Max Planck Institute for Astronomy

Heidelberg-Königstuhl

Annual Report 2007

MAX-PLANCK-GESELLSCHAFT

Cover Picture:

The Crab Nebula Messier 1 is located in the constellation Taurus at a distance of 6300 light years. It is the still rapidly expanding remnant of the supernova explosion of a star with about ten solar masses. The explosion was observed and recorded AD 1054 by Chinese astronomers.

The image is a three-colour composite of exposures taken with the blue-sensitive Large Binocular Camera at the prime focus of the left 8.4 meter mirror of the LBT. The field shown is 24.5 arcminutes wide.

Credits: Vincenzo Testa, LBTO

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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 2007 has brought a rich scientific harvest at topics ranging from the structure of the Milky Way to exoplanets.

There was also good, steady progress on crucial, upcoming facilities, including the LBT's first binocular observations, second generation VLTI instruments and JWST instrumentation, laying the foundation for future astronomical discoveries.

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.

Hans-Walter Rix, Thomas Henning

Heidelberg, August 2008

I. General

I.1 Scientific Goals

At the Max Planck Institute for Astronomy (Fig. I.1) research is aimed at exploring and understanding the nature and evolution of planets, stars, galaxies and the Universe as a whole. This is done 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 modeling. The MPIA focuses its observational capabilities on the optical and infrared spectral regions, taking a leading role in both ground-based and space-borne instrumentation.

The research at the MPIA is organized within two scientific departments: Galaxies and Cosmology, and Planet and Star Formation. In addition to the long-term staff in these departments, there are seven independent Junior Research Groups (four Emmy Noether groups supported by the German Science Foundation DFG, and three groups supported by the Max Planck Society). There are 56 junior and visiting scientists and 50 PhD students currently working at the institute. Strong ties exist between the Institute and the University of Heidelberg, with its new 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, but even the instrumentation and 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 spectral region.

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

Galaxies and Cosmology

The "Realm of Galaxies"

We know that the Universe was rather "simple" and nearly homogeneous shortly after the Big Bang, yet at the present we see 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 can, however, only be understood if it is assumed to be driven by gravitational instabilities arising 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, of gas and dust, all embedded in halos of dark matter. As Edwin Hubble already realized 70 years ago, these "island universes" do not show the variety of morphology (or visual appearance) and structure that seem physically possible. On the one hand, the variety of galaxies seems vast: galaxies as an object class span ten orders of magnitudes 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.

That 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 the fundamental question of galaxy formation and a central issue of cosmology.

In principle, there can be three broad lines of explanation for the limited variety 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 pursueing ultimately address, when and where any of these three mechanisms plays a role.

Some of the specific questions beeing persued 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?
- 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 happen?
- 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; the comparison of observations with physical models. The observational capabilities for the field require survey telescopes, large telescopes for sheer photon collecting of faint sources, and interferometric techniques to achieve high spatial resolution. Comprehensive studies of galaxy evolution require observations from the X-rays to the radio wavelengths.

MPIA has been an important partner in several of the surveys that have brought, or promise to bring, breakthroughs: the Sloan Digital Sky Survey (SDSS and SEGUE) for the Milky Way and Local Group, to be followed by the PanSTARRS.1 survey in 2008 – and just this 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 to 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 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 which have to be answered. 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.

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 systems 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, both in the low and high stellar mass regime. Observations with space observatories such as Iso and Spitzer, 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 the objects? What is the composition of their atmospheres? These are among the burning questions which are attacked by MPIA scientists.

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 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 provide 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.

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 are providing 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 Planet finder instrument.

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 Brown Dwarfs 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. The 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, the largest observatory on the European continent, had been the central focus of the MPIA, and the 2.2 and 3.5m telescopes are still scheduled for competitive observing programs. Since 2005 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 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, with commissioning well advanced and the camera ready to be offered for the first science programs. The MPIA also uses its 2.2m telescope on La Silla, Chile, operated by the European Southern Observatory (Eso), with 25 percent of the time available to MPG researchers.

The MPIA has a prominent and successful tradition of developing and building instruments for ground-based and space-based astronomical observations. Ground- and space-based observations are, almost by necessity, com-

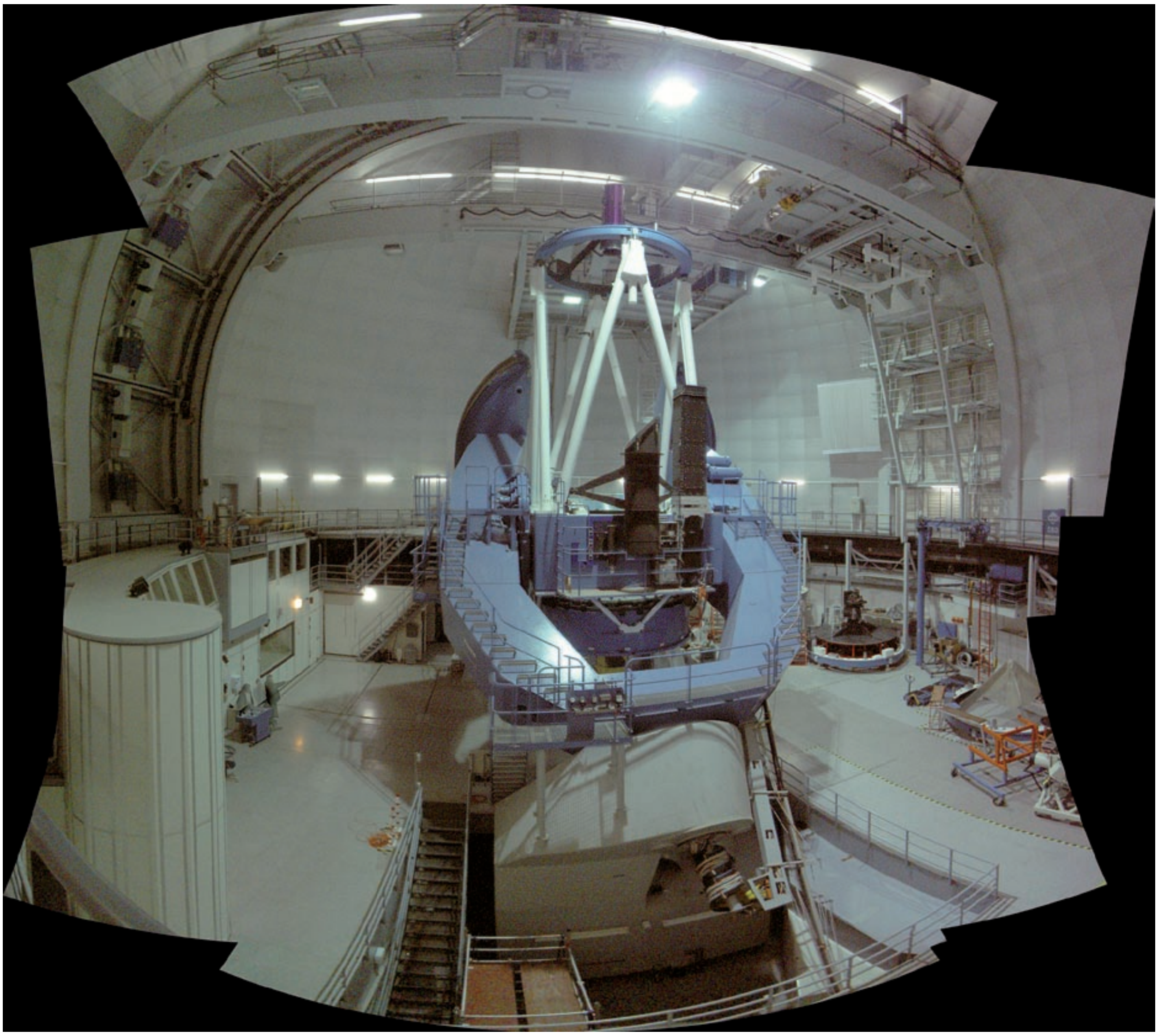


Fig. I.2: The 3.5 m telescope on Calar Alto.

plementary. 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 the atmosphere absorbs the radiation or generates a bright background, as it is the case, for example, in wide regions of the infrared spectral regime.

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 world's first Infrared Space Observatory of the European Space Agency ESA, was lead by the MPIA. From 1996 to 1998, it acquired excellent data, particularly in the previously inaccessible farinfrared range. The knowledge gained with ISO has enabled the MPIA's prominent role in new 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 8 m-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 new large telescopes and scientific instruments, 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 now 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 usage 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 has intensified its collaboration to the international PanSTARRS1 (PS1) project, which grants full access rights to the data from a 1.8 m wide-field telescope on Haleakala/Maui. The first Gigapixel Camera for this telescope was installed in August 2007.

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).

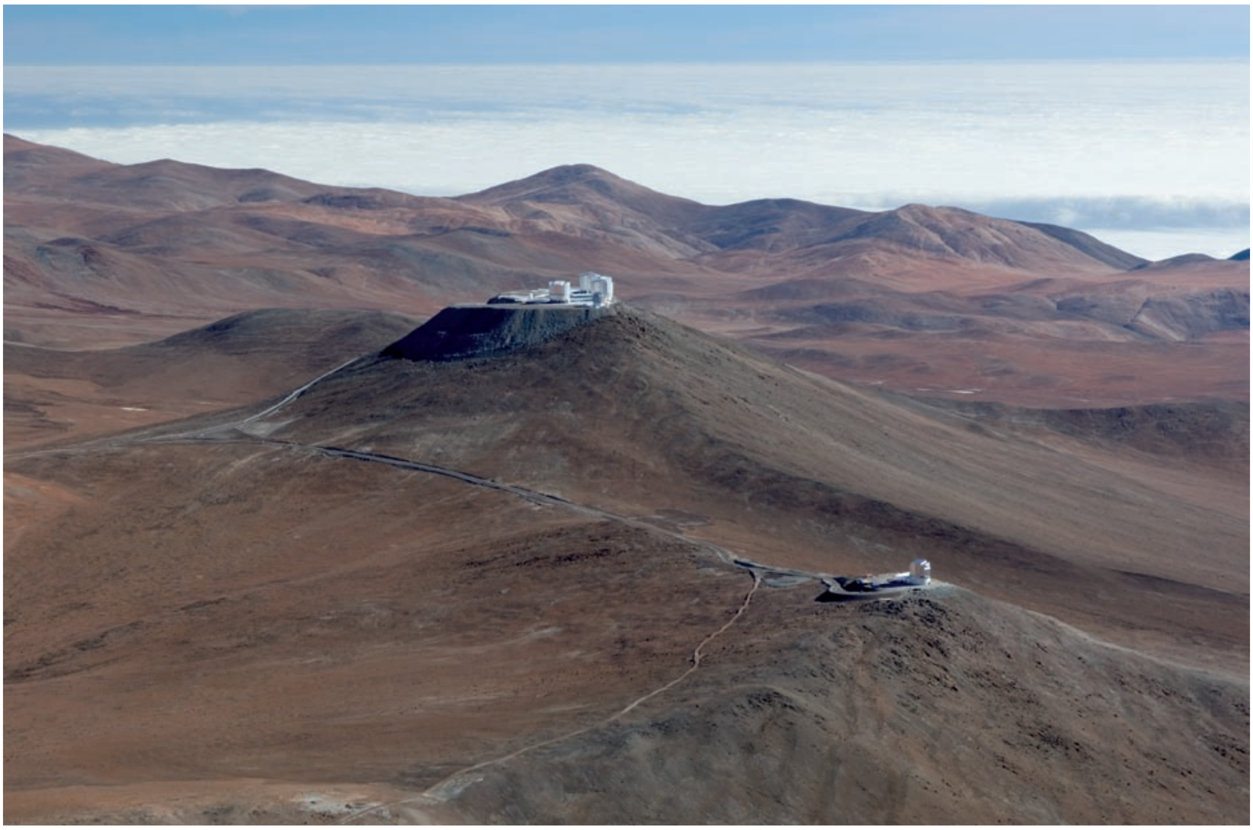


Fig. I.3: The Very Large Telescope, located in the Northern Chilean Andes. (Image: ESO)

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

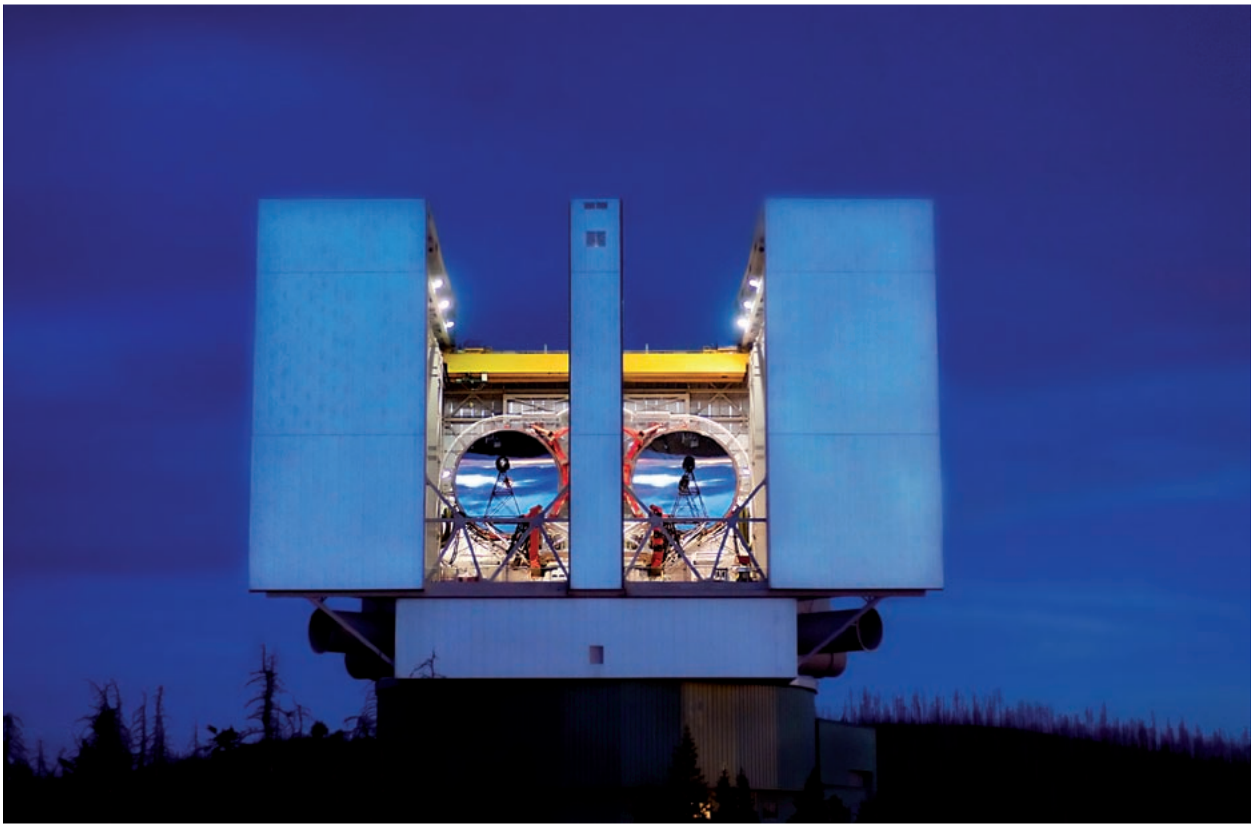
VLTI instrumentation

In 2007 the differential delay lines for the dual-feed VLTI system **Prima** were being prepared to be installed on Cerro Paranal, Chile. They 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 on 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 participates in the second generation VLTI projects Matisse and Gravity. **Matisse** is a successor of the very successful Midi instrument built by the MPIA and 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 the circumstellar environments.

Gravity is the successor of Prima. Like Matisse it will combine four VLT 8.2 m telescopes, but in the near-infrared. The Gravity consortium is led by MPE Garching; partners are the 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 imaging stars and gas in obscured regions of AGNs, star forming regions, or protoplanetary disks.

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



High-fidelity imagers

After leaving the MPIA integration hall, **Lucifer 1**, the first of two identical mid-infrared cryogenic imaging cameras and multi-object spectrographs for the LBT has just arrived on Mt. Graham at the time of writing. This instrument built together with the Landessternwarte Heidelberg, the MPE Garching, the University of Bochum, and the Fachhochschule for Technology and Design Mannheim will be ready for scientific exploitation in January 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 $0\overset{'}{.}5 \times 0\overset{'}{.}5$. Adaptive optics will also permit users to achieve spectral resolving powers of several 10 000. Scientific applications for the multi-mode Lucifer instruments are many, such as 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 currently under construction in its integration hall 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 $10\overset{''}{.}5 \times 10\overset{''}{.}5$ field of view in the $1 - 2.4\,\mu$m 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 and the Laboratoire d'Astrophysique in Marseille, the MPIA coleads 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 MPIA's 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 $15\overset{'}{.}4 \times 15\overset{'}{.}4$ 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 $4\,K \times 4\,K$ 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.

Instruments for telescopes of the next generation

In preparation for the future, MPIA participates in studies for instruments for the 42 m E-ELT telescope: Midir and Micado. The **Midir** 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.

The **Micado** concept 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 a 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 $z = 1$.

Instrumentation for Space-based Astronomy

The experience gained with the development of the Isophot instrument on Iso was decisive for the MPIA's crucial and prominent role in the construction of **Pacs**, the infrared camera and spectrometer which will operate aboard Herschel (Fig. I.5), the European Infrared

Fig. I.5: The European Herschel Infrared Observatory, to be launched in 2009.

Observatory (Chapter IV.5). 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 launch is scheduled for 2009.

The MPIA is the leading institute in Germany for the development of instrumentation for the James Webb Space Telescope (JWST, Fig. I.6), the successor to the Hubble Space Telescope. The JWST will be equipped with a folding primary mirror about 6 m across as well as three focal-plane instruments. A part of a European consortium, MPIA develops the cryo-mechanics for the positioning of the optical components in one of the three focal-plane instruments called **Miri**. This instrument, designed for the mid-infrared range from 5 to 28 micron, consists of a high-resolution camera and a spectrometer of medium resolving power. Miri will be built half by American and half by European institutes.

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 the cryo-mechanics. This contribution will provide the astronomers at MPIA with further excellent opportunities for high-resolution and highly sensitive infrared observations. For the development of the precision-optical hearts of Miri and Nirspec, the MPIA is also closely cooperating with Carl Zeiss Optronics, Oberkochen.

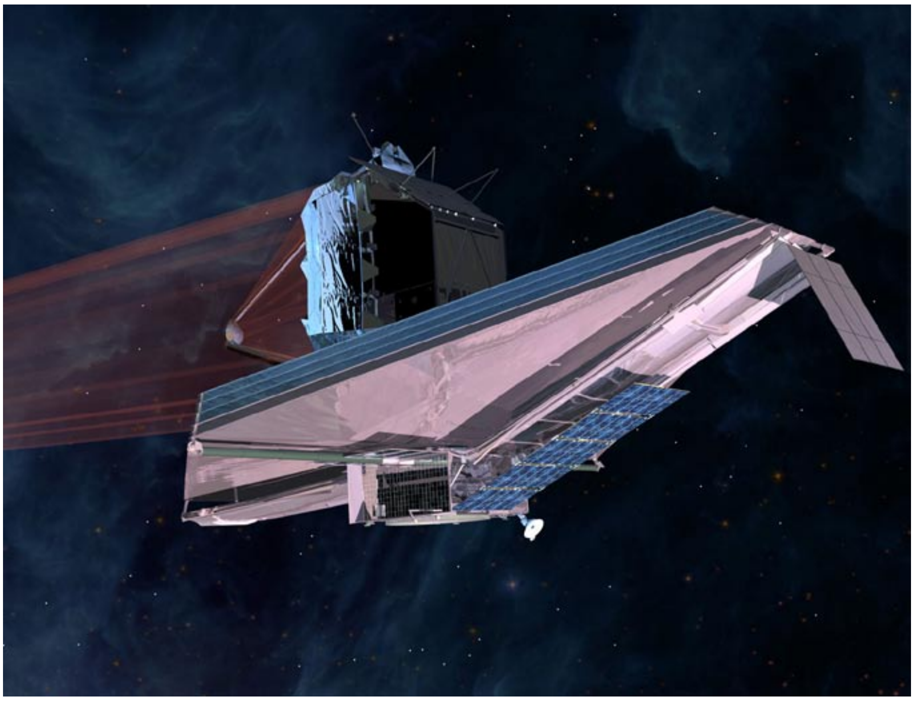
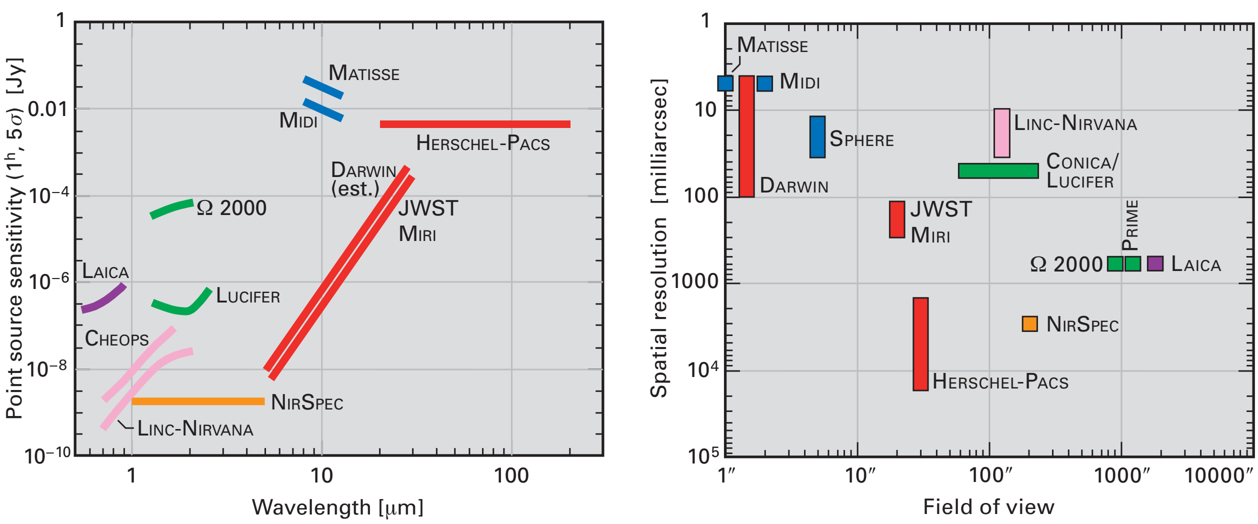


Fig. I.6: Foreseen design of JWST, the successor of the HUBBLE Space Telescope to be launched in 2013, with the large primary mirror and the characteristic sun shield.

