, 27. – 30. Oct. (Talk)

Marcello Cacciato: 25th LBNL, Berkeley, California, 25. March (Talk)

Helmut Dannerbauer: Oamp, Marseille, Astrophysical Colloquium, 7 Nov. (Talk)

Jelte de Jong: ; Conference "Back to the Galaxy II", 29. Sep. – 3. Oct., Santa Barbara, USA (Talk)

Cornelis Dullemond: Conference "Astronomy at high angular resolution", Bad Honnef 21. – 25. Apr.; Conference "Origin and Evolution of Planets 2008", Ascona, Schweiz, 29. June – 4. July; Conference "Unstructured meshes with periodic boundaries", 20. Oct.; 1-Day symposium on the interstellar medium, Leiden, 7. Nov.; Grenoble, LAOG, 7. Feb.; Berlin, DLR, 9. May

Markus Feldt: Symposium "Basic Research in Space", München, 13. June (Talk)

Christian Fendt: "Astrophysical Jets – Formation and Propagation", Institute Colloquium, Lund Observatory, Lund, 15. May; "MHD simulations of jet formation" Haupt- Colloquium, MPI für Radioastronomie, Bonn, 30. May

Fabio Fontanot: University of Ljubljana (Slovenia), 25. March (Talk); Estec, Noordwjik, 3. Dec. (Talk)

Kelly Foyle: Conference "Galaxy Evolution: Emerging Insights and Future Challenges", Austin, Texas, 11. – 14. Nov. (Talk); MPI für Astrophysik, Garching, 23. May (Talk)

Dimitrios Gouliermis: University of Sheffield, Feb. (Colloquium); MPIA "Galaxy Coffee", March (Talk); Esa/Estec, Apr. (Talk); International Workshop Star-forming Dwarf Galaxies, Oct. (Talk)

Thomas Henning: IAU Symposium 251 "Organic Matter in Space", Hong Kong, 18. – 22. Feb. (Talk); First Chinese-German Workshop "Star and Planet Formation, Nanjing, 31 March – 4. Apr. (Talk); ETH Conference "Origin and Evolution of Planets, Ascona, 29 June – 4. July (Talk); Meeting "Early Phases of Star Formation", Ringberg, 28 July – 1. Aug. (Talk); "New Light on Young Stars: Spitzer's View of Circumstellar Disks", Pasadena, 26. – 30. Oct. (Talk); Physikalisches Colloquium, Universität Köln, 4. Nov.; Ringvorlesung, Universität Heidelberg, 8. Dec. (Talk)

Tom Herbst: Infrared Astrophysics, Tarquinia, Italien, 9. June (Talk); Natural Limits to Observations, Tarquinia, Italien, 10. June (Talk); Infrared Telescopes and Instruments, Tarquinia, Italy, 11. June (Talk); SPIE – Astronomical Telescopes and Instrumentation, Advanced

Optical and Mechanical Technologies in Telescopes and Instrumentation, Marseille, 23. – 28. June (Talk); Second Generation Science with the LBT, Ringberg, 15. – 17. July (zwei Vorträge); IMPRS Summer School, Heidelberg, 1. Sep. (Talk); Future Ground-Based Solar System Research, Elba, 11. Sep. (Talk)

Sebastian Jester: Conference "The High-energy Astrophysics of Outflows from Compact Objects", Ringberg, 7. – 13. Dec. (Talk)

Viki Joergens: Argelander-Institut für Astronomie und MPI für Radioastronomie, Bonn, 18. Jan. (Talk); Hamburger Sternwarte, 24. Jan., (Talk); Conference "Cool Stars 15", St. Andrews, Schottland, 21. – 25. July (Talk)

Hubert Klahr: Universität Tübingen, Januar (Habilitationstalk); University of California, San Diego, March (Colloquium); University of California, Santa Cruz, March (Colloquium); MPIfR Bonn, Apr. (Talk); Conference "Origin and Evolution of Planets", Ascona, 29. June – 4. July (Discussion, Chair); JENAM 2008, Wien, 8. – 10. Sep. (Talk); ENS Paris, September (Colloquium); MPI für Dynamik und Selbstorganisation, Göttingen, Nov. (Colloquium)

Rainer Klement: Conference "Back to the Galaxy II" UC Santa Barbara, 29 September – 3. Oct. (Talk)

Oliver Krause: Helsinki Observatory, Astrophysical Colloquium, 25. Aug. (Talk), Observatory of Turku, 28. Aug. (Colloquium)

Jaron Kurk: ESO Workshop on Large Programmes, Garching, 13. – 15. Oct. (Talk)

Martin Kürster: ESO Workshop on Large Programmes, Garching, 13. – 15. Oct. (Talk)

Ralf Launhardt: VLTI School, Keszthely, 2. – 13. June, (Talk)

Dietrich Lemke: "Fernrohre im Weltraum – Entdeckungen im kalten Kosmos", Studium Generale, Universität Heidelberg, 15. Dec.; "Infrarot-Weltraumteleskope", Studium Generale, Universität Marburg, 17. Dec.