The MPIA is also leading a major data analysis aspect of ESA's **GAIA** project, a space observatory scheduled for launch between 2010 and 2012. GAIA will be the successor to 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, however, GAIA need not be provided with an input catalogue, but will measure systematically all accessible objects. An 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).

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

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



redshifts $z = 2$, 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 extra-galactic sky at a spatial resolution of 0.3″. It will also yield medium resolution ($R = 400$) 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 Visions 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 and/or later detailed studies of their host stars. Plato will observe 100,000 stars with a photometric precision better than 1ppm/month of observing and more than 500,000 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 (557 square degrees). The required short focal length led to the concept of a bundle of 28 identical 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, where 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 two orders of magnitude sensitivity advantage over current far-infrared facilities like Herschel. Spica is led by the Japanese Space Agency Jaxa. Europe will participate with the Spica Far Infrared Instrument Safari, the telescope mirror, and support to the ground segment.

Figure 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 Cooperations

The MPIA's location is strategic: Heidelberg has become one of Germany's foremost centers of astronomical research. Cooperation with the Kosmophysik department of the MPI für Kernphysik and with the institutes of the Center for Astronomy Heidelberg (ZAH), established on January 1st 2005, is manifold: the ZAH consists of the Landessternwarte, the Astronomische RechenInstitut, and the Institut für Theoretische Astrophysik der Universität. At present, this is particularly true for the long-standing DFG-Sonderforschungsbereich No. 439, "Galaxies in the Young Universe", in which all the institutes named above are participating. There is also a close cooperation within the "International Max Planck Research School" (IMPRS) for Astronomy and Cosmic Physics (see Section I.4).

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, is extensive. An overview is given in Fig. I.8.

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 trend-setting 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 VLTI-instruments 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, and participation in preparing the DARWIN space mission. 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 Insitut for Solar Physics in Freiburg, the MPI for Extraterrestrial Physics in Garching, the MPI for Radio Astronomy in Bonn, the University of Hamburg, and the I. Physical Institute of the University of Cologne.

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

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

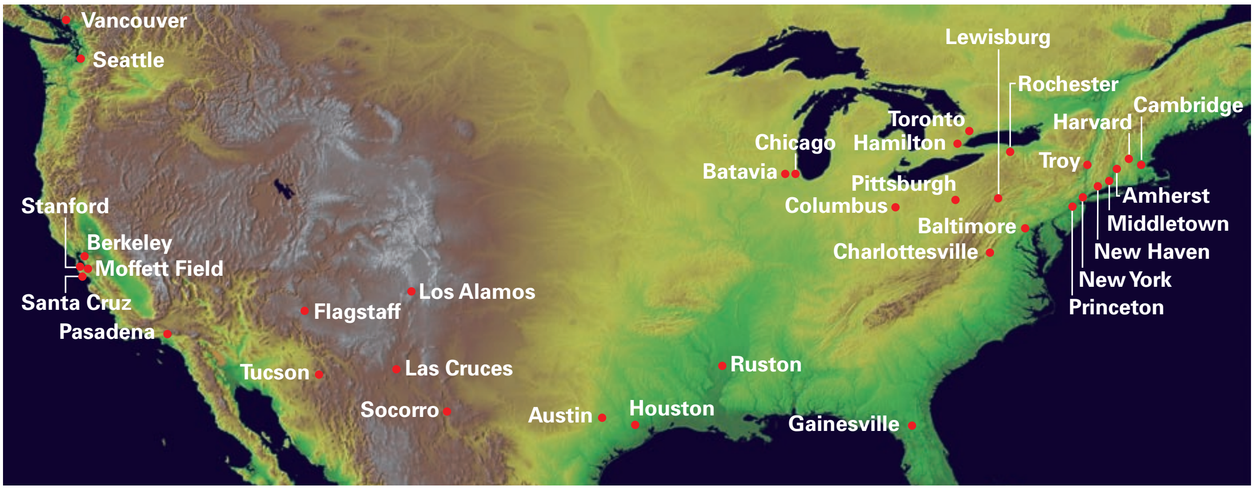
OPTICON: A network of all operators of major telescopes in Europe, financed by the European Union. Its first main goal is to optimize use of the scientific-technical infrastructure in order to increase scientific results and reduce costs. OPTICON other main goal is to coordinate technology development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

Together with the Universities of Braunschweig, Chemnitz, Dresden, Jena, and Leiden, the MPIA is participating in the DFG Research Group "Laboratory Astrophysics". This field of research is being pursued by the MPIA group at the University of Jena.

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 GEMS surveys. Additional partners are: University of Durham, Institute for Astronomy in

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

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



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

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

Edinburgh, University of Oxford, University of Groningen, Osservatorio Astronomico Capodimonte in Naples, and Eso in Garching.

Planets: A "research training network" of the EU to study theoretical and empirical aspects of the formation and evolution of protoplanetary disks and planets.

Spitzer Legacy Programs: The Nasa infrared telescope Spitzer (formerly Sirt-F) has started its planned two and a half year mission on August 25th, 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 the 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 the 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 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, focusing for example on Milky Way structure was approved. SDSS-II / Segue, especially with its focus on Milky Way structure, is now well underway to its completion in mid 2008.

I.4 Teaching and Public Outreach

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

Even in their early semesters, 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 topics, including the analysis of observational data or numerical simulations as well as work on instrumentation. These practical courses offer the students an early, practically-orientated insight into astrophysical research, particularly in view of a later diploma or doctoral thesis.

The International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics, which was established in July, 2004 by the Max Planck Society and the University of Heidelberg, offers 40 PhD students from all over the world a first-class three year education 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 MPIA's mission also includes communicating the results of astronomical research to the general public. Members of the MPIA give talks at schools, adult education centers and planetaria. They also appear at press conferences or on radio and television programs, particularly 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. In cooperation with the Landessternwarte, a one-week teacher training course for teachers of physics and mathematics in Baden-Württemberg is held regularly in autumn at the MPIA.

A special highlight in the year under report has been the "*Nacht der Wissenschaft*" on November 10^{th}, when throughout the region a large number of institutions opened their doors to the public until after midnight. Due to the isolated location of the Königstuhl and to the many alternatives offered downtown, we participated in this initiative without expecting much attention. Instead, the rush of people was overwhelming, as described in Chapter V.2. In addition, our new initiative for the general public, a series of eight "*Public Lectures on Sunday Morning*", always packs the large auditorium at the MPIA.

As in the years before, the one week long practical course which was offered to interested schoolboys and -girls (BOGy), was immediately booked out. Applicants came from all-over the country.

As in the years before, the MPIA participated in the 2007 *Girls' Day*, a nationwide campaign intended to encourage schoolgirls to learn about professions that are still mainly male-dominated. At various stations about 60 schoolgirls obtained a general idea of the work at an astronomical institute (Chapter V.1).

Now in its 46^{th} year, the monthly astronomical 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 this field.

II. Highlights

II.1 Youngest Extrasolar Planet Discovered in a Circumstellar Disk

The question of how planets are created has always fascinated astronomers. Even the very discovery of an extrasolar planet orbiting around a sun-like star provided this astronomy research branch an enormous observational and theoretical impetus. At the MPIA the search for extrasolar planets and the numerical simulation of planetary formation is now an important research priority.

Within the context of a long-term research program, a team at the institute has now found an eight to ten million year old star, the youngest exoplanet so far, circling around TW Hydrae. This discovery delivers for the first time an upper limit to the time it takes for the formation of Jupiter-sized planets. Because the central star still possesses a circumstellar disk of gaseous dust, this is also the first direct evidence that planets indeed form in disks of this type. A further companion to a roughly 100 million year old star was found at the same time.

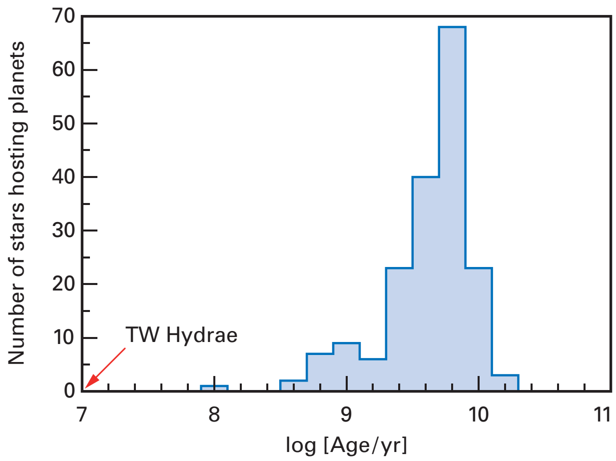


Fig. II.1.1: Age distribution of known extrasolar planets as of the end of 2007.

Until now, the most successful method of searching for and discovering exoplanets has been the Doppler or radial velocity method. It relies on the Doppler effect which alternately shifts light to larger and smaller wavelengths when the light sources and receivers move away or toward each other. Should a planet orbit around a star, then both bodies rotate around a common gravitational center which generally is located within the star. The planetary orbit thus causes a periodic stellar movement which expresses itself in its spectrum as a periodically changing Doppler-shift in the spectral lines, thus betraying the existence of an otherwise not directly visible planet. The measurement data directly deliver the planet's orbital period and a lower limit for its mass. The true mass may be calculated when the orbital inclination against the celestial plane is known.

By the end of 2007 approximately 250 extrasolar planets had been discovered. They all orbit stars that are at least 100 million years old (Fig. II.1.1). For various reasons, the Doppler method could not be used where the stars are younger. For example, most young stars rotate very rapidly. This spreads the spectral lines and reduces the precision with which the Doppler shift can be measured. Add to this younger stars' often strong and periodically varying activity, such as pulsations, orbital oscillations, and the occurrence of star spots. All these phenomena make it more difficult to search for periodic variability among the spectra.

Nevertheless, an MPIA research team began searching for planets among young stars: in 2003, the program was started at the Fibre-fed Extended Range Optical Spectrograph (FEROS) on the MPG/ESO 2.2-m telescope at La Silla in Chile. The program covered roughly 200 stars with ages between 8 and 300 million years and a distance of roughly 500 light years. Roughly 30 % of these stars showed surprisingly diminished stellar activity and relatively diminished orbital speeds. Thus they were especially well suited for the radial velocity method. The radial velocities could be measured with an accuracy of ± 10 m/s so that it was easy to prove the existence of particularly massive planets – so-called "white Jupiters" – in very close proximity to their central star.

The TW Hydrae Planet

Usually, to determine the Doppler shift of a star, very many absorption lines within its spectrum are used simultaneously. For the younger stars, on the other hand, the MPIA team excluded those spectral lines which were strongly affected by stellar activity. Among these were the CA II H & K, Hα and Hβ, as well as He I and Na I lines. Periodic Doppler shifting was then searched for by comparing a theoretical spectrum against the roughly 1300 remaining lines.

The team finally made a discovery at TW Hydrae, a star that is 180 light years away. It is among the best studied young stars in the sun's environment. It has a mass of roughly 0.7 sun masses, a luminosity of 0.2 solar luminosities, and it is between 8 and 10 million years old. Images taken by the HUBBLE space telescope showed

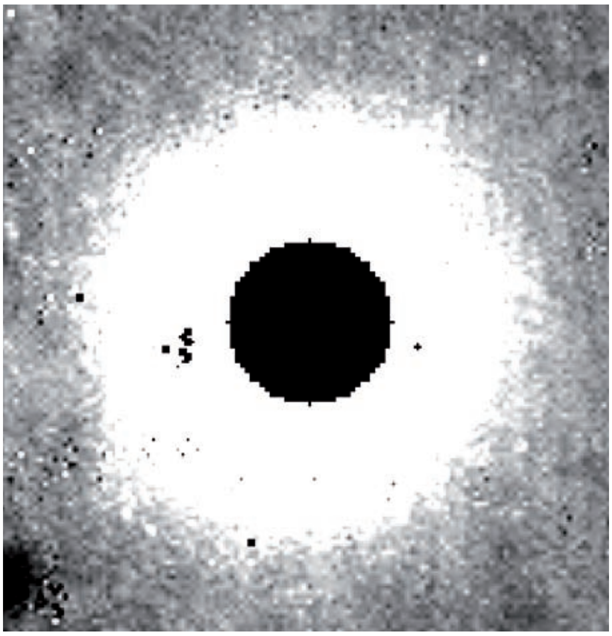


Fig. II.1.2: TW Hydrae's dust disk taken by the WFPC2 camera on board the HUBBLE space telescope. The central star is covered by a chronographic disk. (image: D. E. Trilling, NASA/ESA)

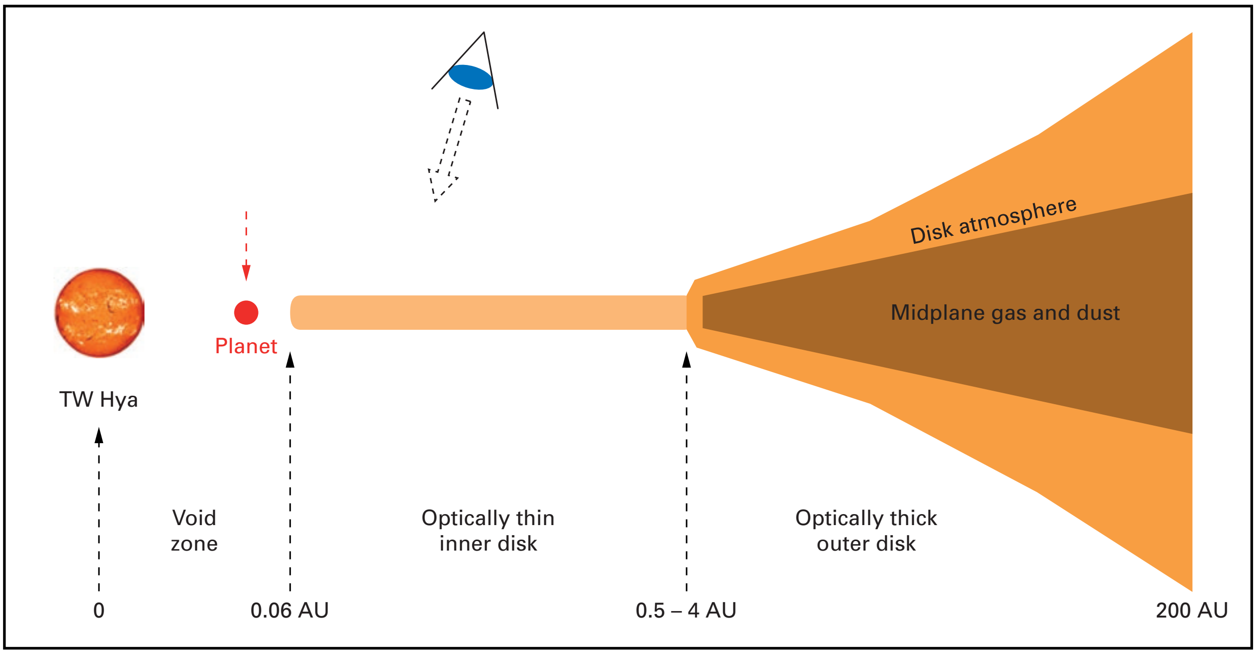
an expanded dust disk which is almost perpendicular to our sight (Fig. II.1.2). Further observations led to the inference that its angle of inclination to the visual ray is roughly 7 degrees. In addition, examinations in near- and mid-infrared as well as in millimeter ranges had unveiled further disk characteristics (Fig. II.1.3): it has a "void" in its center, the inner edge of which is located at approximately 0.06 astronomical units. An optically thin disk connects towards its exterior which then passes into an optically thick disk at a distance of 0.5 to 4 AU.

Already in 2005 there was speculation that a planet was likely responsible for the disk's structure, although it avoided detection. The MPIA team has now found a body that orbits its star in an extremely short interval.

The spectra revealed Doppler fluctuations with periods of 0.78, 1.36, and 3.56 days. While the first two were not deemed significant, the third can be traced to the gravitational effect of a non-visible planet which orbits around the star in 3.56 days at a distance of 0.04 AU (Fig. II.1.4). The planet therefore moves inside the hole along the inner edge of the thin disk. If one assumes that the planet's orbital plane and the circumstellar disk are coplanar, then it turns out that the mass of the planet is 9.8 Jupiter masses.

To exclude stellar activity as the reason for this linear shift, the astronomers conducted several tests. Star rotation and non-radial pulsations result, for example, in the line *form* changing periodically and thus simulating a variable radial speed. An exact analysis revealed that this is not the case with TW Hydrae. The astronomers also used a so-called bi-sector analysis to search for a correlation between radial speed variation and parameters which would normally point to stellar activity. No significant correlation could be found, leaving an orbiting planet as the most likely reason for the periodically variable Doppler effect.

Fig. II.1.3: The structure of the disk surrounding TW Hydrae, as revealed by observations in several wavelength regions.



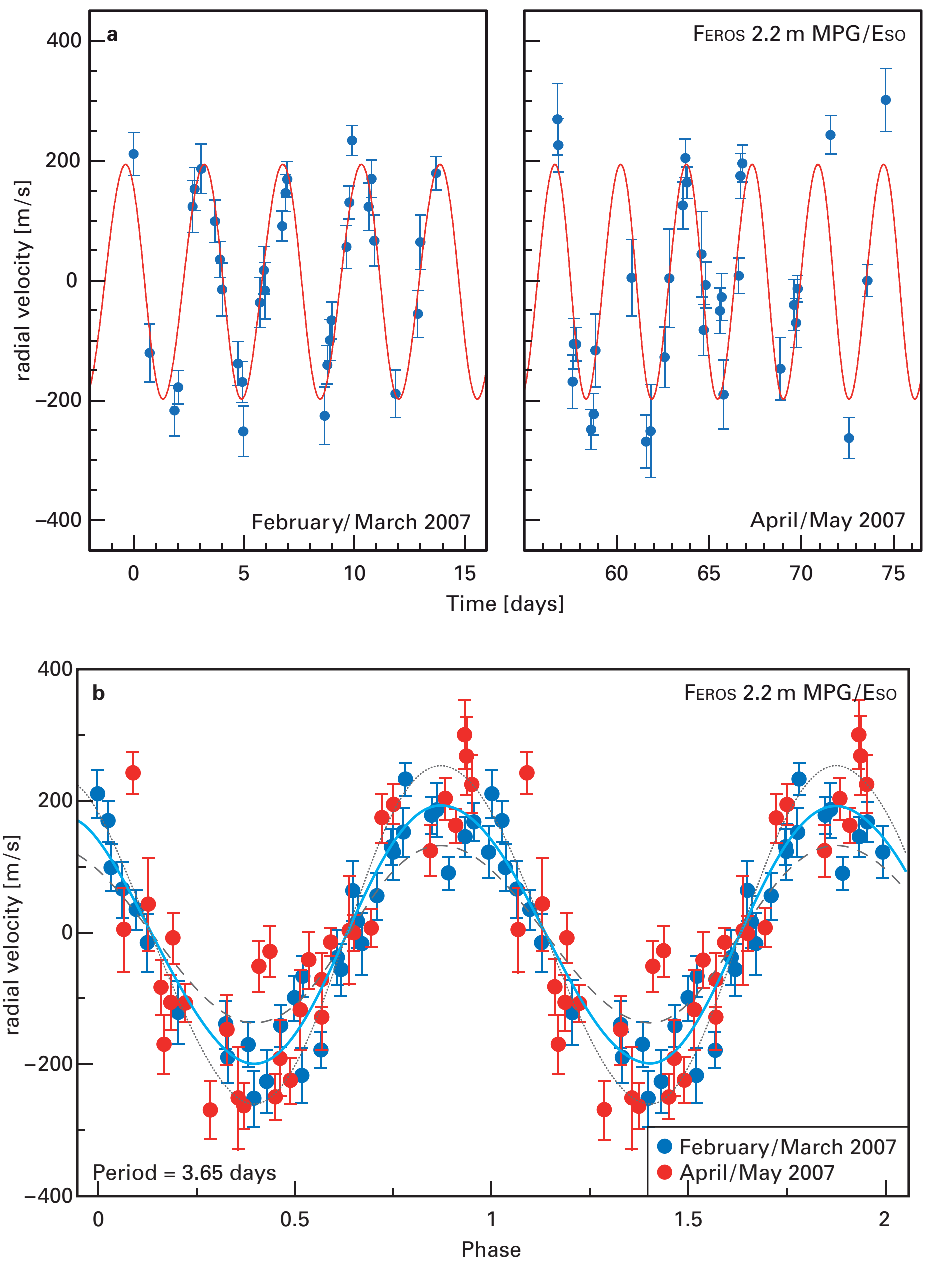


Fig. II.1.4: The radial velocity in the spectrum of TW Hydrae was measured over a total of 32 nights during the Spring of 2007: Its variation of 3.56 days is caused by the planet's orbit.

Rapid Planet Formation and Migration

The discovery of the planet that has been named TW Hydrae b provides important new reference points for the theory of planetary formation. Until now, it was known from statistical analyses that the mean life-span of circumstellar disks is several tens of million years. This is thus the maximum available period of time for the creation of planets in the disk. The observation of TW Hya b provides for the first time a true upper limit for the required time span of planetary formation: It could not have lasted longer than eight to ten million years. Thus TW Hya is an ideal touchstone for numeric models of planetary formation.

For one, TW Hya b marks out the time frame for planetary formation. Simultaneously, the planet renews the question for theoreticians as to how such a massive body can orbit its central star at such a short distance. To date, there are several of these hot Jupiters among the known exoplanets. According to currently accepted theory, none of them was formed there: there is never enough material present near the star and, furthermore, it is too hot there. One therefore assumed that the planets formed in the further outlying, cool and dense regions of the circumstellar disk. Subsequently, an exchange of the rotation impulse between the disk material and the planet leads to the latter slowly wandering in a spiral shaped orbit toward the central star.

Computer simulations conducted at the MPIA have shown that a planet forming within five astronomical units from its central star will, within a few thousand years, open a void in the disk (Annual Report 2006, p. 27). At the same time it wanders inward. After a few tens of thousand years, it will have cut its distance to the star in half and doubled its mass, because during its migration it accretes the surrounding dust.

Thus the decisive question: When and how does this wandering come to a halt? Is the reason for this the almost material free void at the disk's center? TW Hydrae b's orbit along the interior edge of the disk seems to support this hypothesis. Yet, this is not theoretically compelling. Whether additional braking effects – such as magnet fields or tidal forces – play a role, is currently a matter of research. In the final analysis an alternative theory is also being considered, according to which a planet is formed, like a star, through direct contraction and not through a gradual gathering of surrounding dust and gas. TW Hydrae b may in the future possibly provide further hints toward answers to these burning questions.

An additional planet around HD 70573

MPIA's astronomers were able to count a further success during their search program: they discovered a periodic Doppler shift with a period of 852 days at the 150 light year distant star HD 70573. Here too the bisector analysis showed no correlation with star activity signatures so that, again, the likeliest explanation is a non-visible planet. Because in this case the orbital inclination is unknown, only a lower limit of 6.1 Jupiter masses can be indicated for its mass. Here one assumes that the mass of the star – a G dwarf – is 1.0 solar masses.

HD 70573 is a member of the Hercules-Lyra Association, a local group estimated to be 200 million years old. An analysis of the stellar spectrum (equivalent width of the lithium line at 670.8 nm) yielded an age between 78 and 125 million years. Thus, this similarly aged planet is the second youngest known extrasolar planet after TW Hya b.

The discovery of a planet at HD 70573 is significant also because this star is part of a Spitzer space telescope research program (Spitzer/Feps Legacy Program) examining the relationship between planets and older dust disks (so-called debris disks).

Both of the described discoveries have shown that despite initial concerns, it is absolutely possible to prove that young stars have planets. This opens the door to completely new research inquiries into planetary formation. In addition to this program, the MPIA is now developing and building next generation observation instruments using other methods to track down extrasolar planets: direct imaging, astrometrical measurement of the apparent movement of the star in the sky, and the measurement of central star light intensity changes when the planet passes in front of it (transit photometry).

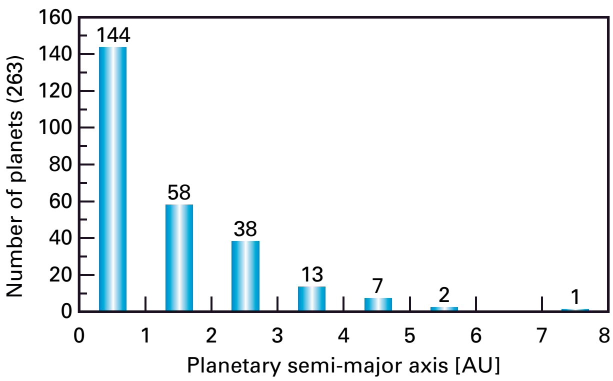
Johny Setiawan, Thomas Henning, Ralf Launhardt, André Müller, Patrick Weise, Martin Kürster

II.2 A Search for Extrasolar Planets Around 54 Nearby Stars

Until now not a single one of the approximately 250 extrasolar planets discovered by the end of 2007 could be unequivocally imaged; the overwhelming majority was found indirectly with the aid of the so-called radial velocity method. However, for planets orbiting at a great distance from the star, this method is very inefficient because of their long orbital period. An international team of astronomers, led by Wolfgang Brandner and Rainer Lenzen at MPIA as well as Beth Biller and Laird Close at the Steward Observatory in Arizona, has been searching with a special camera, the Simultaneous Differential Imager (SDI), for Jupiter-like planets orbiting 54 nearby, mostly young, stars. Although this has produced by far the most contrast-rich images of this type that have ever been taken from Earth or from space, astronomers have still been unable to find any planets. This result delivers strict upper limits for the distribution of massive exoplanets at distances beyond 5 AU from their central star.

Using the radial velocity method to prove the existence of extrasolar planets relies on the fact that a star and a planet orbit around their common center of gravity. This expresses itself in a periodic variation of the absorption lines in the star's spectrum (see Chapter II.1 in this annual report). In order to prove a planet for certain, one must therefore observe it for at least for one full rotation. For a planet at a distance of roughly 5 AU from its star (corresponding to our planet Jupiter), the period of rotation is already in the range of ten years. Thus, it is not surprising that most known exoplanets circulate their sun in very narrow orbits where the periods are in the range of days. By the end of 2007, only three planets were known to have a distance greater than 5 AU (Fig. II.2.1).

Fig. II.2.1: The distribution until the end of 2007 of known extrasolar planets in dependence on their large semiaxis (Source: exoplanet.eu).



The question remains, however: Does this finding involve a selection effect that depends on the observation, or are large gas planets truly a rarity at such great distances from their central star? The MPIA astronomers and their colleagues pursued this question in the new survey.

Searching for planets with NACO SDI

Recently, several instruments designed especially to prove the existence of companions to nearby stars were built around the world. Thus, since 2003, several observation campaigns have taken place to find exoplanets with the aid of cameras with adaptive optics; yet none of them has been successful.

Although adaptive optics have matured in the meanwhile, there is still the fundamental problem of superspeckles (granular structure in the created image) – a problem which hinders the discovery of exoplanets. Superspeckles are caused by an aberration in the instruments that slowly changes during observation. They randomly appear over a time scale of minutes and vary in wavelength. The result is a correlated speckle interference that is rather difficult to calibrate and difficult to remove from the data. The signal-to-noise ratio cannot be improved after a specific exposure time because the speckle interference is too high. Theoretical considerations show that because of this effect, a brightness contrast of 1000 between main stars and companions can not be exceeded, which leads to a considerable limitation on the discovery of extrasolar planets. Even the HUBBLE space telescope suffers from superspeckles. The source is temperature variation during exposure which leads to a change in the point spread function.

At the MPIA, a camera has been developed with which this problem can be considerably diminished. The instrument is the NACO SDI and was built expressly for the task of taking images of cool, faint objects in close proximity to a star. It operates according to the following principle: The camera includes an adaptive optic system (NACO) which eliminates blurring caused by turbulence in the earth's atmosphere. The additional SDI system splits the light of every individual star into four identical images in neighboring wavelengths. These lie inside and outside the infrared methane bands that are characteristic for low-mass objects (gas planets or some brown dwarfs). On suitable differential images of these four exposures, the main star disappears almost completely with its bright halo and the low-mass, cool companion becomes clearly discernible.

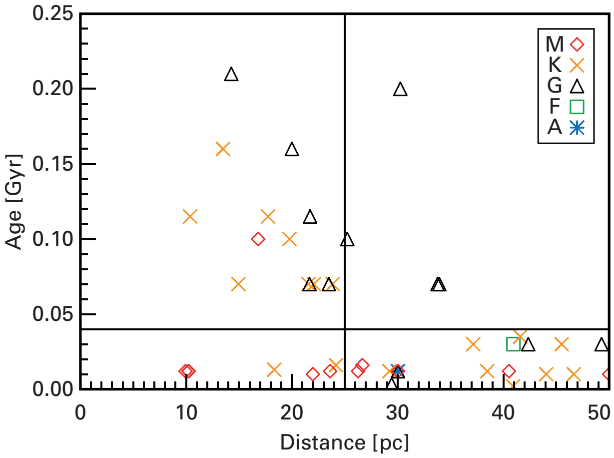


Fig. II.2.2: Age and distance of the stars observed in the survey.

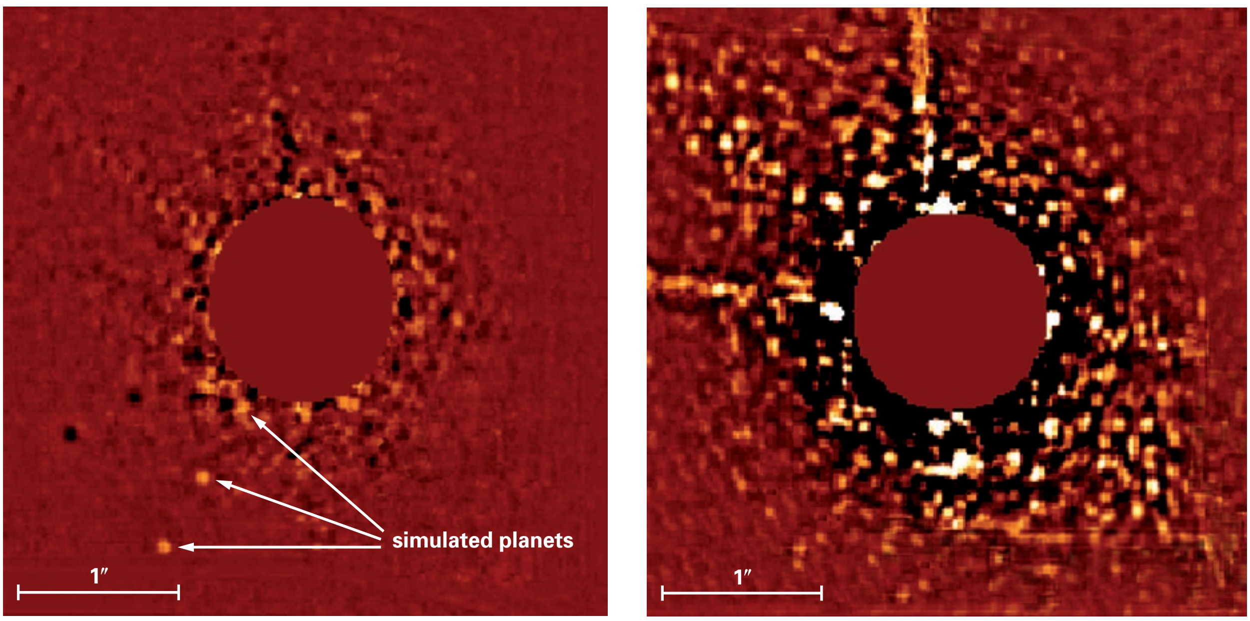
Even during the test phase, the NACO SDI system was able to achieve a significant discovery by separating the 12 light-year distant object, υ Indi B, into two T-dwarfs. Both components, υ Indi Ba and υ Indi Bb, are the nearest known brown dwarfs (Annual Report 2006, p. 22). Further successes followed. Thus in AB Dor C, a companion was discovered that is, sofar, the faintest and is only 0.16 arcseconds distant from the main star. And in Gl 86B, the only white dwarf in an exoplanetary system known sofar, the orbital movement could be proved. Furthermore, the second nearest brown dwarf was discovered. The object, designated as SCR 1845-6357B, is at a distance of 12.7 light years and orbits a low-mass star of spectral type M 8.5.

Rainer Lenzen, Wolfgang Brandner, and their team searched in a full-scale survey conducted between 2004 and 2006 for planets around a total of 54 stars. In their selection they concentrated on 45 young and near (up to 250 million years old and 160 light years distant) stars. More specifically, the stars that were up to 80 light-years away were younger than 250 million years and the stars up to 150 million light-years away were younger than 20 million years (Fig. II.2.2). The reason for the distinction is that planets cool after their formation, so that the brightness contrast between planet and central star (which impedes discovery) increases with age. To these 45 nearby, young stars, nine more stars were added: three for which the existence of planets had already been proven through the radial velocity method; four older stars which, at a distance of up to 65 light years, are very close; and two further distant (490 light years) very young stars.

Observations took place at the Very Large Telescope (VLT) as well as with a second camera at the Multiple Mirror Telescope (MMT) in Arizona. Each series of exposures was performed on two different camera rotation angles, which offered the advantage of being able to take an image of a possible star companion from two different locations on the detector. Thus it is easier to identify false planet images caused by noise.

The instrument's strength is documented in Fig. II.2.3. In the image on the left, showing exposures of AB Dor A (at a distance of 50 light years), the NACO-SDI exposures were reduced in two rotation angles according to all rules of the art. Furthermore, three artificial planet images at distances of 0.55, 0.85, and 1.35 arch seconds were fitted in the data. At a wavelength of 1.575 μm (*H*-Band), the planets are fainter than the star by a factor of 1000. At least both outer "planets" can be clearly identified.

Fig. II.2.3: Completely reduced images of star AB Dor A with three simulated companions. *Left:* data from NACO SDI, *right:* normal adaptive optics images.



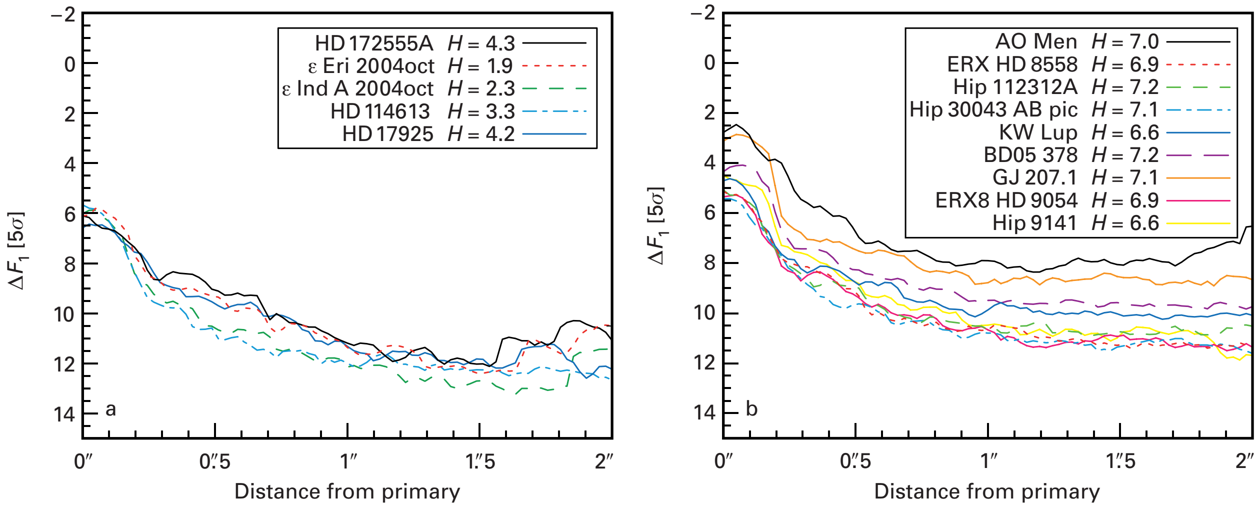


Fig. II.2.4: Brightness contrast achieved depending on distance to star. *a)* Stars with a brightness of $H < 4.5$, *b)* Stars with $7.5 > H > 6.5$.

This would not have been possible with a conventional exposure with adaptive optics (right).

In the end, the astronomers were not able to detect any companions to the 54 stars. However, even with this negative result, new insights can be extracted if one fully understands the sensitivity of the instrument. For this a strict analysis is required.

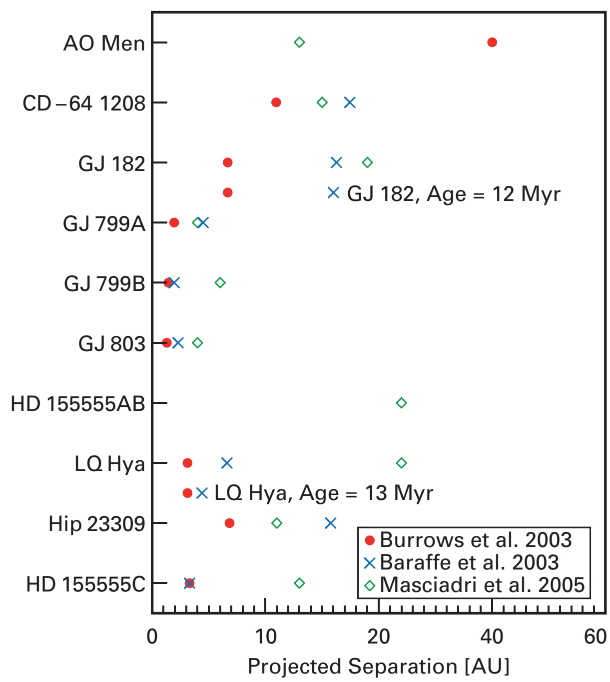
For one thing, the brightness contrast achieved in the images between star and planet was established in dependence on the mutual distance. This contrast is not dependent on the star's apparent brightness but is dependent on "Seeing" and thus requires an individual analysis of all images. These values were then compared to current models for exoplanet spectra. According to current theories, the temperature of a giant planet which is older than ten million years should have sunk to 800 K and it should possess a T 8 or later spectral type.

Fig. II.2.4 a is an example of stars which are brighter than 4.5 mag in the *H*-Band with the achieved brightness contrast having a significance of 5 σ. Accordingly, in a distance range of one half to one arcsecond, a contrast of 10 to 12 mag was achieved. This corresponds to intensity ratios of between 10,000 and 60,000 and thus surpasses the above-mentioned superspeckle-interference limit by more than one order of magnitude. These are currently the most contrast rich images of methane-rich companions that have ever been taken from space or earth. Stated differently, a brightness contrast of 10 mag at a distance of 0.5 arc seconds could be achieved for 45 percent of the stars in the survey. Fig. II.2.4b highlights the loss of contrast for stars with $7.5 > H > 6.5$.

These technical characteristics could then be compared with the mentioned models for planet spectra in order to make statements regarding the detection limits for these companions. Said more simply, the astronomers should have been able to discover a gas planet of at least five Jupiter masses at a distance of 24 AU from the star and a planet with at least ten Jupiter masses more than 9 AU from the star (Fig. II.2.5) – had there been one.

However, the distance of a planet projected on the celestial plane to the central star varies with its position on the orbit. Only twice per orbit does it reach the greatest angular distance from the star. In order to take this effect into account, the astronomers estimated the orbital movement of 10,000 hypothetical planets for each observed star whereby they varied the mass, the large semiaxis of its orbit, and its eccentricity within specific limits. In combination with the contrast curves (Fig. II.2.4), the probability of a possible discovery was determined for each star.

Fig. II.2.5: Minimal distance at which among ten selected stars a planet with five Jupiter masses would still be detectable.



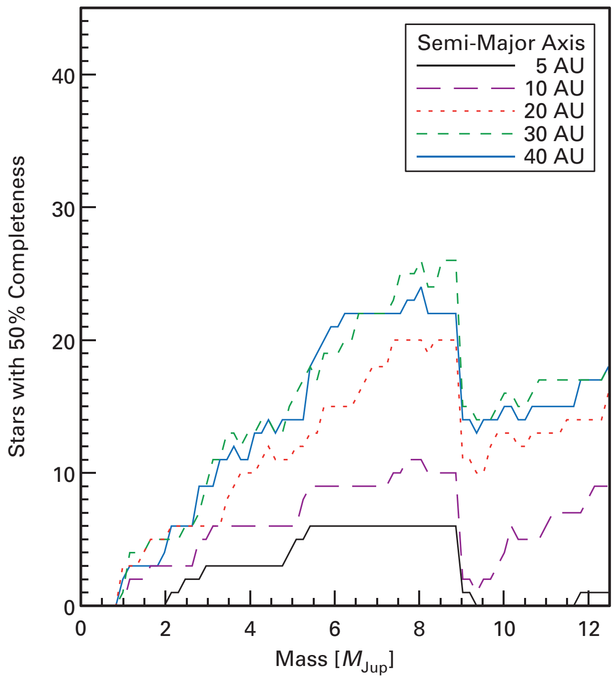


Fig. II.2.6: Planets with varying masses which should have been discoverable with a likelihood of 50 percent at varying minimal distances from a star.

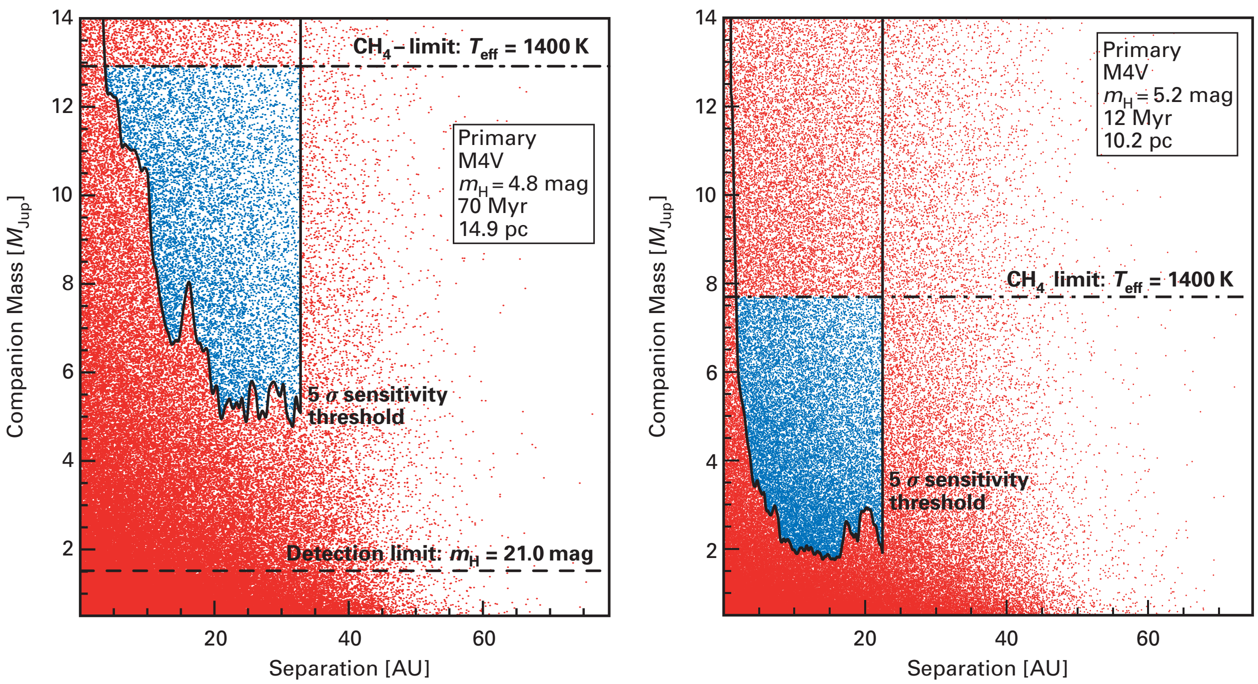
Fig. II.2.6 shows those areas in which the survey should have found, with a likelihood of at least 50 percent and a significance of ± 5 σ, a planet with an appropriate mass and major orbital axis. One sees that the survey is particularly sensitive for planets of 4 to 8 Jupiter masses and orbits of 20 to 40 AU. Young planets of more than 8 Jupiter masses are theoretically so hot, that they do not show any strong methane bands in their spectra.