Hendrik Linz: MPI für Radioastronomie, Bonn, 24. July (Colloquium); CSIRO ATNF Headquarters Marsfield, Sydney, 23. Sep. (Talk)

Andrea Macciò: Conference "Dark Matter at Small Scales", Paris, 12. – 15. Feb. (Übersichtstalk), Hebrew University, Jerusalem, 14. May (Talk); Lausanne, EPFL, 15. Oct. (Talk)

Nicolas Martin: Institute of Astronomy, Cambridge, UK, Januar (Colloquium); "Back to the Galaxy II", Kavli Institute for Theoretical Physics, Santa Barbara, California, September (Talk)

Klaus Meisenheimer: Oxford University, 10. June (Colloquium)

Kim Nilsson: Sternwarte Stockholm, Schweden, 30. Apr. (Seminar)

Hans-Walter Rix: UC Berkeley, 6. March (Colloquium); Institute of Geophysics and Planetary Physics at LLNL, Livermore/CA, USA, 7. March (Colloquium); Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, 27. May (Colloquium); Institute of Astronomy Cambridge, UK, 29. May (Talk); Ringberg-Workhop "Second Generation Science with the Large Binocular Telescope", Ringberg Castle, Tegernsee, 15. July (Talk); 3rd Sino-German Workshop on Galactic Astronomy with LAMOST, Weihai, China, 24. July (Talk); Conference "Back to the Galaxy II", The Kavli Institute for Theoretical Physics, UCSB, Santa Barbara, CA, 3. Oct. (Talk); FestColloquium Prof. Werner Holzmüller, Universität Leipzig, 16. Dec. (Colloquium)

Ralf-Rainer Rohloff: Society for the History of Science in Jena e.V., 11. June (Talk)

Eva Schinnerer: Kapteyn Institute, Universität Groningen University (Colloquium)

Johny Setiawan: Universität Jena 16. Jan. (Talk); Kiepenheuer-Institut für Sonnenphysik: 14. Feb. (Talk); ESA/ESTEC, 15. Feb. (Talk); Asian Science Camp, 3. – 9. Aug. (Talk)

Aurora Sicilia-Aguilar: IAA Granada, 17. Jan. (Talk)

Kester Smith: ELSA School, Barcelona, 1. – 5. Sep. (Talk)

Jürgen Steinacker: University of Applied Sciences, Remagen, 29. May (Talk); Marie Curie Research Training Network JETSET: 5th School on High Performance Computing in Astrophysics, Galway, 9. Jan. (Talk)

Christy Tremonti: Austin Conference "Galaxy Evolution" (Talk); Massachusetts Institute of Technology, 18. Nov. (Colloquium)

Roy van Boekel: Conference "The Universe under the Microscope", Bad Honnef, 21. – 25. Apr. (Talk)

Frank van den Bosch: University of Utah, Salt Lake City, 14. Feb. (Colloquium); Rutgers University, Piscataway, New Jersey, 28. March (Colloquium); University of Massachusetts, Amherst, 28. Aug. (Colloquium); Leiden University, 13. Nov. (Colloquium)

Fabian Walter: NRAO, Charlottesville/USA, May (Colloquium); Workshop "Gas and Stars in Galaxies – A Multi-Wavelength 3D Perspective", Garching, 10. – 13. June (Talk); Conference "Cosmic Dust, Near and Far", Heidelberg, 8. – 12. Sep. (Talk); Straßburg, Dec. (Colloquium)

Xi Kang: Shanghai Astronomical Observatory, 4. July (Talk)

Lecture Series

Coryn Bailer-Jones: "Introduction to Machine Learning and Pattern Recognition", MPIA, Feb./March

Joseph Carson: "Introduction to IDL", MPIA, Feb. and Dec.

Andrea Macciò: "Large Scale Structure Simulations vs. Observations", Young Researcher Meeting, Transregio 33, Heidelberg, March

Fabian Walter: SPP Summerschool of the DFG, Bad Honnef, Aug.

Hans-Walter Rix: "The Milky Way in a Cosmological Context XX". Canary Islands Winter School of Astrophysics, Teneriffa, Spanien, 17.–20. Nov.

Popular Talks

Eric Bell: Talk on the Solar Eclipse in the Eva von Tiele Winkler Kindergarten, Leimen

Wolfgang Brandner: "Brown Dwarfs – failed Stars or Super-planets?", Astronomy on Sunday Morning, MPIA, 1. June, and Planetarium Mannheim, 7. Oct.