Fig. II.2.7 shows, as an example, the minimal verifiable planet mass for two stars in dependence on the distance to the stars. To produce these diagrams, one million model planets with varying masses, major semiaxes (of 0.02 to 45 AU) and eccentricities were simulated for each star. In the distribution of the major semiaxis a, it was assumed that its number *N* remains constant with increasing distance. Arbitrary phases of the planets in their orbit and varying orbital tendencies were also taken into consideration. Planets that should have been discovered during the NACO-SDI survey are shown in blue. The others are red. Assuming that these stars each had planets, the likelihood of discovery noted above the diagrams is obtained. Thus, for example, one should have been able to find a planet of at least two Jupiter masses at a distance of between 10 and 20 AU with a likelihood of 20 percent around the 12 million year old, 33.5 light years distant, GJ 799B.

If one takes these probabilities for all observed stars together, then one obtains the likelihood of discovery for this survey. As Fig. II.2.8 shows, the astronomers should have been able to find two to three planets. Thus they can exclude with a very high probability (93 %) that large planets are distributed evenly over the large semiaxis ($N(a)$ = const) up to a distance of 45 AU from their central stars.

The SDI survey's null result thus sets for the first time limits to the distance distribution of younger, extrasolar giant planets. Apparently there are not many giant

Fig. II.2.7: Two examples for detectable planet masses (the values corresponding to the blue dots) in relation to the distance to the central star: left a 50 light year distant, 70 million year old K1V star; right a 33.5 light year, 12 million year old M4V star.



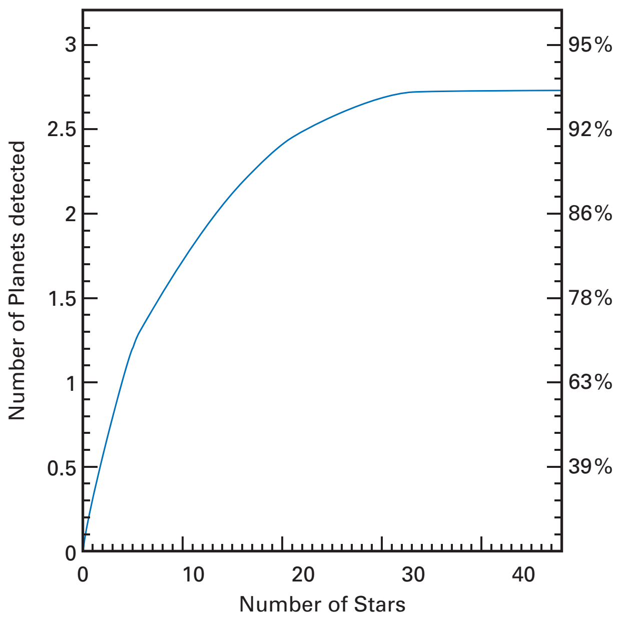


Fig. II.2.8: Cumulated number of planets which should have been discovered, if present, in the NACO-SDI survey. This curve is dependent on certain assumptions such as a uniform distribution of major semiaxes.

planets at a large distance from the star. A statistical analysis showed that not more than 20 percent of all stars could have a planet with a size of more than four Jupiter masses at a distance beyond 18 AU (which corresponds to Ura-nus's orbit). This statement is valid with a 95 percent likelihood.

Why this is the case is completely open. Either the gas giants are not created at such distances, or they prefer to wander closer to the central star during their formation phase. This phenomenon, also known as "migration", can explain the existence of "hot Jupiters", that is those gas planets which orbit their sun on extremely narrow orbits within approximately 0.1 AU.

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II.3 Rapid Formation of Planetesimals in Turbulent Disks

During the first phase of planet formation, dust particles collide, adhere to each other, and grow. Once a body reaches a diameter of around one kilometer, its gravitational force is large enough to attract and accrete further bodies in its surroundings: in this way, it eventually forms into a planet. It is unclear however, how a body can ever reach that critical one kilometer diameter, because the initial growth mechanism ceases to be effective at sizes beyond ten centimeters. Rock fragments of this size either rapidly plunge into the central star, or are likely to destroy each other in collisions. MPIA theoreticians have now found a path through which nature can surmount this ten centimeter barrier: In protoplanetary disks, turbulences help form "high pressure vortices" in which the rock fragments accumulate and are able to coalesce as a result of their common gravity. In this manner, bodies the size of our minor planet Ceres are formed in a very short time.

In mutual collisions, the smallest dust particles remain stuck to each other because of the attracting Van-der-Waals force operating between them. The relative velocities required are obtained from Brownian motion, which decreases with increasing particle mass and can therefore only have an influence in the very early protoplanetary cloud. As the particles continue to grow over time, they fall because of gravity into the forming protoplanetary disk's middle plane. Because the falling speed increases with growing particle size, relative velocities also arise here between the dust particles, leading to further collisions and growth. Thus, by the time they reach the disk plane, the particles attain a likely size of up to several centimeters.

Within the disk plane, dust density is relatively high, so that particles now collide more often and can, in principle, grow into planetismals with diameters of several kilometers. Two processes, however, fundamentally hinder this. Above a certain velocity, the dust fragments rebound from each other or mutually destroy each other. Recent results in laboratory physics document that the collision-adhesion mechanism alone can not lead to stone fragments much greater than roughly ten centimeters in size.

Furthermore, bodies of this size lose their angular momentum through friction with the gas and, in a relatively brief period, approach the central star along a spiral-shaped track. Estimates show that a fragment of this size comes so close to the star after several hundred years that it vaporizes. In this short time period, a stone the size of a tennis ball cannot grow by more than two orders of magnitude in diameter, that is by roughly six orders of magnitude in mass.

Turbulence concentrates stone boulders

High drift rates of boulder pieces appear in disks in which gas and dust have a laminar flow. For some time now astronomers have suspected that also turbulences occur which significantly influence the movement of the particles, primarily the Kelvin-Heimholtz (KH) turbulence which forms in the following manner: First the dust sediments toward the middle plane of the disk. There, temperature and density sink with increasing distance from the central star. For this reason a radial pressure gradient rules, leading to the gas rotating more slowly than it would in a pure Kepler orbit. In contrast, the dust particles do not react to the pressure gradient, but only "feel" the gravity. They therefore rotate in Kepler orbits around the central star. Should the dust to gas ratio in the middle plane be high enough, then the dust will tear the gas particles along with it, forcing them as well into the velocity of a Kepler orbit. As a result, the gas in the middle plane moves more quickly than the gas above and below it, creating a vertical velocity sheer which triggers KH instabilities.

The resulting turbulent gas flow creates vortices in the dust in the middle plane and hinders the clumping of the dust into planetisimals. This problem was already recognized in 1973 by Goldreich and Ward, who saw here a fundamental limit to the accretion of dust particles into planetismals.

Only a few years ago did the suspicion arise that the turbulences would permit the creation of local regions with increased gas density in which solid particles could gather. The astronomers at MPIA pursued this phenomenon in 2006 with computer simulations and were able to confirm this (see Annual Report 2006, Chap. III.2). Could these high pressure vortices be the birthplaces for planetisimals?

The theoreticians pursued the question with several two-dimensional model calculations, each with 1.6 million particles and with varying spatial resolution. In doing so they varied several physical parameters, such as the ratio between dust and gas. Furthermore they took into consideration that the dust particles were coupled to the gas so that friction would be created. The strength of the coupling depends on the size of the particles: Large particles couple with the gas more weakly than smaller ones. In the models, two coupling forces were considered, representing particle sizes of 20cm and 100cm each.

The model runs showed clearly how turbulences quickly formed in disk flows that remain stable over a course of several orbits. Because these are mainly vertically oriented, they can easily take on and accrete further

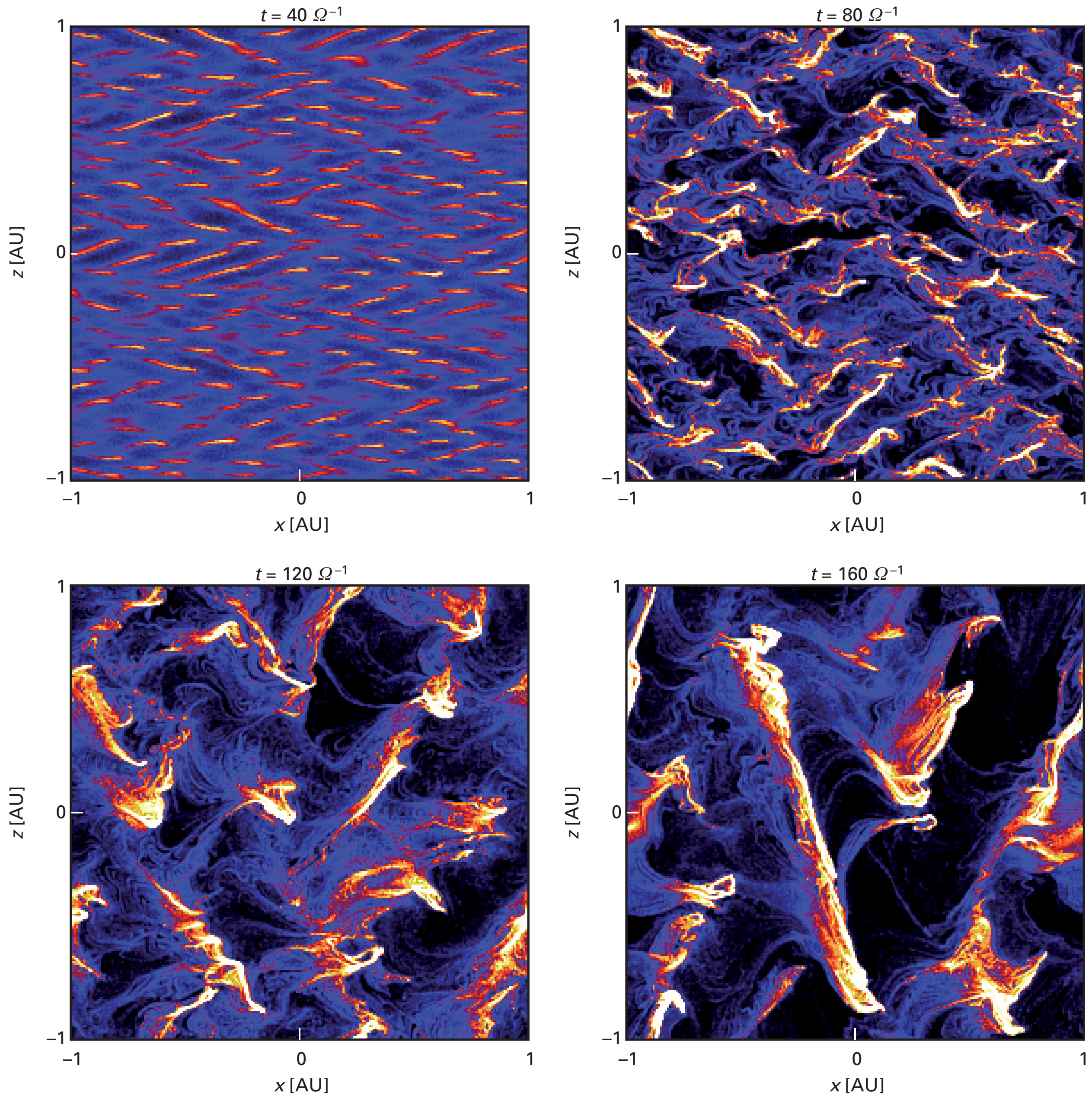


Fig. II.3.1: Development of particle density in a disk with (small) particles that are strongly coupled to the gas and have a small dust-to-gas ration of 0.2. One can see how the densities accrete and partially expand almost vertically to the disk plane. Ω is the Kepler frequency at a given distance r from the star.

particles during their orbits (Fig. II.3.1). The decisive point for the dynamics is that the particles are no longer subjected to the gas's "headwind" when inside such an accumulation. The total friction of a particle group is thus less than if all particles remained "loners". Therefore, such a group does not drift so quickly toward the star.

We should emphasize here that the self-gravity of the particle assembly was not taken into consideration. It involves a purely dynamic, self-strengthening effect in which the particles are captured as if in a traffic jam. Fig. II.3.2 shows how the density in the weakly coupled models (that is for large particles) increased in several turbulence cells. The parameter ε is the ratio of the mass of the dust particles to the mass of the gas with in a region. The maximum density in all three cases achieves roughly the hundred-fold value of the number density of individual particles at the beginning of the simulation.

If the dust-to-gas ratio was small and a strong coupling was present (small particles), then the effect was less: The density increase was only moderate and the dust clumps remained smaller and shorter-lived. In the extreme case the density increased only to about 20 percent. All cumulatively achieved overdensities are shown in Fig. II.3.3.

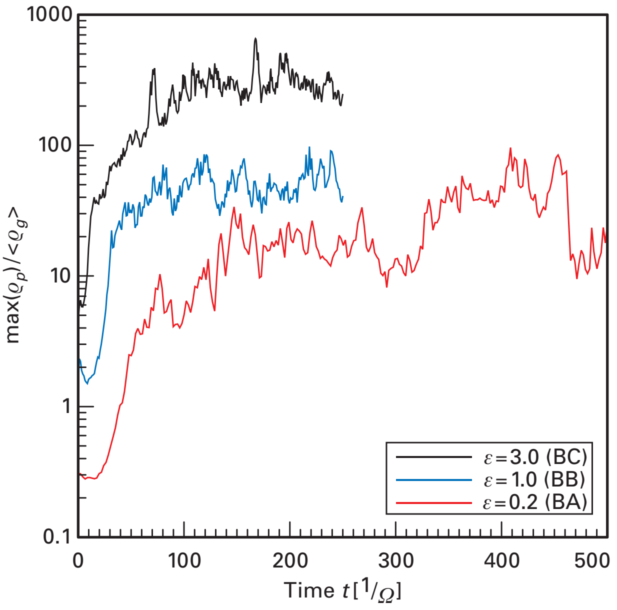


Fig. II.3.2: Development of maximum particle density in units of average gas density. Shown are results for three models with varying dust-to-gas ratio ε.

With increased computing effort and 20 million particles, two cases were calculated even three-dimensionally, whereby he limited himself to a cube-like volume in the disk. In the case of small particles and a limited dust-to-gas ratio (as in Fig. II.3.1) one can clearly see how the dust filaments are drawn out longitudinally (Fig. II.3.4).

An exact time analysis of simulations indicates that the condensations involve a dynamic, collective phenomenon, rather than a permanent increase in density. Accordingly, rather than large boulders, loose "sand heaps" develop in the disk which dissolve again later. Yet this phenomenon can have something to do with the fact that self-gravity of the condensations is not considered in the models. The theoreticians pursued this additional phenomenon in a second work in which they additionally considered the effect of magnet fields. The magneto-rotational turbulence (MRI turbulence) appearing here additionally strengthens the turbulences and supports the formation of planetisimals.

Magnet Fields support the Formation of Planetesimals

The MRI turbulence results from an interplay of sheer flows and magnetic fields which could be imagined as follows: In the protoplanetary disks the gas that is nearer to the star flows faster than at greater distances. Experiments and analytical investigations have shown that the sheer flows, which otherwise grow rapidly unstable, do not so easily become turbulent in disks, because the disk rotates around the star with a high speed: The rotation's high angular momentum stabilizes the sheer flow.

Near the young star, the gas is probably ionized and the charged particles couple to the magnetic field lines. Like rubber bands, these pull through the disk and attempt to prevent the sheering, with the effect that the inner region

Fig. II.3.3: Cumulative distribution of particle density for all six models with varying coupling strength (τ) and dust-to-gas ratio (ε).

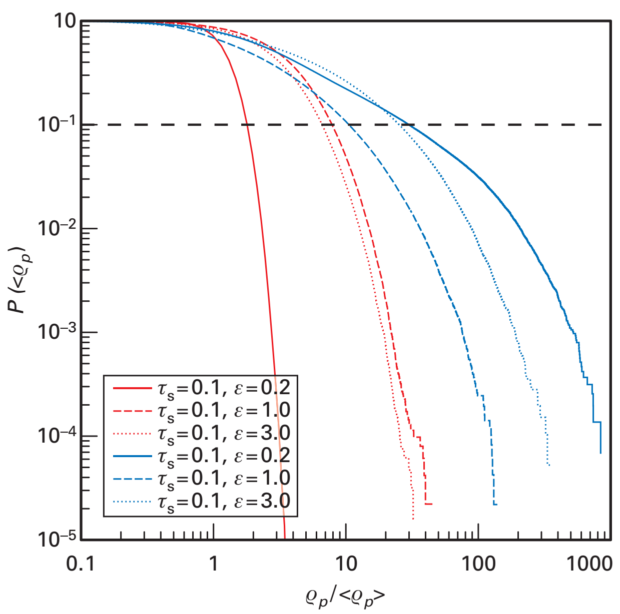
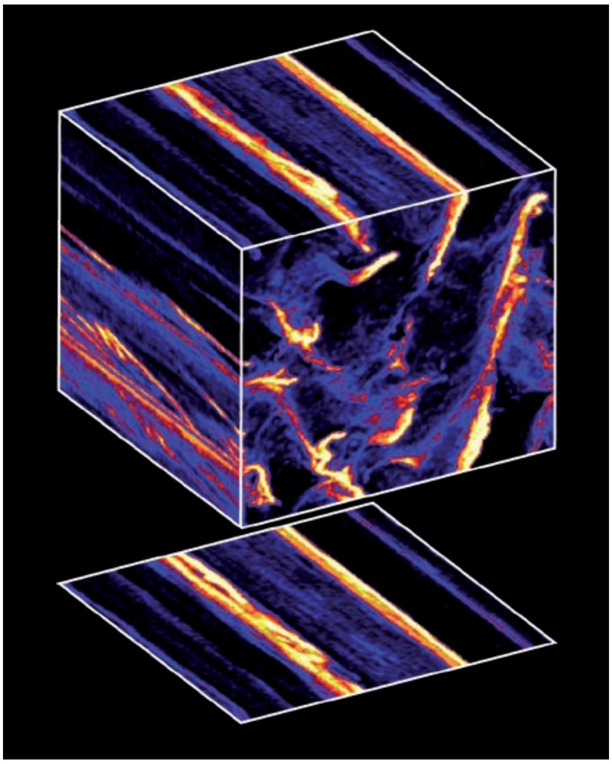


Fig. II.3.4: Three-dimensional development of particle density in the same case shown in two dimensions in Fig. II.3.1.



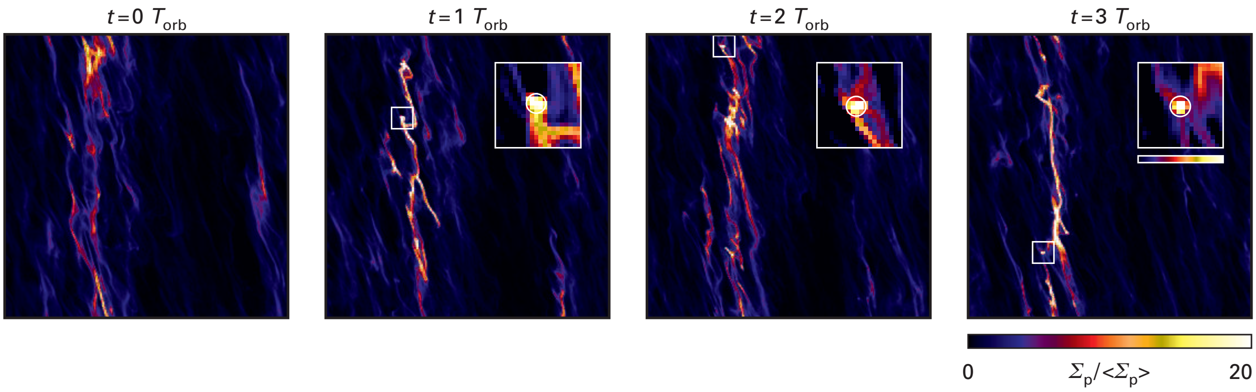


Fig. II.3.5: Development of particle density in the disk while considering magneto-rotation and self-gravity of the rock boulders in the turbulence elements. *F. l. t. r.* snapshots after intervals of one orbit each are shown. In the small box the accretion of the largest rock collection can be recognized.

of the disk is slowed down and the outer region is accelerated. This destabilizes the flow in the disk so strongly that it must become turbulent – vortices are created. The magnetic fields thus act similar to an antenna on the roof of a stream-lined sports car: the air resistance is increased and the flow of the air becomes turbulent.

The MPIA theory group's simulations could already establish that the MRI turbulence strengthens the concentration of larger bodies in high pressure vortices; now the theoreticians additionally incorporated the self-gravitation between the particles. This was only possible after they had further developed the simulation program. It solves the magnetohydrodynamic equations on the grid for a gas which can essentially interact with the smaller particles. It was only thanks to the new development of a parallel solver that the gravitational accretion of dust fragments could be quantitatively recorded.

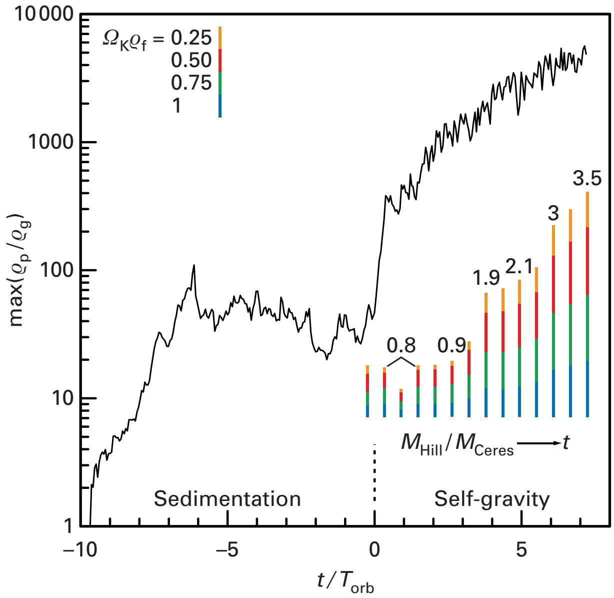
In the simulations again, a cubic volume was selected in the protoplanetary disk, orbiting the young star at a fixed distance of roughly 5 AU. The gas particles circled in orbits at a sub-Kepler speed while the dust particles moved with Keplerian speed around the star. As a result these particles not only experience a strong headwind, causing them to drift toward the star. They also experience experience the friction of the gas while they sink to the middle plane.

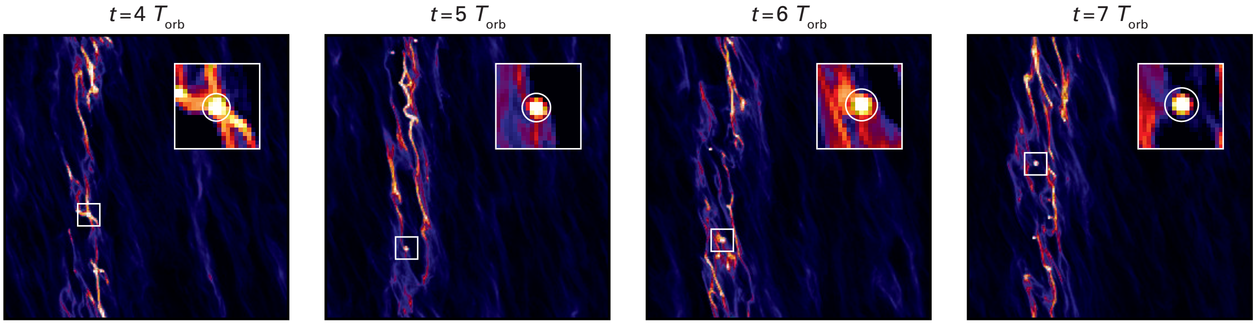
The MRI turbulence creates vortices in the gas with a slightly increased density and slightly higher pressure than in the surroundings. These densities are maintained in the disk over several orbits, corresponding to a period of several decades or – in the outer regions of the disk – even several hundred years.

If one now includes the reaction of the solid bodies, the coupling degree of which corresponds to four different diameters between 30 and 120 cm, then the following happens: The gas particles running at sub-Kepler speed are swept away by the rock fragments and now also move at Keplerian speeds. As a result the headwinds against the rock fragments decrease. Then the rock fragments move into the already existing areas of over-density where they accumulate. The collisions between the fragments within these regions lead to a dynamic cooling of the ensemble and thus to a further density increase. However, here material characteristics such as coagulation or mutual destruction had to be left unconsidered in the model calculations.

Then, however, gravitation plays a decisive role: It effects a densification of the ensemble. Fig. II.2.5 shows the selected volume over the course of seven orbits. One sees now an initially very small collection of rock fragments accumulates more and more material and thus strongly accretes. The largest clump is shown in the enlarged image on the right. At the end of the simulation it had achieved a mass which corresponds to three times the sizes of the dwarf planet Ceres (Fig. II.2.6).

Fig. II.3.6: Accretion of a boulder agglomeration. Friction and vertical gravitation in the disk were considered from $t = -10$ on, while self-gravitation and cooling through impacts of rock fragments against each other were only "switched on" at $t = -0$. One can recognize the rapid accretion of the rock ensemble at up to 3.5 Ceres masses.





Is this then the solution to the puzzle of how the small pebbles in the protoplanetary disk avoid vaporizing in the star and overcome the ten-centimeter barrier? Much supports this conclusion, even if some questions remain unanswered. For instance, a magnetic field can strengthen the turbulences only if the material in the disk is ionized; but especially in the outer regions of the protoplanetary disk, temperature is likely to be so low that the gas is not ionized.

Nevertheless, the progress to date has been very convincing. For the first time it seems possible to fully explain the growth of micrometer-sized dust particles into planets.

As the next step, theoreticians want to better understand the high pressure regions in the MRI. In larger simulations boxes, very strong zonal flows along the rotational direction of the disk are created, between which long-term high pressure zones develop. Similar flows appear in the sun and in planets like Jupiter: the bands in Jupiter's atmosphere are just such regions with varying rotational velocities. It may be that, in protoplanetary disks, the boulders are captured in similar zonal flows. Furthermore, one could imagine that even smaller particles could be concentrated between such zonal flows, where kernels develop of one to five centimeters in size.

At the same time, the group is trying to determine with their model calculations the size distribution of planetismal masses, similar to how one determines the "initial mass function" in star formation. To achieve this, the simulations must run a little while longer.

Films to the computer simulations can be found at: www.strw.leidenuniv.nl/~ajohan/research.php.

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II.4 An Exoplanet's First Calibrated Spectrum

After an extrasolar planet was indirectly proven to exist in 1995, astronomers immediately sought to discover other such heavenly bodies and then to analyze them spectroscopically in order to ascertain their atmospheric composition. Due to the high contrast between a star's brightness and that of its planet, as well as the small distance between them, this undertaking is extremely difficult however and is, almost in all cases, beyond current technical capabilities. A team of astronomers under Mark Swain from the Jet Propulsion Laboratory and Jeroen Bouwman from the MPIA have now been able to capture a mid-infrared spectrum from the exoplanet HD 209458b. It is the first spectrum ever of any planet to supply the radiation flow in absolute units. These data are already allowing for careful conclusions regarding the atmospheres of these "Hot Jupiters".

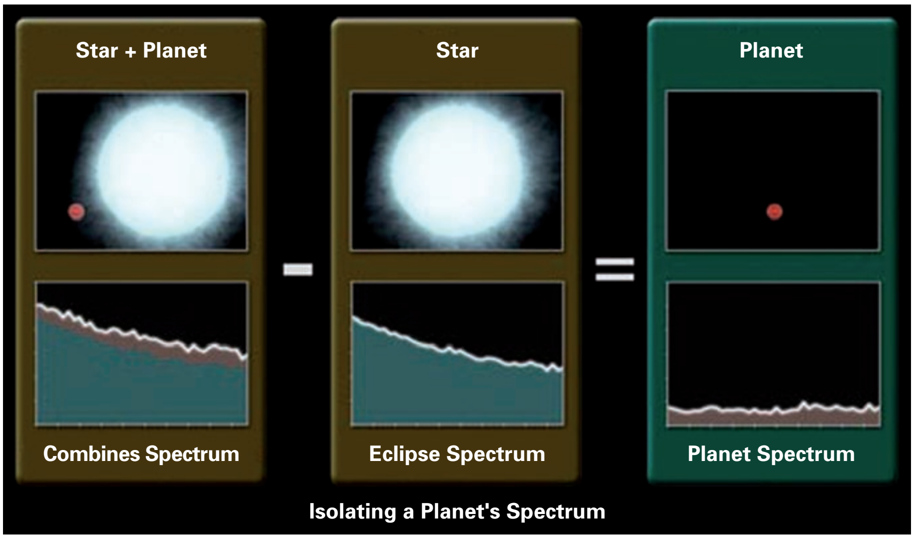
Because the images of the star and its planets practically fall together, their spectra are also overlaid. They must be separated from each other with the help of tricky techniques in order to obtain information about the planets. To do this there are methods which can be used to search for so-called transit planets; these are found in systems which, by chance, are observed from a viewpoint exactly at the edge of the planet's orbital plane, so that the planet transits in front of the star and later disappears behind it. This geometry allows for three observation modes.

Spectroscopic Methods for Exoplanets

First, the *Reflection Method*: A planet (or its atmosphere) reflects the star's light. A telescope captures both the direct light of the star as well as the light reflected from the planet. When the planet disappears behind the star, the telescope captures only the star's light. Subtracting the pure stellar spectrum from the spectrum of the combined light of the star and the planet leaves the planet's spectrum. This can contain absorption lines from elements in the planetary atmosphere. However, no experiments to date of this type have been able to provide unambiguous results.

Second, the *Transmission Method*: If the planet passes in front of the star, a portion of the star's light traverses the planet's atmosphere; this light contains spectroscopic information about the chemical composition of its gaseous shell. In order to extract this from the full spectrum, two spectral series are taken: one of them briefly before the planet transits in front of the star (the primary occultation) – it contains the star's radiation as well as possible thermal emission from the planet's night side; the second series is taken during the transit phase. In the difference spectrum derived from these two spectra, absorption lines of elements in the planetary atmosphere may appear. In this manner, two American astronomers were able to prove the existence of sodium as well as water and methane in the atmo-

Fig. II.4.1: Scheme of the Secondary Occultation Method. Spectra are taken while the planet is on its way to transiting behind the star und turns its hot side toward earth. These spectra contain the light of both star and planet. Spectra are then taken of the star spectrum alone while the planet transits behind the star. The difference between the two spectra leaves the planet's spectrum. (Diagram: NASA)



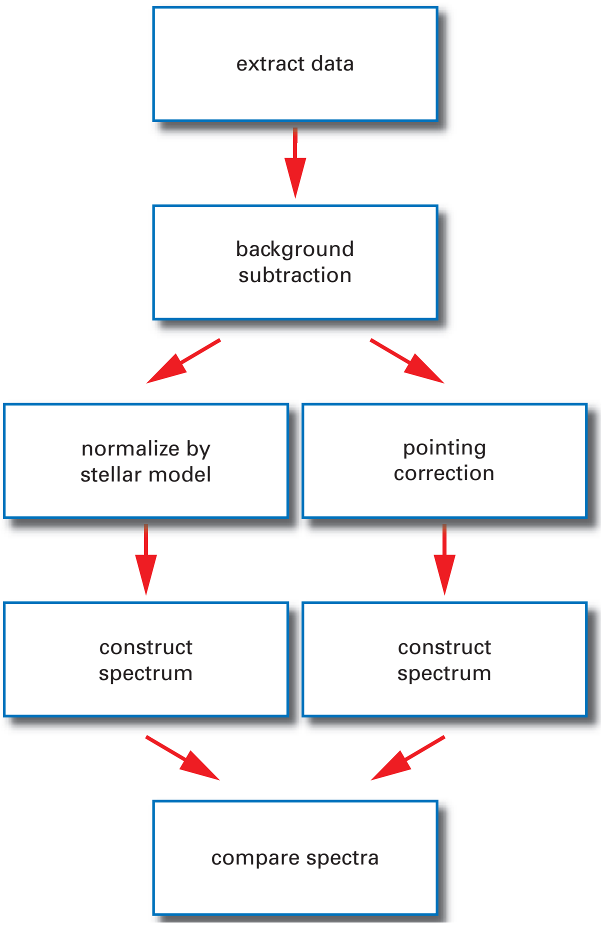
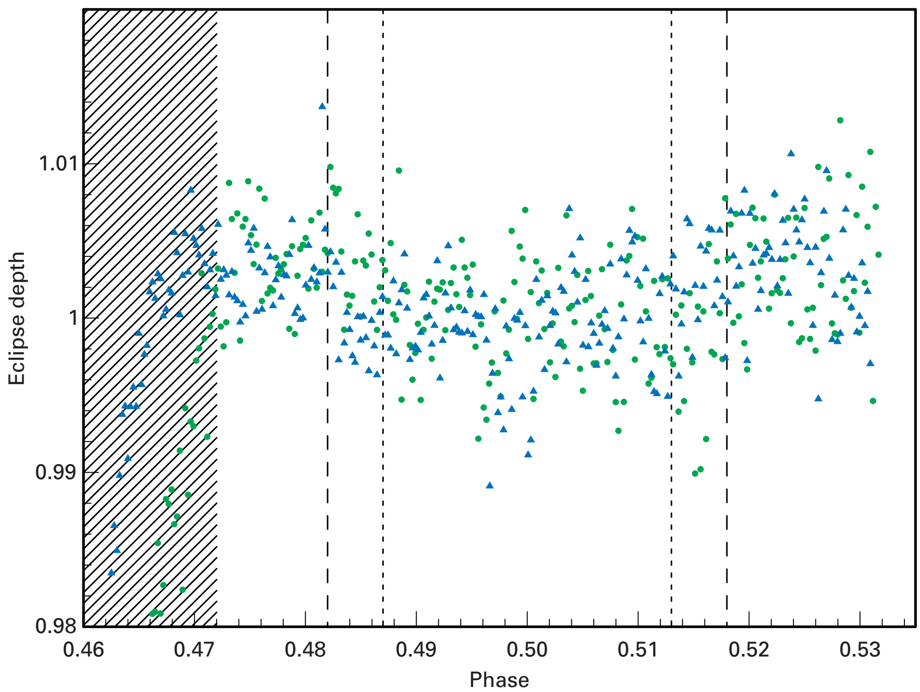


Fig. II.4.2: Scheme of both independent calibration processes.

Fig. II.4.3: HD 2095458 light curve integrated over the total wavelength range depending on the planet's phase during its orbit.



sphere of the exoplanet HD189733b. The depth of the sodium absorption line was 0.7 per thousand of the surrounding continuum.

Third, the *Method of Thermal Emission or Secondary Occultation* (Fig. II.4.1): A planet that orbits a star at a very short distance, is powerfully heated and therefore emits thermic radiation in the infrared band. In order to identify this, spectra are first taken while the planet is on the way to the transit behind the star and its hot side is turned toward earth: These spectra contain the light of the star plus planet. Then spectra of the star alone are taken, while the planet is located behind the star. The difference between both sets provides the planetary spectrum.

Results for Exoplanet HD 209458b

This secondary occultation method was applied by the Swain and Bouwman team. To achieve this, they selected the 153 light year distant Type G0 star HD 209458 where a transit planet had already been discovered in 2000. Several years of observations had led to a very precise determination of the orbital parameters: The planet orbits a central star over 3.525 days at a distance of 0.0474 astronomical units. The periods of the individual phases, especially when it is occulted, are also very precisely known und this is the premise for a successful application of this observational method. The mass of the planet is 0.64 Jupiter masses; it has a radius of 1.32 Jupiter radii. As a result it has an average density of 0.31 g/cm^3.

Because of the central star's proximity, temperatures on this exoplanet are higher than 1000 Kelvin and its atmosphere correspondingly radiates in the thermal infra-red. The astronomers observed HD 209458 in a

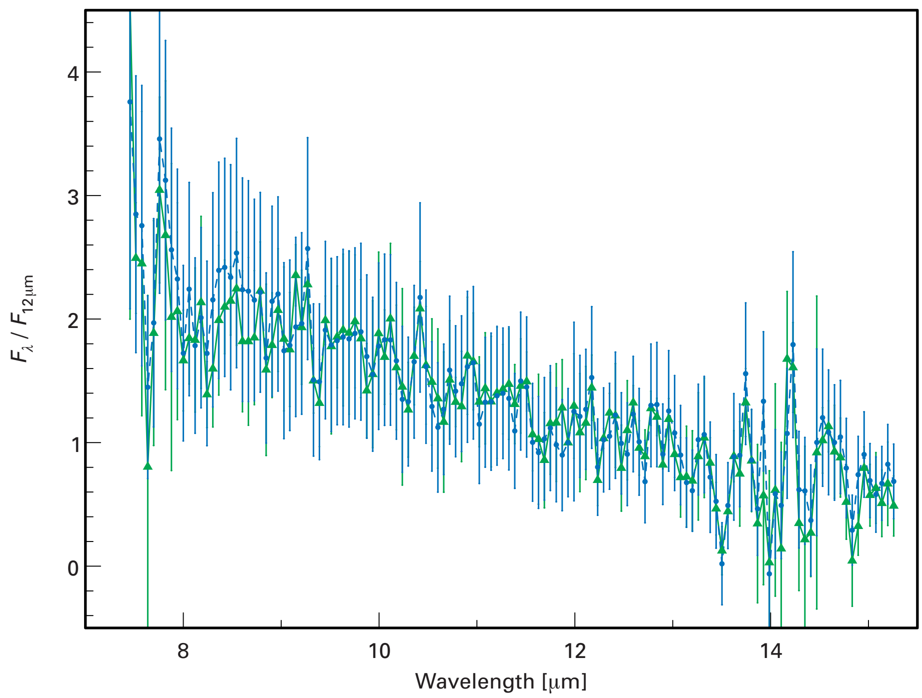
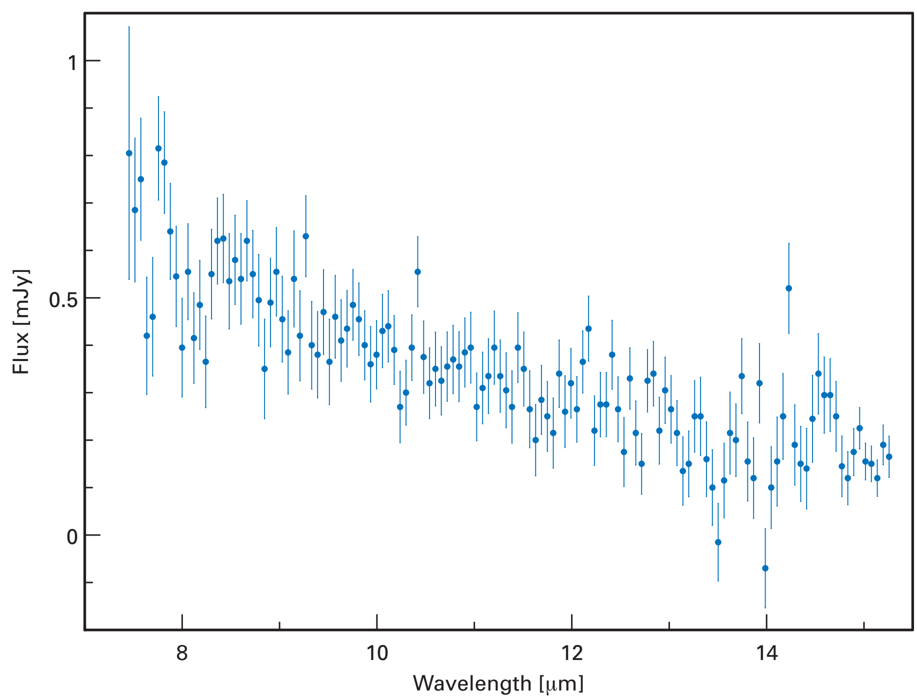


Fig. II.4.4: Both independently obtained planetary spectra, normed to an averaged flow at 12 μm wavelength. The absolute spectra match very well with each other.

Fig. II.4.5: The absolute spectrum of the exoplanet HD 2095458b. It essentially appears as a continuum; emission lines between 7.5 and 8.5 μm are indicated.

wavelength range of 7.5 μm to 15.2 μm with an infrared spectrograph on board the Spitzer space telescope. In doing so, approximately 700 spectra were taken, each with a one minute time exposure. Before subtracting the pure stellar spectrum from the overall spectrum (star plus planet) a very complex analysis of the dataset was required during which systematic errors had to be eliminated. It depends on the quality of the data analysis whether the planet's spectrum obtained is reliable in the end and permits genuine spectral characteristics to be recognized.

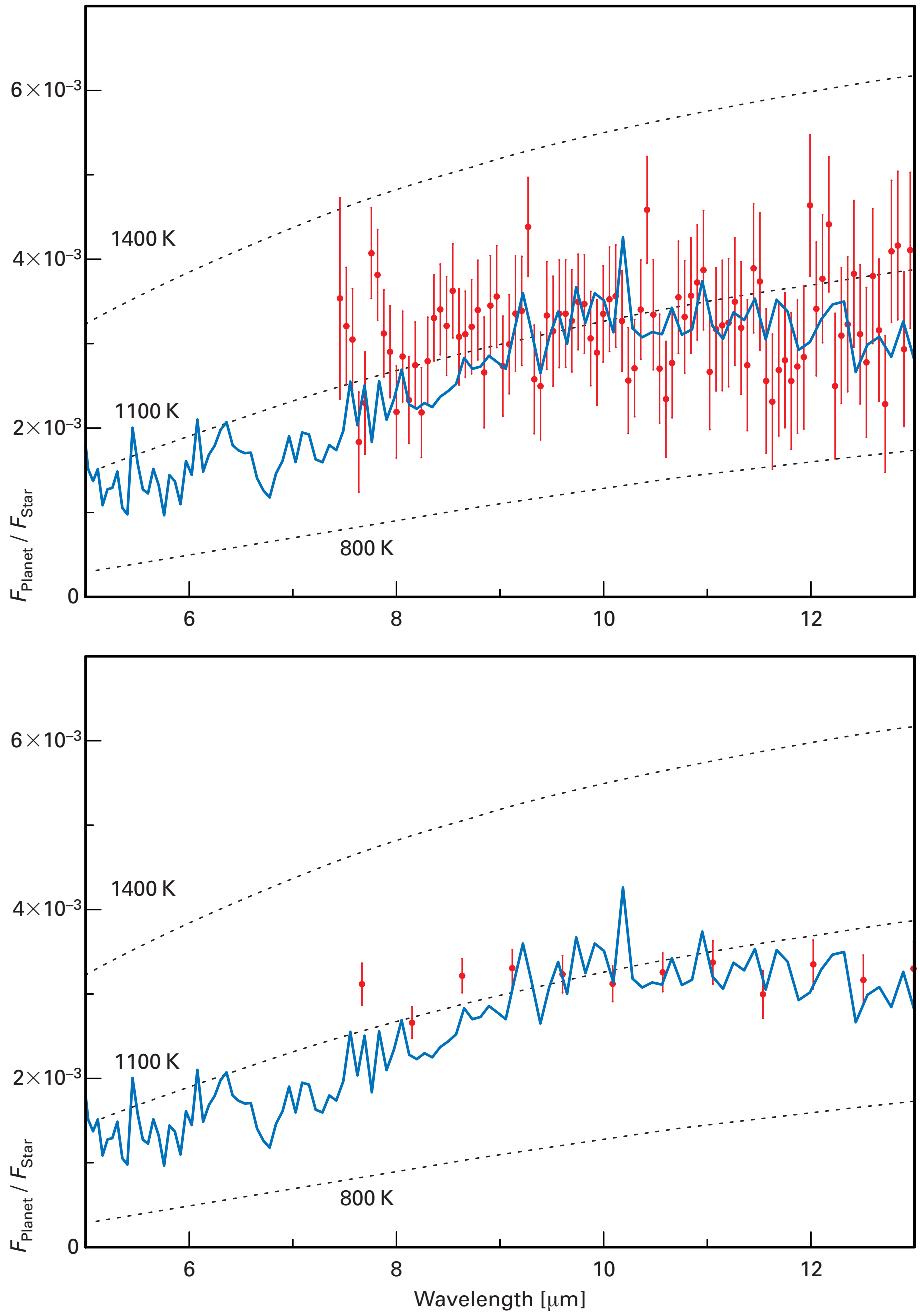


The astronomers identified four dominant sources of error which produce a signal that is overall ten times stronger than the expected flux from the planetary continuum. Included in the noise effects are intensity shifts between observations, periodic flow modulations, and a steady signal drift during observations. Nevertheless, these spurious effects did not randomly appear but were correlated in time and could be classified as concrete, technical deficiencies. They were caused by the erroneous pointing of the telescope, an insufficient subtraction of the infrared background, and gathering of electrical charges on the detector.