Helmut Dannerbauer: "Collisions of Galaxies", Astronomy on Sunday Morning, MPIA, 13. July

Christian Fendt: "Jets from Young Stars and Black Holes", Planetarium Mannheim, 15. Apr., and Astronomy on Sunday Morning, MPIA, 29. June

Markus Feldt: "Hands-on Astronomy", Explore Science 2008, Mannheim, 11. June

Kelly Foyle: MPG Workshop on Arts and Science, Munich, 12. Sep.

Roland Gredel: "The New Giant Telescopes", Gesprächskreis Rhein-Neckar, 31. Jan.; "New Telescopes in ground-based Astronomy", Gymnasium Cotta, 24. June; "The New Giant Telescopes", Gymnasium Dippoldiswalde, 25. June; "The Large Binocular Telescope", IMPRS, Heidelberg, 1. Sep.; "The European Giant Telescope E-ELT", Planetarium Mannheim, 12. Dec.

Thomas Henning: "Formation of Planetary Systems", Planetarium Mannheim; "Extrasolar Planets", Rotary Club, Mainz

Tom Herbst: "Building the Large Binocular Telescope", Talk for school students, MPIA, 21. July

Klaus Jäger: "Galaxies and Terabytes – Optical Astronomy in the Era of Giant Telescopes", Weekend Seminar on Astrophysics, Bildungszentrum Butenschoen-Haus in Landau (Pfalz), 8. March; "Mysterious Quasars", "Internationale Amateur-Sternwarte Gamsberg/Namibia", Schriesheim, 19. Apr.; "Sharp Eyes for Deep Space", Starkenburg-Sternwarte Heppenheim, 22. Apr.; "The Sky in my Computer – Virtual Planetaria", GirlsDay, MPIA, 24. Apr.; "Mysterious Quasars", Astronomy on Sunday Morning, MPIA, 24. May; "Mysterious Quasars", Planetarium Mannheim, 6. Sep.; "Galaxies and Terabytes – Optical Astronomy in the Era of Giant Telescopes", BOGy Course, MPIA, 20. Oct.; "Mysterious Quasars", Starkenburg-Sternwarte Heppenheim, 25. Nov.; "Sharp Eyes for Deep Space", Fachhochschule Rüsselsheim, 12. Dec.

Oliver Krause: "HERSCHEL and Planck – Europe' new Space Observatories", Astronomy on Sunday Morning, MPIA, 15. June

Dietrich Lemke: "Back to the Moon", Starkenburg Sternwarte, Heppenheim, 18. March; "Are we alone in the Universe?", JVA, Lüneburg, 8. May; "400 Years of Telescopic Astronomy", Sternfreunde Nordenham, 9. Oct.; "Are we alone in the Universe?", Car Training Institute Conference, Berlin, 2. December

Rainer Lenzen: "Giant Optical Teleskopes: Past, Present, and Future", School talk, Annual Meeting of the Max Planck Society, Dresden, 26. June; "Heath radiation from Space: Infrared Astronomy", Astronomy on Sunday Morning, MPIA, July, and Planetarium Mannheim, 9. December

Klaus Meisenheimer: "VLT – das largest Telescope on Earth", Ravensburg Telescope Meeting, 27. September

Hans-Walter Rix: "The Birth of Galaxies and the Large-scale Distribution of Matter", Talk Series on Cosmology and Astrophysics, DLR, Köln-Porz, 15. Apr. and Karl Rahn Academy, Köln, 16. Apr.; "Galaxies – their Birth from Nothingness",Astronomy on Sunday Morning, MPIA, 8. June; "How Light Came into the Universe", Explore Science, Mannheim, 9. June; "Our new View of the Milky Way", Explore Science, Mannheim, 9. June

Hermann-Josef Röser: "The Quest for Distant Clusters of Galaxies", School talk, MPG General Assembly, Dresden, 8. June; Presentation of the MPIA at the MPG Work's Committee in Lüneburg (22. June)

Johny Setiawan: "Planets Around Young Stars", Board of Trustees' Meeting, MPIA, 22. Feb.; "Extrasolar Planets", Astronomy on Sunday Morning, MPIA, 20. July; "Astronomy: a culture, science and philosophy for the humanity", Asian Science Camp: 3. – 9. August

Jürgen Steinacker: "The Unsolved Riddle of the Giant Stars", Astronomy on Sunday Morning, MPIA, 22. June, and Planetarium Mannheim, 4. November

Roy van Boekel: Talk in the Duch Cosmological Society "Triangulum", Heidelberg

Publications

In Journals with Referee System

Adelman-McCarthy, J. K., M. A. Agüeros, S. S. Allam, C. Allende Prieto, K. S. J. Anderson, S. F. Anderson, J. Annis, N. A. Bahcall, C. A. L. Bailer-Jones, I. K. Baldry, J. C. Barentine, B. A. Bassett, A. C. Becker, T. C. Beers, E. F. Bell, A. A. Berlind, M. Bernardi, M. R. Blanton, J. J. Bochanski, W. N. Boroski, J. Brinchmann, J. Brinkmann, R. J. Brunner, T. Budavári, S. Carliles, M. A. Carr, F. J. Castander, D. Cinabro, R. J. Cool, K. R. Covey, I. Csabai, C. E. Cunha, J. R. A. Davenport, B. Dilday, M. Doi, D. J. Eisenstein, M. L. Evans, X. Fan, D. P. Finkbeiner, S. D. Friedman, J. A. Frieman, M. Fukugita, B. T. Gänsicke, E. Gates, B. Gillespie, K. Glazebrook, J. Gray, E. K. Grebel, J. E. Gunn, V. K. Gurbani, P. B. Hall, P. Harding, M. Harvanek, S. L. Hawley, J. Hayes, T. M. Heckman, J. S. Hendry, R. B. Hindsley, C. M. Hirata, C. J. Hogan, D. W. Hogg, J. B. Hyde, S.-i. Ichikawa, Z. Ivezic, S. Jester, J. A. Johnson, A. M. Jorgensen, M. Juric, S. M. Kent, R. Kessler, S. J. Kleinman, G. R. Knapp, R. G. Kron, J. Krzesinski, N. Kuropatkin, D. Q. Lamb, H. Lampeitl, S. Lebedeva, Y. S. Lee, R. F. Leger, S. Lépine,

M. Lima, H. Lin, D. C. Long, C. P. Loomis, J. Loveday, R. H. Lupton, O. Malanushenko, V. Malanushenko, R. Mandelbaum, B. Margon, J. P. Marriner, D. Martínez-Delgado, T. Matsubara, P. M. McGehee, T. A. McKay, A. Meiksin, H. L. Morrison, J. A. Munn, R. Nakajima, E. H. Neilsen, Jr., H. J. Newberg, R. C. Nichol, T. Nicinski, M. Nieto-Santisteban, A. Nitta, S. Okamura, R. Owen, H. Oyaizu, N. Padmanabhan, K. Pan, C. Park, J. Peoples, Jr., J. R. Pier, A. C. Pope, N. Purger, M. J. Raddick, P. Re Fiorentin, G. T. Richards, M. W. Richmond, A. G. Riess, H.-W. Rix, C. M. Rockosi, M. Sako, D. J. Schlegel, D. P. Schneider, M. R. Schreiber, A. D. Schwope, U. Seljak, B. Sesar, E. Sheldon, K. Shimasaku, T. Sivarani, J. A. Smith, S. A. Snedden, M. Steinmetz, M. A. Strauss, M. SubbaRao, Y. Suto, A. S. Szalay, I. Szapudi, P. Szkody, M. Tegmark, A. R. Thakar, C. A. Tremonti, D. L. Tucker, A. Uomoto, D. E. Vanden Berk, J. Vandenberg, S. Vidrih, M. S. Vogeley, W. Voges, N. P. Vogt, Y. Wadadekar, D. H. Weinberg, A. A. West, S. D. M. White, B. C. Wilhite, B. Yanny, D. R. Yocum, D. G. York, I. Zehavi, D. B. Zucker: The Sixth Data Release of the Sloan Digital Sky Survey. The Astrophysical Journal Supplement Series 175, 297-313 (2008)

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Araya, E. D., P. Hofner, W. M. Goss, H. Linz, S. Kurtz, L. Olmi: A Search for H_2CO 6 cm emission toward young stellar objects. III. VLA observations. The Astrophysical Journal Supplement Series 178, 330-338 (2008)

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Bouy, H., E. L. Martín, W. Brandner, T. Forveille, X. Delfosse, N. Huélamo, G. Basri, J. Girard, M. R. Zapatero Osorio, M. Stumpf, A. Ghez, L. Valdivielso, F. Marchis, A. J. Burgasser, K. Cruz: Follow-up observations of binary ultra-cool dwarfs. Astronomy and Astrophysics 481, 757-767 (2008)

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The Max Planck Society for the Promotion of Sciences was founded in 1948. It operates at present 82 Institutes and other facilities dedicated to basic and applied research. With an annual budget of around 1.5 billion € in the year 2008, the Max Planck Society has about 13 000 employees, of which 4700 are scientists. In addition, annually about 11 850 junior and visiting scientists are working at the Institutes of the Max Planck Society.

The goal of the Max Planck Society is to promote centers of excellence at the forefront of the international scientific research. To this end, the Institutes of the Society are equipped with adequate tools and put into the hands of outstanding scientists, who have a high degree of autonomy in their scientific work.

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