The astronomers applied several calibration processes in order to eliminate these errors as much as possible. Two processes that treated the systematic errors differently were independently applied; the one process results after several steps in a differential spectrum in arbitrary units, while the other one results in an absolutely calibrated spectrum. The comparison of these spectra thus yields a measure for calibration procedure quality. The individual steps are shown schematically in Fig. II.4.2.

Fig. II.4.3 shows the HD 2095458 light curve integrated over the entire wavelength region depending on the planet's phase during its orbit. The drop in brightness as

Fig. II.4.6: *Top:* The HD 2095458b spectrum compared with model atmospheres. *Bottom:* Red dots mark significant spectral deviations from the model.



the planet disappears behind the star (secondary cover) can be seen in the phase at around 0.5. Here the drop of the continuum is only 3.1 per thousand.

Both independently obtained planetary spectra are shown in Fig. II.4.4. The measurement values (green triangles for the relative spectrum, blue dots for the absolute spectrum) correspond very well, thus strengthening the reliability of the calibration processes. As a result, the astronomers were able to obtain for the first time an exoplanet's absolute spectrum. Given the precision of 0.1 % for the flow calibration, in the future this method should even permit the measurement of thermal emissions of the night side of the planet. As Fig. II.4.5 shows, it covers a flux range of 0.2 to 0.6 milli-Jansky. What conclusions about the atmosphere can be derived from this spectrum?

A comparison of model spectra (Fig. II.4.6) allows for several statements that are made with caveats. The continuum matches a 1100 K hot atmosphere. A significant deviation in the continuum between 7.5 and 8.5 μm can be explained by the fact that the atmosphere transports a substantial amount of heat from the day to the night side. Furthermore a small structure appears at 8.1 μm with a statistical significance of 4 σ. Nonetheless a decision cannot clearly be made as to whether this is due to an emission or an absorption feature. Also at 7.7 μm wavelength, an emission or an absorption line could be present.

It was surprising that – in contrast to the "hot Jupiter" HD 189733b – no indications of water were found in the spectrum. The cause for this is still unclear. The strongest emission bands are expected by the researchers to appear in the near infrared where Spitzer can help to prove their existence. In the surroundings where H_2O lines are likely, carbon monoxide (CO) and carbon dioxide (CO_2) would also be detectable. Transmission spectra could also aid in answering the question of the missing water.

Somewhat simultaneous with the work of Swain, Bouwman, and colleagues, a publication came out by Jeremy Richardson's group at Nasa's Goddard Space Flight Center, who were also using Spitzer to observe HD 2095458. This group too found the wide modulation between 7.5 and 8.5 μm. However, they claimed to have additionally found a wide emission line around 9.65 μm which they traced back to silicates. This could not be confirmed by the Swain and Bouwman team.

With this first measurement of an exoplanet's absolutely calibrated spectrum, the astronomers now made an important step forward. The success increased confidence in the method with the consequence that the astronomers now plan to measure additional emission spectra of other transit planets and then of each planet's full orbit. This way, one will be able to obtain the chemical composition of the planetary atmospheres under varying phase angles, from which conclusions about the chemical processes on the day and night sides can be derived. Processes such as photochemistry and heat distribution would then become accessible for the first time. The group has therefore submitted observation proposals for the Spitzer and Hubble space telescopes. Observations with telescopes on earth, such as the InfraRed Telescope Facility (IRTF) on Mauna Kea, are also planned.

Jeroen Bouwman
In cooperation with:
Jet Propulsion Laboratory, Pasadena,
California Institute of Technology, Pasadena

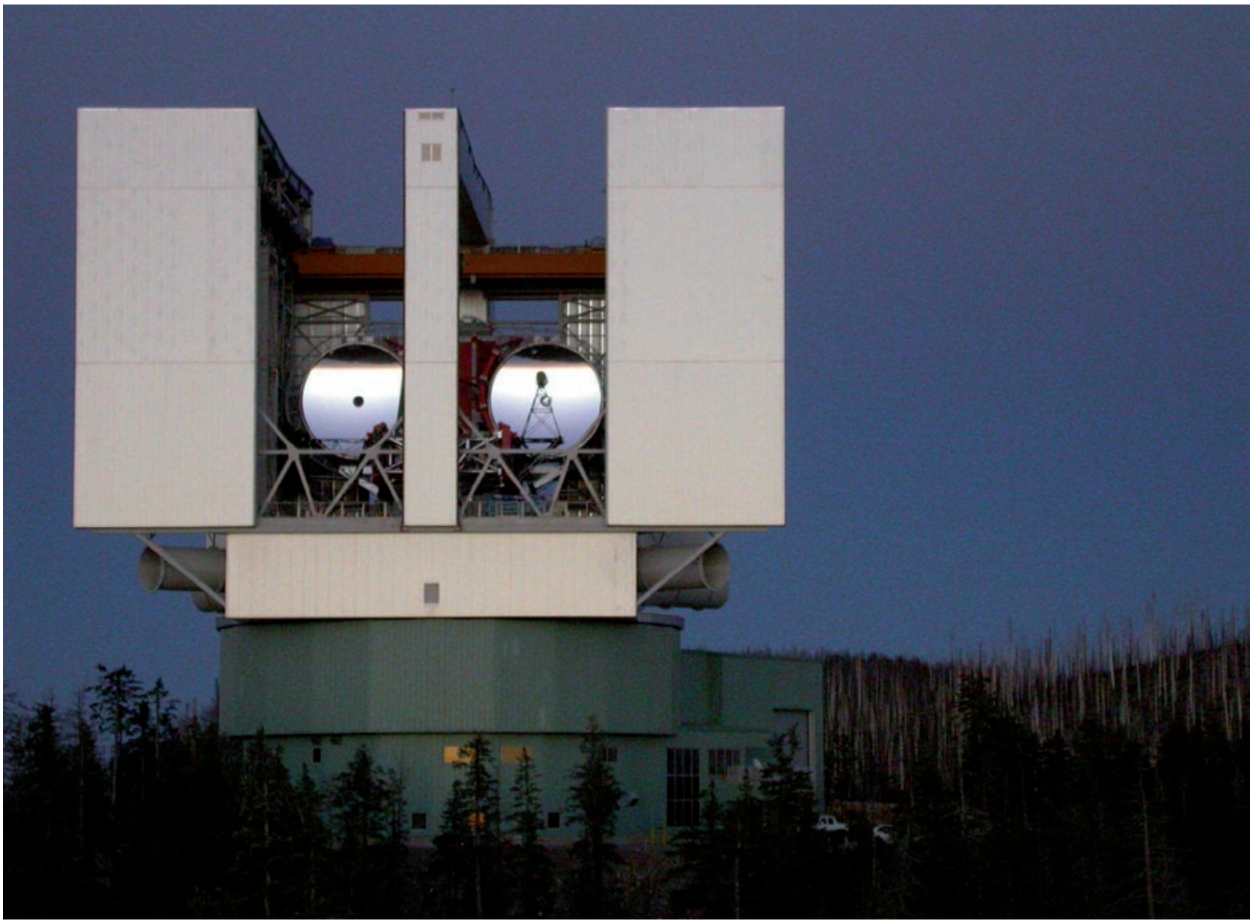
II.5 Dwarf Galaxies Under the Magnifying Glass

The first scientific work on the Large Binocular Telescope

With the decisive participation of the MPIA, the Large Binocular Telescope (LBT) is coming to life on Mount Graham in Arizona. It is unique because two large primary mirrors on a common mounting gather the light of the stars and galaxies and direct it into a single focal point. In the spring of 2007, the scientific demonstration phase began with one of the two mirrors and a camera located at its primary focus. The first results of this new phase were published by an international astronomer team led by MPIA's Matthew Coleman. The team studied three only recently discovered dwarf galaxies which are companions to our Milky Way System. The shape of the Hercules dwarf galaxy proved surprising: It is rather strongly flattened and is similar to a disk or a cigar. The reason for this has not been definitively clarified – it is possible that the Milky Way System's gravitational field is deforming the dwarf galaxy. Both of the other dwarf galaxies, Canes Venatici I and Leo T are also rather interesting: Their stellar populations are of varying age, thus hinting at complex formation histories.

Throughout 2007, the second mirror was also installed in the LBT (Fig. II.5.1) but the first observations were made with only the first of the two 8.4 meter mirrors. Here the Large Binocular Camera was made available with a primary focus on the blue channel (LBC Blue). LBC Blue and its future twin for the red spectral range, LBC Red, were developed by the Italian LBT partners. LBT Blue is equipped with four CCDs each having 2048 × 4608 pixel and creating a 23 by 23 square arc minutes field of view, corresponding almost to the size of the full moon. This camera is, to some extent, a 38 megapixel CCD wide-angle camera. It specializes in the wavelength region of 320 to 500 nm and is equipped with a range of standard color filters.

Fig. II.5.1: The LBT with the two main mirrors. The first observations were made with the mirror on the right. (Picture: LBTO)



The Hercules Dwarf Galaxy

By the end of the 20th Century, it was known that nine spherically shaped dwarf galaxies (dwarf spheroidal galaxies) accompanied our galaxy. In the Sloan Digital Sky Survey (SDSS), in which MPIA also took part, this number doubled within a period of only three years. These small galaxies possess a very low surface brightness and are therefore very difficult to discover and to study.

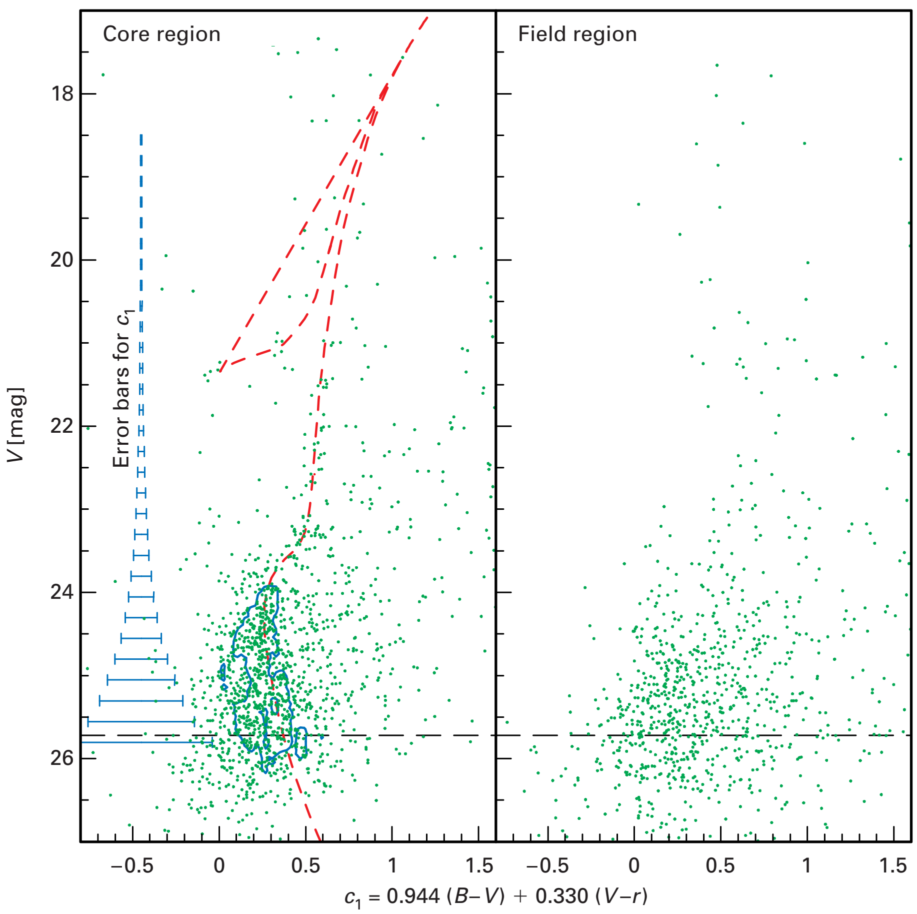
From the objects of this type that have already been examined, it is known that their total mass is dominated by dark matter. In addition, they show highly varying evolution histories, which is reflected in the age of their stars' pulsations. The study of these faint stellar systems requires high-performing telescopes – which is why our knowledge about them has so many gaps. In particular, it is unclear how the formation and evolution of these satellite galaxies is interwoven with that of our Milky Way. Why is the ratio of dark to normal matter much higher in dwarf galaxies than in the Milky Way System? These are only two of the widely unsettled questions.

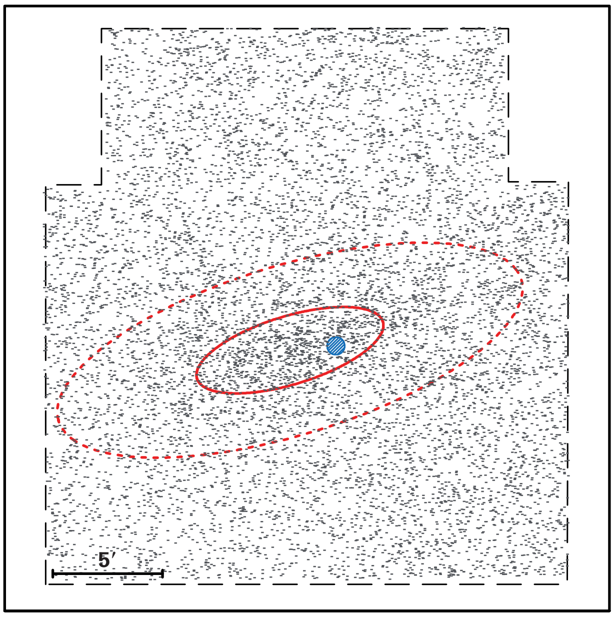
The dwarf galaxy in the constellation Hercules was only recently discovered among SDSS data after the LBT observations described here. It is approximately 45,600 light-years away and its mass-to-light ratio has an extremely high value of 332 $M_\odot/L_\odot$, with an uncertainty of 50 percent. To compare: the mass-to-light ratio of the Milky Way System lies in the range of 50 to 100 $M_\odot/L_\odot$. Until observations by Coleman and his colleagues more was not known about the Hercules dwarf galaxy.

For its photometric research, the team took images of the Hercules dwarf galaxy through three filters (B, V, and r). The image series reached down to a luminosity of 25.5 mag, so that, for the first time for this galaxy, a nearly complete color-brightness diagram has been derived and one has been able to model the entire population (Fig. II.5.2). The best fit resulted for a single 13 billion years old stellar generation with a correspondingly low metallicity. The distance turned out to be 430,000 light-years. These values were at first determined for stars in the core region.

With these values the astronomers also attempted to identify stars in the regions lying further out – a difficult undertaking because, in several steps, stars in the foreground and galaxies in the background had to be identified. The latter could be eliminated to a large extent, because in contrast to the stars they are not point-like but appear rather elongated. The remaining, point-like back-

Fig. II.5.2: The color-magnitude diagram of the Hercules dwarf galaxy's central region (*left*) and the stars of a near field region. (*right*).





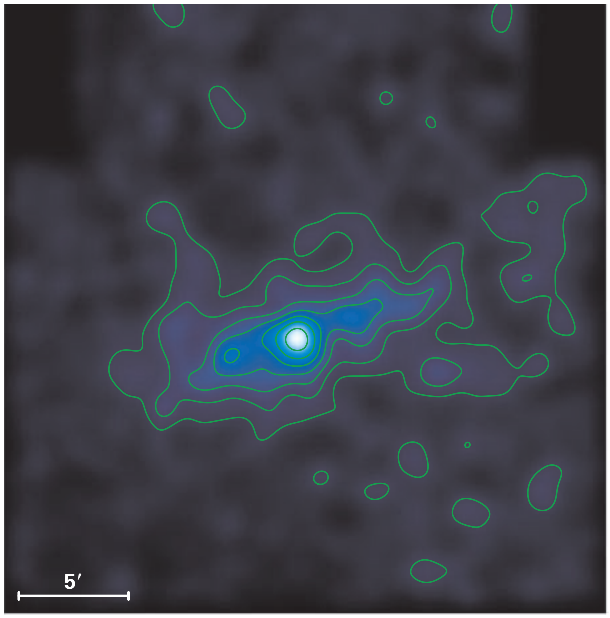


Fig. II.5.3: The contour representation of star density in the Hercules dwarf galaxy reveals its widely stretched-out, long form.

ground galaxies could be excluded on the basis of their color. Field stars, which do not belong to the Hercules dwarf galaxy, could be excluded with the aid of a luminosity criterion as well as through the comparison to a neighboring field (Fig. II.5.2, right).

Through both of these processes, around 85 percent of all objects in the color-brightness diagram were removed. In this way, the spatial extent and structure of the Hercules dwarf galaxy could be determined. As Fig. II.5.3 shows, the stellar system is shaped elliptically with an unusually large axis ratio of 3 : 1; the major semi-axis is 550 light years long.

So far, such a large axis ratio has not been observed in other dwarf galaxies. Only the Sagittarius dwarf galaxy, which lies at a distance of 65,000 light years, shows a similarly curious form, which has its origin in the Milky Way System's strong tidal forces. The 230,000 light-years distant Ursa Minor dwarf galaxy also suffers a similar fate, given its 2 : 1 axis ratio. Yet both of these stellar systems lie much closer to the Milky Way System than the Hercules dwarf galaxy. An estimate shows that the tidal forces only deform the Hercules dwarf galaxy significantly when it is within 240,000 light-years from the Milky Way System (all distance references relate to the center of the Milky Way System). Because the current distance is 400,000 light-years, tidal forces could only then be responsible for the elliptical form if the Hercules dwarf galaxy orbits the center of the galaxy on a highly eccentric track (eccentricity $e > 0.9$) and if it were currently at its furthest point. Further analyses should show whether this model is credible.

The other explanation would be that the dwarf galaxy's elliptical shape is the result of rapid rotation. However, no other stellar system of this type is known which rotates nearly as fast as would be required for the Hercules dwarf galaxy. Further spectroscopic observations are therefore necessary to test this possibility. In any case, the Hercules dwarf galaxy is a surprising object which adds an interesting facet to models relating to the evolution of the Milky Way System.

Complex Star Formation Histories in Canes Venatici I and Leo T

Two additional dwarf galaxies, named Canes Venatici I and Leo T, were found in the SDSS data. Canes Venatici I is very distant from our galaxy at 730,000 light years and has therefore escaped surveys so far. Its mass is 10^7 to 10^8 solar masses.

A preliminary examination confirmed the suspicion that this stellar system – as is typical of dwarf galaxies at this large distance – is very old. Yet, a further study then pointed to the existence of a young star population. Observations by an international group of astronomers led by Rodrigo Ibata from the Strasburg Observatory led to the additional assumption that these stellar populations were kinematically different. Another group of astronomers, however, was not able to prove this assumption. Deep photometric observations were required to decide the challenging question about the existence of these two differently aged stellar populations.

A team led by Nicolas Martin and Matthew Coleman of the MPIA therefore again took images of the dwarf galaxy with the LBC blue through two color filters (*B* and *V*) up to the limiting magnitude of around 25.5 mag: These images reached approximately three magnitudes further than the then-existing data. And again, the stars on the giant branch and the point of departure from the main sequence could be measured. After the data were cleansed of field stars and background galaxies, theoretical isochrones of stellar evolution could be fitted to the color-brightness diagram, showing that Canes Venatici I is 719,000 light-years away, its main star population is poor in metals, and it is around 14.1 billion years old.

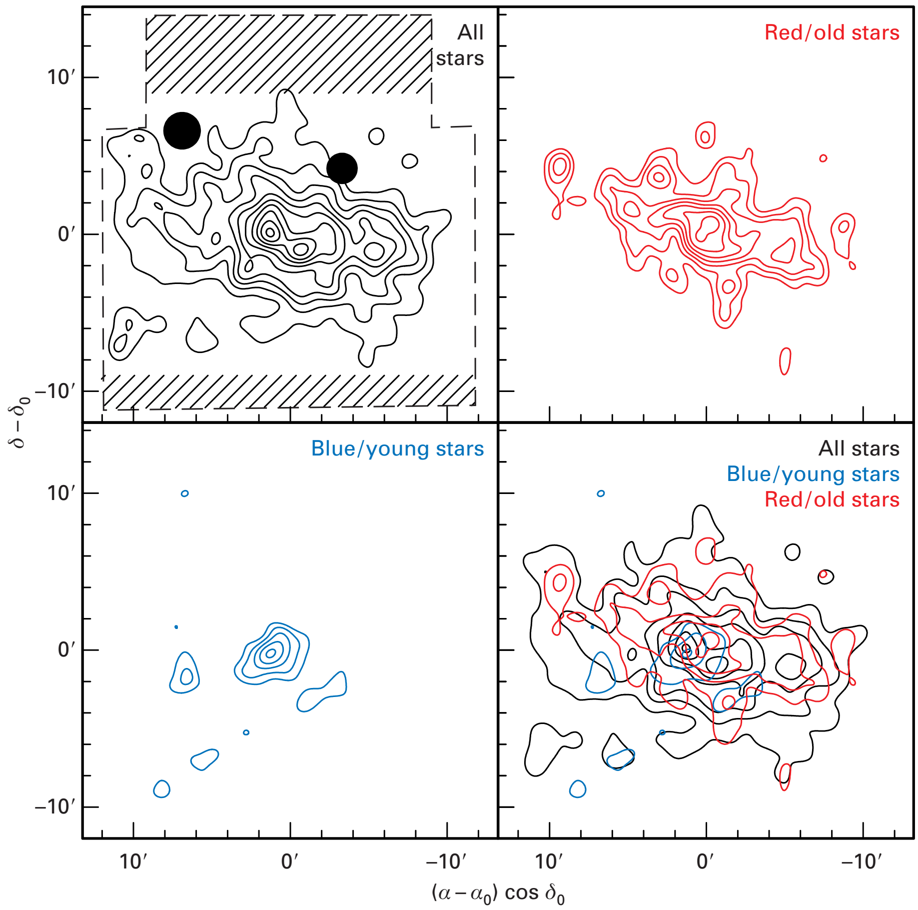
At the same time, a group of blue stars became discernible. This group, which was also spatially separated, was located at around 210 light-years east of the dwarf galaxy's center. Thus a possible interpretation of these blue stars as so-called "blue stragglers" (these are double stars which appear blue but which are not young stars) is excluded. Because, however, there is no visible reason for the assumption that a group of blue stragglers would have gathered in a special part of a dwarf galaxy, the simplest explanation remains that the blue objects are young stars. According to model estimates, their age is between 1.4 and 2 billion years. These young stars appear somewhat more metal-rich than those of the older generation.

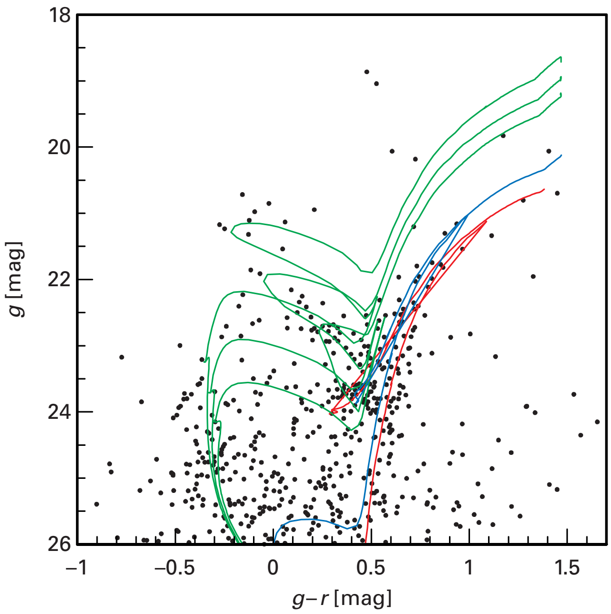
A more exact analysis of the old star generation was derived from total luminosity: 35,000 solar luminosities for the old stars and 3,500 for the young. Converted, this means that the young population contributes three to five percent of the stellar mass of Canes Venatici I.

Fig. II.5.4 shows a contour representation of the old (represented in red) and young (blue) star populations observed with the LBT. The spatial distribution of the young population revealed in the LBT study corresponded well with the distribution found spectroscopically by Ibata et al. Accordingly, one would have to assume that both star groups also differ kinematically. Initial studies thus reveal a complex evolution history in these far-lying dwarf galaxies which will soon attract further observations.

The dwarf galaxy Leo T, also discovered within the SDSS, poses serious challenges for the observers because, at 1.38 million light-years, it is by far the most distant known dwarf galaxy. Here too the images with the LBT made a much deeper-reaching photometry possible. The color-brightness diagram (Fig. II.5.5, left) proved to be rather complex and could only be represented through the overlaying of several populations. It follows that a very young star generation, with an age between 400 million and one billion years, co-exists with a significantly older population. A more exact analysis points to the fact that there was a long-lasting phase of star formation

Fig. II.5.4: Contour representation of the stellar distribution in Canes Venatici I. *Above:* all stars, old stars, *below:* young blue stars, both populations.





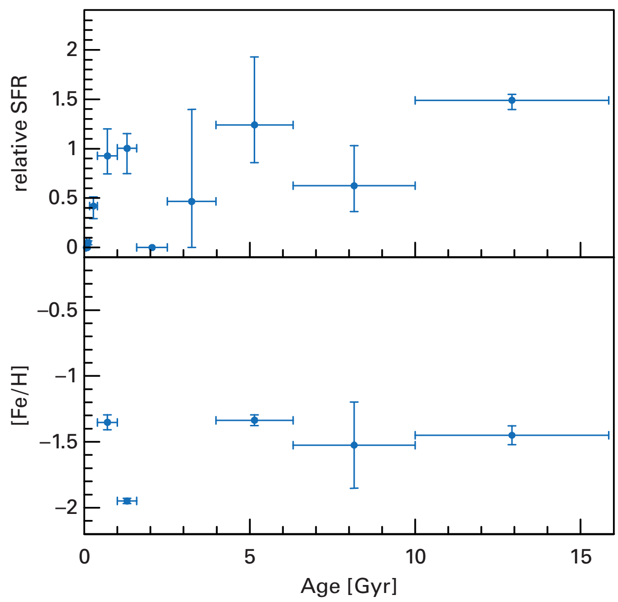


Fig. II.5.5: *Left:* the color-brightness diagram for the dwarf galaxy, Leo T, with evolution models; *right:* evolution of the star formation rate and of metallicity.

which ended approximately 400 years ago in this dwarf galaxy. Surprisingly, the metallicity of the stars did not change significantly from the first to the second star formation phase (Fig. II.5.5, right).

These first, impressive observations have brought LBT's performance ability to light. Simultaneously, the studied dwarf galaxies proved to be very interesting, and the results raise a series of questions: Why have dwarf galaxies evolved so differently? How can their evolution be fit into the entire evolution scenario for our galaxy? What role do dark matter halos play?

These questions will continue to be pursued by the MPIA group. LBT observations of the dwarf galaxies Leo II and Ursa Major II are already planned and will be analyzed by various ways and means. Observations of other dwarf galaxies have already been requested, in order to obtain as comprehensive a picture of as many dwarf galaxies as possible. This should lead to further conclusions about the evolution of these faint stellar systems.

Additionally, further observations of the Hercules dwarf galaxy are planned to pursue the question as to whether the Milky Way's tidal forces really did deform this galaxy. Should this be the case, then one should be able to discover additional stars which were dragged out of the galaxy and which now form a "tidal tail".

In a more distant future, astronomers hope to discover additional dwarf galaxies within the scope of the PanStarrs project in which the MPIA is also participating. These too could then be examined in detail with the aid of the LBT.

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II.6 Black Hole Activity in Quasars at High Redshift

In years past, several studies strengthened the thesis that super-massive black holes in the centers of galaxies decisively influenced the formation and evolution of stellar systems. Close correlations between the mass of the black holes on the one hand and the velocity dispersion and the mass of the surrounding bulge on the other hand strongly support this. Many questions still remain open in this context: How rapidly did black holes grow in the young universe? What role did they play in the young universe, especially during the reionization age? These questions were pursued by an international team headed by the MPIA. The team spectroscopically examined five quasars at redshifts around $z = 6$ (Fig. II.6.1). These objects emitted the light we receive today around one billion years after the big bang. (According to current knowledge, the universe is 13.7 billion years old.)

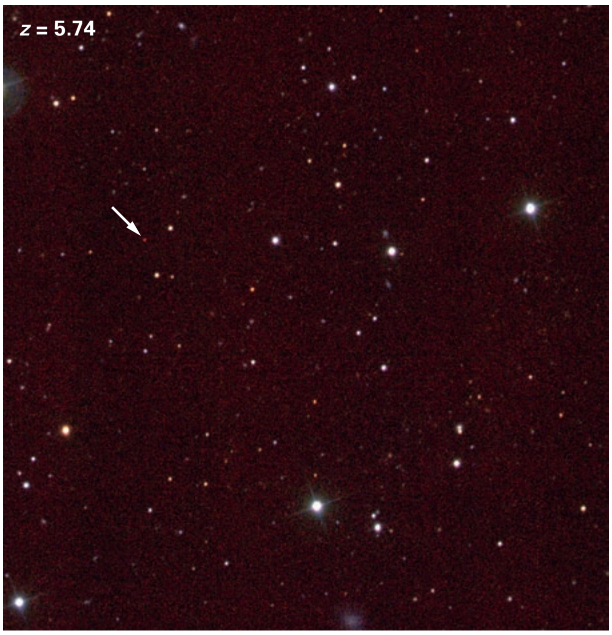
Several wide sky surveys in recent years have brought to light a rich variety of data relating to quasars. The Sloan Digital Sky Survey (SDSS), in which the MPIA participated, alone delivered more than 46,000 quasars in a 5282 square degree area of the sky. A study based thereon conducted in 2002 showed a strong evolution in the number density of these sources, whereby the maximum lay at redshiftings between $z = 2$ and $z = 3$. At that time, the universe was between 2.5 and 3.5 billion years old. Thus the number density of these objects at $z = 3$ is around 40 times as high as those at $z = 6$. Here the expansion of the universe was taken into consideration ("co-moving density").

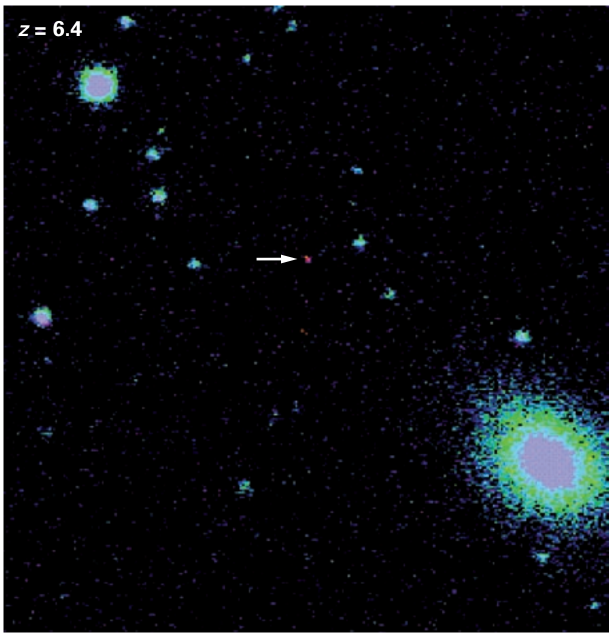
On the other hand, no significant spectroscopic differences could be ascertained in quasars between $z = 6$ and $z = 0$. This hints at a very rapid evolution of black holes – found in the center of quasars and that are responsible for their immense luminosity – within the first billion years after the big bang (at $z > 6$).

Selection of observed Quasars and Data Analysis

So far, more than 20 highly redshifted quasars with $z > 5.7$ have been found within the SDSS data set. From these a group of astronomers led by MPIA chose five objects with $5.8 < z < 6.3$ for observation with the Very Large Telescope (VLT). The observations were performed with the ISAAC (Infrared Spectrometer And Array Camera) near-infrared spectrograph. In the wavelength region of 1.0 to 2.5 μm there are C IV, Mg II, and Fe II emission lines which are suitable for the analysis of several quasar characteristics, especially of the masses of their central black holes. The objects showed luminosities in the z-Band between 18.7 and 20.5 magnitudes which required integration times of up to 12 hours for the spectra.

Fig. II.6.1: Two highly redshifted quasars at $z = 5.74$ and $z = 6.4$ which were discovered in SDSS images. The second quasar is the most distant known object. It emitted its light at a time when the universe was 800 million years old. (Image: S. Kent, SDSS Collaboration)





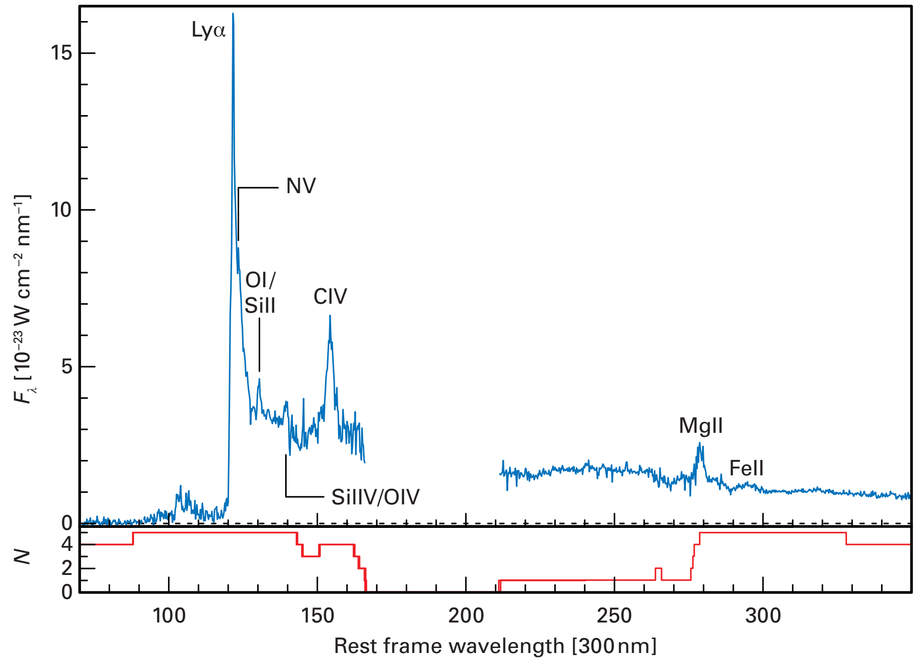


Fig. II.6.2: An overlay of all five quasar spectra (related to the same rest frame) shows their most important emission lines.

Fig. II.6.2 shows an overlay of all spectra while taking into consideration varying redshifts. They demonstrate the typical characteristics very clearly: Dominant emission lines, such as Lyman-α, C IV, and Mg II, can be easily recognized while Fe II lines are quite weak. Below Lyman-α the intensity sinks almost to zero. This phenomenon, which is typical for highly redshifted quasars, is called the Gunn-Peterson trough. It is due to the absorption of neutral hydrogen which is located between the quasar and earth. In quasars in the reionization era (that is, the era in which interstellar hydrogen was still mostly neutral) this leads to an almost complete absorption.

The masses of the central black holes in quasars are determined from the equivalent widths of their emission lines. As Fig. II.6.2 demonstrates, this is possible only after careful subtraction of the underlying continuum. What complicated matters even more was that, in this wavelength region, a so-called Balmer pseudo-continuum occurs next to the "normal" thermal continuum. This pseudo-continuum is composed of a series of hydrogen emission lines.

After the modeling and subsequent subtraction of both of these continua, the equivalent widths of the emission lines were ascertained. Here a procedure for Fe II had to be applied because a series of lines were involved. This was done with the aid of a sample spectrum (template) as is typical for highly redshifted quasars. This template was established from numerous, less extremely redshifted quasars in the SDSS.

Enrichment of the Quasar Environment with Heavy Elements

One of the most remarkable findings in the analysis of highly redshifted quasar spectra resulted from studies of the abundance of "heavy" elements (heavier than helium), also known as metallicity. According to the prevalent theory, only the lightest elements – hydrogen and helium – were formed at the time of the big bang. Heavier elements, such as carbon, nitrogen or oxygen, were formed later in fusion reactions in the interior of massive stars which at the end of their lives injected these "metals" into the environment through stellar winds and supernova explosions. The interstellar medium was thus more and more enriched with heavy elements. From earlier studies of the most distant quasars, one can conclude that this process must have taken place very efficiently.

The abundance of iron (Fe) relative to magnesium (Mg) can, in this sense, serve as a "cosmological clock". Iron is produced first and foremost by type Ia supernovae in which a white dwarf explodes in a double star system. Magnesium, on the other hand, originates predominantly from Type II supernovae which can be traced back to the explosion of collapsing very mass-rich stars. Because the evolution of a mass-rich star up to the supernova explosion of type II proceeds much faster than that of a mass-poorer star into a supernova explosion of type Ia, the Fe/Mg ratio supposedly became very large in the first one to three billion years after the Big Bang and then regressed slowly. However, studies of elliptical galaxies have shown that after only 300 million years, the maximum Fe/Mg ratio has been reached. This time span depends, however, on parameters such as star formation rate, star lifespan, and the initial mass function.

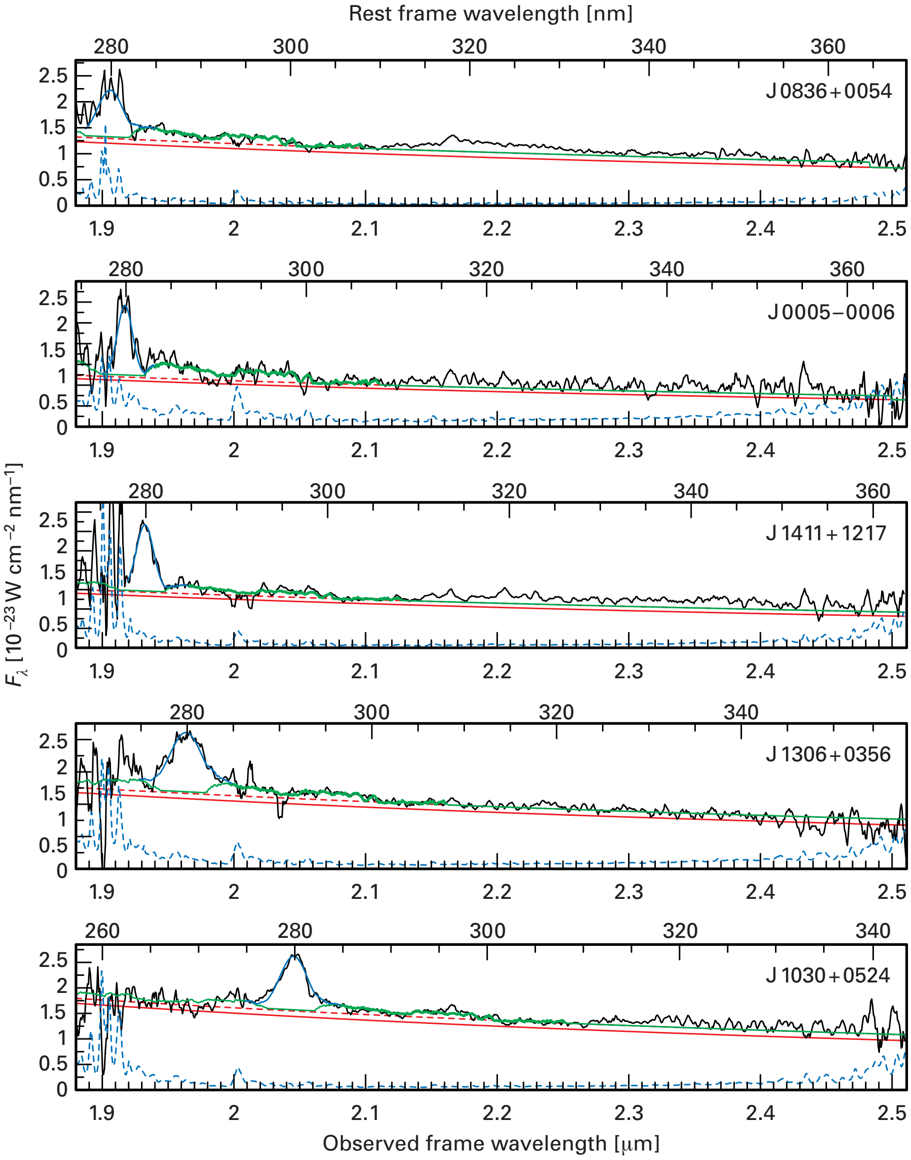


Fig. II.6.3: Spectra of five quasars in the range of the Mg-II line. Several characteristics are highlighted in color: *solid blue:* fit to the emission line; *solid red:* continuum; *dotted red:* Balmer continuum; *solid green:* template spectrum for Fe II; *dotted blue:* noise limit.

The element abundance ratio could be determined from the intensity ratio of the Fe II to Mg II lines in the spectra of five selected quasars (Fig. II.6.3). The values found are between two and five with an accuracy of 20 to 40 percent.

A comparison with other research results is not trivial, because these were partially obtained through other methods and the uncertainties are rather large. Furthermore, how exactly the Fe II to Mg II line ratio reflects the actual abundance ratio has not been completely understood. Still, the comparison shown in Fig. II.6.4 is informative: The new analysis more or less confirms the general trend of previous results according to which – even at large redshifts – no evolutionary trend is indicated. Because the universe was around 900 million years old at $z = 6$, the enrichment with heavy metals must have already progressed much earlier. If one assumes a typical en-richment period of 300 million years, then the star formation era must have already been triggered at redshiftings beyond $z = 8$. This result sets scales for future attempts at finding the stars of the earliest generation (population III).

The Masses of the Central Black Holes

As described at the outset, the evolution of black holes is closely linked to the evolution of galaxies. The evolution of black hole masses could provide insight into this still

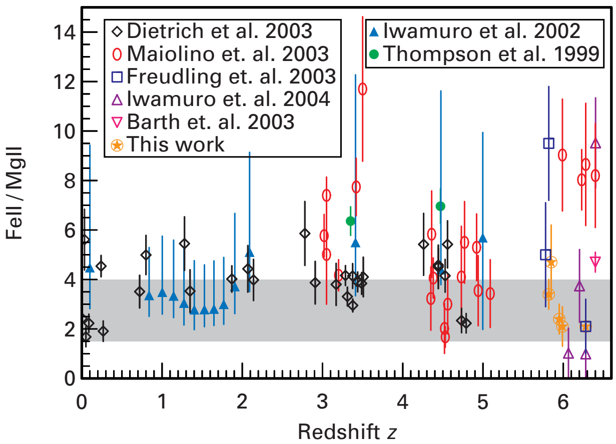


Fig. II.6.4: The Fe II/Mg II line ratio as a function of redshifting. The five values of the recent study around $z = 6$ are represented in yellow by a *circled x*.

unknown interactive relationship. From the new data, these mass values can be ascertained in three different ways:

- The most direct method consists of determining the complete bolometric luminosity of the quasars. If one assumes that the black hole gathers material from its surroundings at the maximum rate possible, then radiation pressure and gravity are held in balance. One says then that the quasar is radiating at its Eddington Luminosity. If one sets the Eddington Luminosity equal to the bolometric luminosity, then one obtains the minimal mass that black holes must have in order to reach the observed luminosity.
- A different method relies on the fact that black holes are surrounded by a region of gas in which the quasar's emission lines are formed. This region is called the Broad Line Region (BLR) because the lines of this region are strongly broadened through rapid rotation. The central mass can be derived from the radius of the BLR and the velocity of the gas that is contained therein. Both quantities can be derived, subject to certain assumptions, from the spectrum, especially from the width of the Mg II line. The central mass then results from the BLR's radius and the velocity of the gas.
- A third method depends on an empirical relation between the central mass and the continuum luminosity at a wavelength of 135 nm and the width of the C-IV line. Here, too, BLR characteristics are used.

All three methods were applied to the spectra of five quasars. Because each of them contains some uncertainties, they yield – as would be expected – different mass values (typically different by factors of two or three), although the CIV based method provided the largest values in all cases. Overall, the result was a range of 300 million to 5.2 billion solar masses. The 300 million solar masses represented the smallest value so far among highly redshifted quasars. Nevertheless in most cases very high mass values resulted, which points to a surprisingly fast growth of supermassive black holes after the big bang. To compare: the black hole in the center of our galaxy has a mass of 3.6 million solar masses. To explain this phenomenon of rapid growth is one of the most urgent tasks of cosmology.

In this context, it would be very interesting to find out whether, in these highly redshifted quasars, the aforementioned correlations between the masses of the black holes and the masses and velocity dispersions of the bulges have validity: question that is difficult to answer because corresponding measurements relating to these extremely distant quasars are still rather inexact. The mass of the bulges can be estimated with the help of observations of molecular gas in the galaxies, such as Dominik Riechers was able to show in 2006 (Annual Report 2006, p. 40).

The results so far point to the fact that the redshifted galaxies deviate from the known relation between the masses of black holes and the masses and velocity dispersions of the bulges. Based on these results, the implication is that the black holes develop faster than the galaxy bulges. Yet the results are still disputed and computer simulations cannot yet deliver clear predictions.

If these initial suspicions are confirmed, then the following fascinating questions follow: Did the black holes come first and then form into galaxies? Did black holes have the possible effect of "condensation seeds" around which the galaxies formed? MPIA research teams are pursuing these gripping questions and initial results are expected in the near future.

Quasar Activity Periods

Earlier research, led by American astronomers who are also a part of the team, of 23 quasars with redshifting around $z = 6$ revealed, in all cases, deep Gunn-Peterson troughs. From this one can conclude that the intergalactic medium up to the proximity of the quasars is overwhelmingly neutral. At the same time it has become clear that the reionization of the medium through energy-rich radiation must have been a complex process that spanned a longer period.

What quasars contributed to the reionization is a much discussed question today. After the "switching on" of the UV and X-ray radiation, the black hole, or rather the accretion disk surrounding it, created around itself a consistently expanding sphere of ionized gases in the then ($z > 6$) still largely neutral intergalactic medium: a so-called Strömgren sphere, the radius of which is marked by the long wave (red) edge of the Gunn-Peterson trough in the continuum spectrum. Yet the determination of an absorption edge is not simple, because the absorption is often incomplete (Fig. II.6.5).

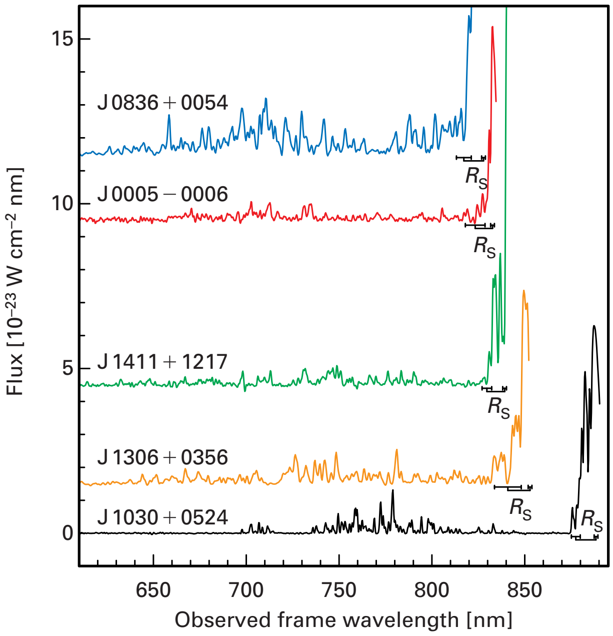


Fig. II.6.5: Gunn-Peterson trough in the five quasar spectra on the "blue" side of the Lyman-α line. The size of the Strömgren spheres, R_S, is marked.

The astronomers established this edge visually in the five quasar spectra. In this manner, they could calculate relatively uniform Strömgren radii of around 16 million light years. The interesting question arises as to how long the quasars needed to create this sphere around themselves.

The activity phase depends on several quantities, especially the emission rate of ionizing photons and the density of neutral hydrogen. Given certain assumptions, these quantities permit the determination of a lower limit for the activity period. However, the values determined in this way are very uncertain. Depending on the method used, the results for the five quasar activity times are between 6 and 90 million years or, alternatively, between one and 20 million years. In this case, the values are small in comparison to the universe's age (at that time) of 900 million years. We were thus observing the quasars in a very early activity phase, according to cosmic standards.

With the described research, Dominik A. Riechers completed his dissertation. In this reporting year, he graduated and received a Hubble Postdoctoral Fellowship at the California Institute of Technology from 2007 to 2010 for his research project "From the Epoch of Reionization to the Peak of Galaxy Formation: Properties of Intensely Star-Forming Galaxies in the Early Universe".

Further steps will consist of broadening the current data base. The MPIA team has therefore already applied for the observation of an additional 23 quasars out of the SDSS. In this study, particular attention will be paid to fainter objects with less massive black holes.

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II.7 Dwarf Galaxies – the "Missing Satellites" of the Milky Way

Our galaxy is surrounded by an extended system of satellites. These include on the one hand around 160 known globular clusters which orbit at a distance range of up to 400,000 light years around the galactic center. Added to them are dwarf galaxies, of which until recently only nine were known to exist in the galactic environment. However, today cosmological models predict, that the Milky Way System is surrounded by at least 50 such low-mass stellar systems. This discrepancy between theory and observation is known as the "missing satellite problem". Now, within a short time, eight additional dwarf galaxies have been found within the data of the Sloan Digital Sky Survey (SDSS). Four of these were discovered by an international astronomer team under the lead of the MPIA and the University of Cambridge. If one considers the low detection efficiency for dwarf galaxies and the limited area of the sky covered by the SDSS, then the "missing satellite problem" appears to be less severe.

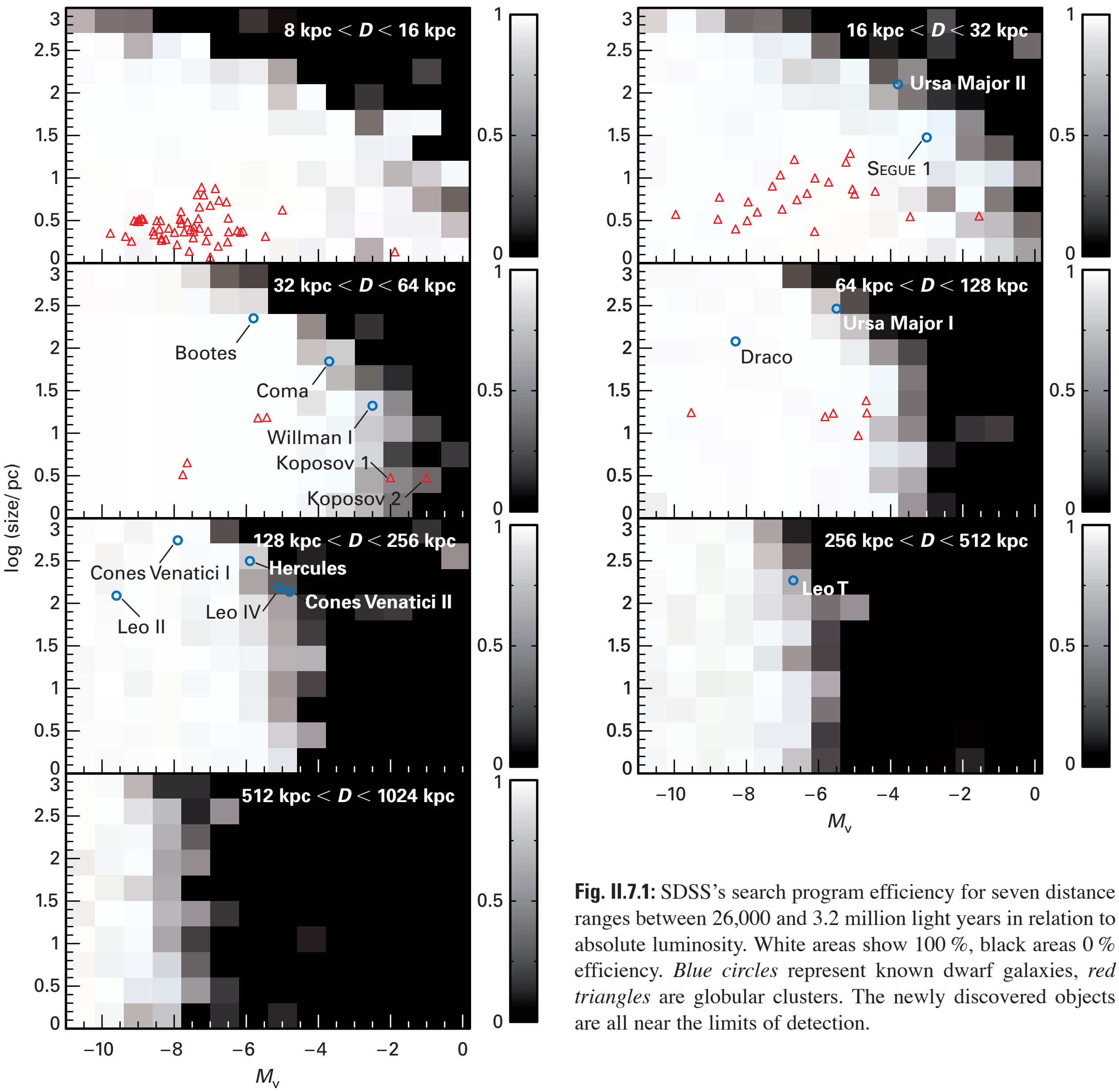
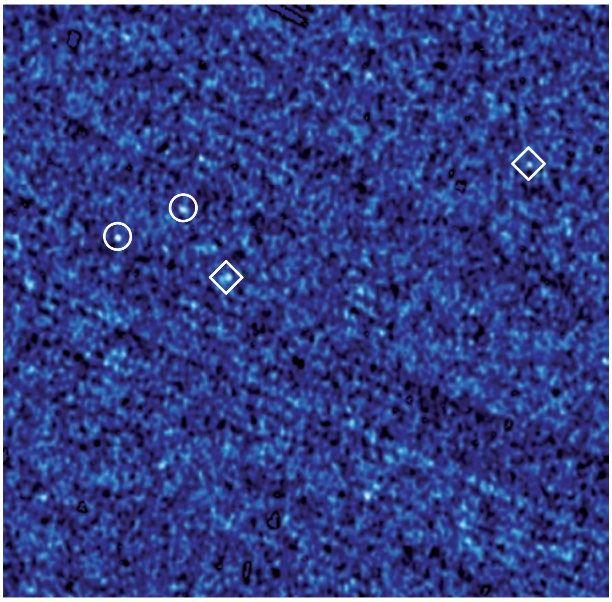


Fig. II.7.1: SDSS's search program efficiency for seven distance ranges between 26,000 and 3.2 million light years in relation to absolute luminosity. White areas show 100 %, black areas 0 % efficiency. *Blue circles* represent known dwarf galaxies, *red triangles* are globular clusters. The newly discovered objects are all near the limits of detection.



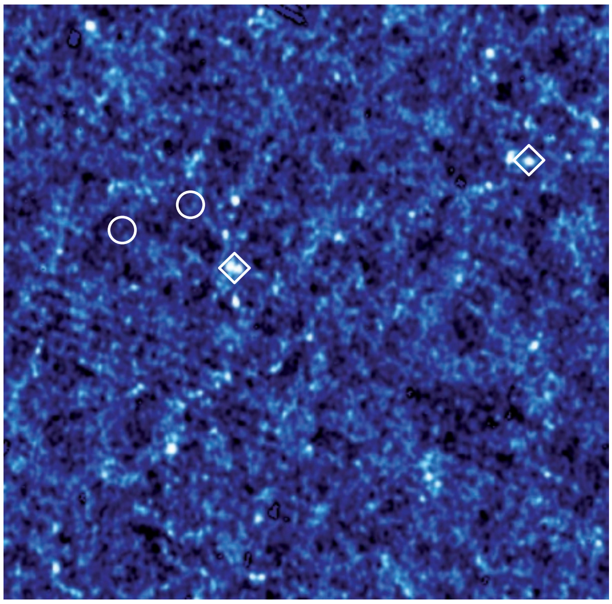


Fig. II.7.2: A 22 times 22 square degree sized field of the SDSS for stars (*left*) and galaxies (*right*). Ursa Major I and Willman I (*circles*), two known satellite systems to our Milky Way, were discovered by the program as well as two distant clusters of galaxies (*diamonds*).

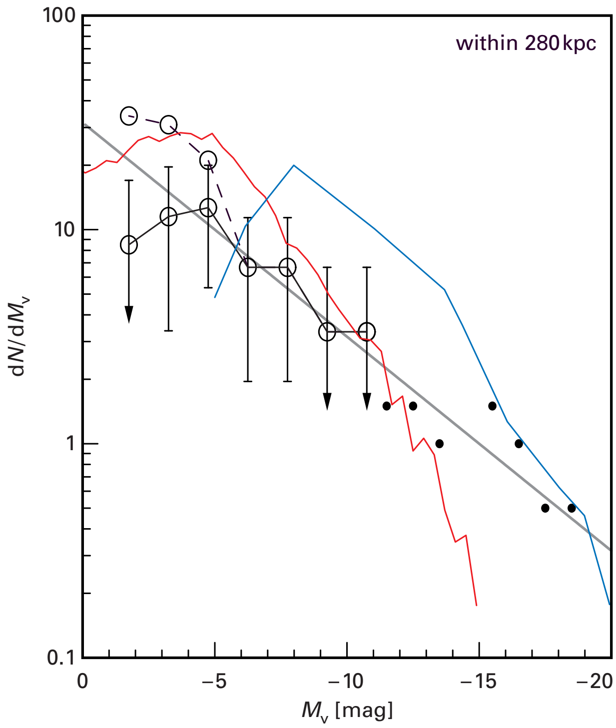


Fig. II.7.3: Volume corrected luminosity function for a maximum distance of 900,000 light years. *Solid line with open circles:* brightness limit $r < 22.0$ mag, *dotted curve:* brightness limit $r < 22.5$. The *red and blue lines* show the results from two model calculations relating to the formation of dwarf galaxies.

Current cosmological models describe the formation of galaxies under the influence of cold, dark matter. According to this scenario, in the early universe huge clouds of dark matter existed, which acted as "gravitation traps" for normal baryonic material. The galaxies therefore formed in the center of large halos of dark matter. However, these halos were not isolated structures but they interacted with each other: Small halos merged into larger ones. A part of the smaller halos continued to exist, however, and orbited the larger halos on satellite paths. While large galaxies formed in the central halos, dwarf galaxies are supposed to have formed in the satellite halos.

Computer simulations already pointed in 1999 to the fact that a galaxy such as our Milky Way System should be surrounded inside a radius of around two million light years by approximately 50 dwarf galaxies; the local group within a radius of five million light-years should even contain up to 300 such satellite galaxies. This prediction stood in clear contrast to observations: Up until a few years ago, only nine dwarf galaxies were known to exist.

On the theoretical side, many possibilities were discussed in order to explain this discrepancy. For example, it was assumed that in some satellite halos, star formation was suppressed for unknown reasons which led to a large number of invisible conglomerates of dark matter. At the same time, however, it was also clear that the discovery of dwarf galaxies was only possible to a limited extent. After all, an adequate instrument to perform such studies only became available it was only with the SDSS, in which the MPIA is taking part.

The Search for Needles in the Hay Stack – Four New Dwarf Galaxies

In fact, four new dwarf galaxies were already discovered among the SDSS data in 2005 and 2006. They were, as is generally so, named after the constellations in which they were found. These were: Ursa Major I and II, Canes Venatici, and Bootes. An international astronomer team led by the MPIA and the University of Cambridge were able during the reporting year to discover four more dwarf galaxies. An additional faint object was added which was very likely a globular cluster.

In the context of the SDSS, an area approximately the size of 8000 square degrees around the galactic north pole (corresponding to about one fifth of the entire celestial sphere) was filmed in five photometric spectral ranges. The dwarf galaxies discovered so far cannot be seen on these images with the naked eye, rather they come to light only after systematic, computer-supported searches for over-densities of stars within specific brightness and color ranges.

An important criterion in searching for dwarf galaxies, and the later interpretation of data, is also the SDSS's sensitivity. Bright stars in the red-giant branch can be detected at distances of up to three million light years; while very faint stellar systems which hardly contain red giants can only be detected at a distance of one million light years. Thus the SDSS reached farther than any survey to date.

Under these boundary conditions, Sergej Koposov, Hans-Walter Rix and Eric Bell at MPIA with their colleagues developed a program to detect dwarf galaxies. A program of this type works as follows: One searches within an area of the sky for stars with selected colors and brightness and compares their numbers with expected values for background stars. A proven method in the search for overdensities in stars or for other deviations from average values within a particular region is the application of a spatial kernel: average values for all data points within a certain area of the sky (in our case the colors and brightness of the stars) are sought. The comparison with these average values will reveal deviations such as the searched-for overdensities in the angular scale of the selected kernel.

In order to test the efficiency of the program, the values of "artificial" dwarf galaxies and globular clusters were inserted. In this manner the search program's detection limit was determined for seven distance ranges from 26 000 to 3.2 million light-years in dependence on the searched for object's brightness (Fig. II.7.1). The size of the kernel played a significant role here: While a smaller kernel allowed for the better discovery of faint objects than a larger kernel did, this was at the expense of galaxy size. A large kernel adds up more stars from extended objects and therefore allows for the recognition of objects with lower surface brightness than a smaller kernel would have.

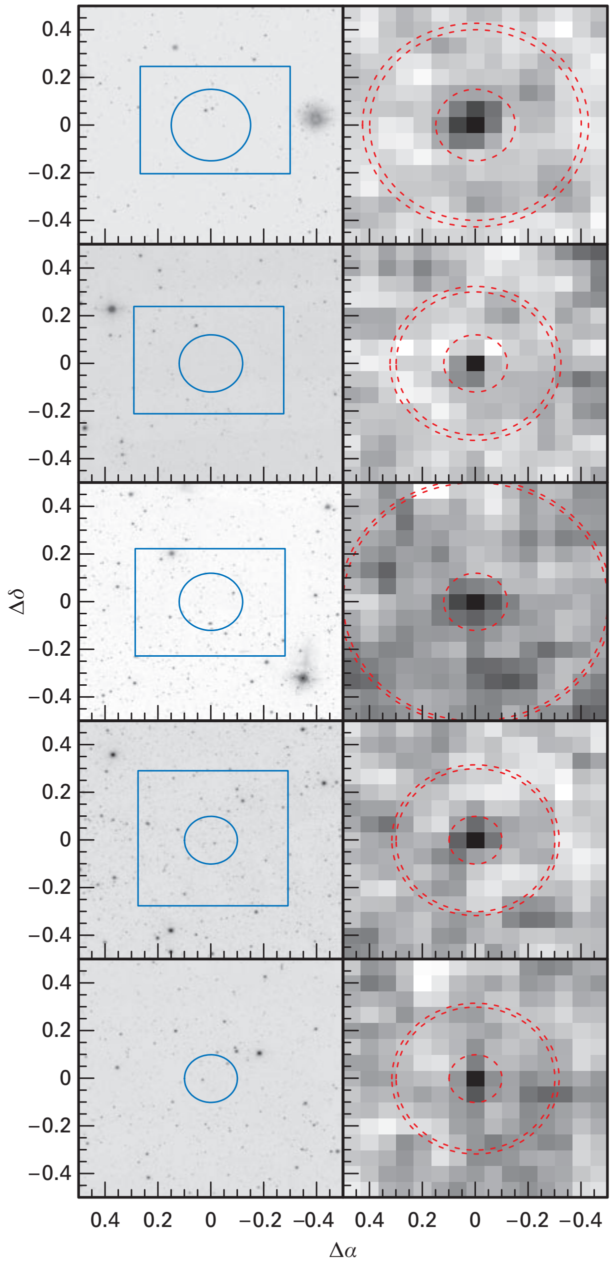
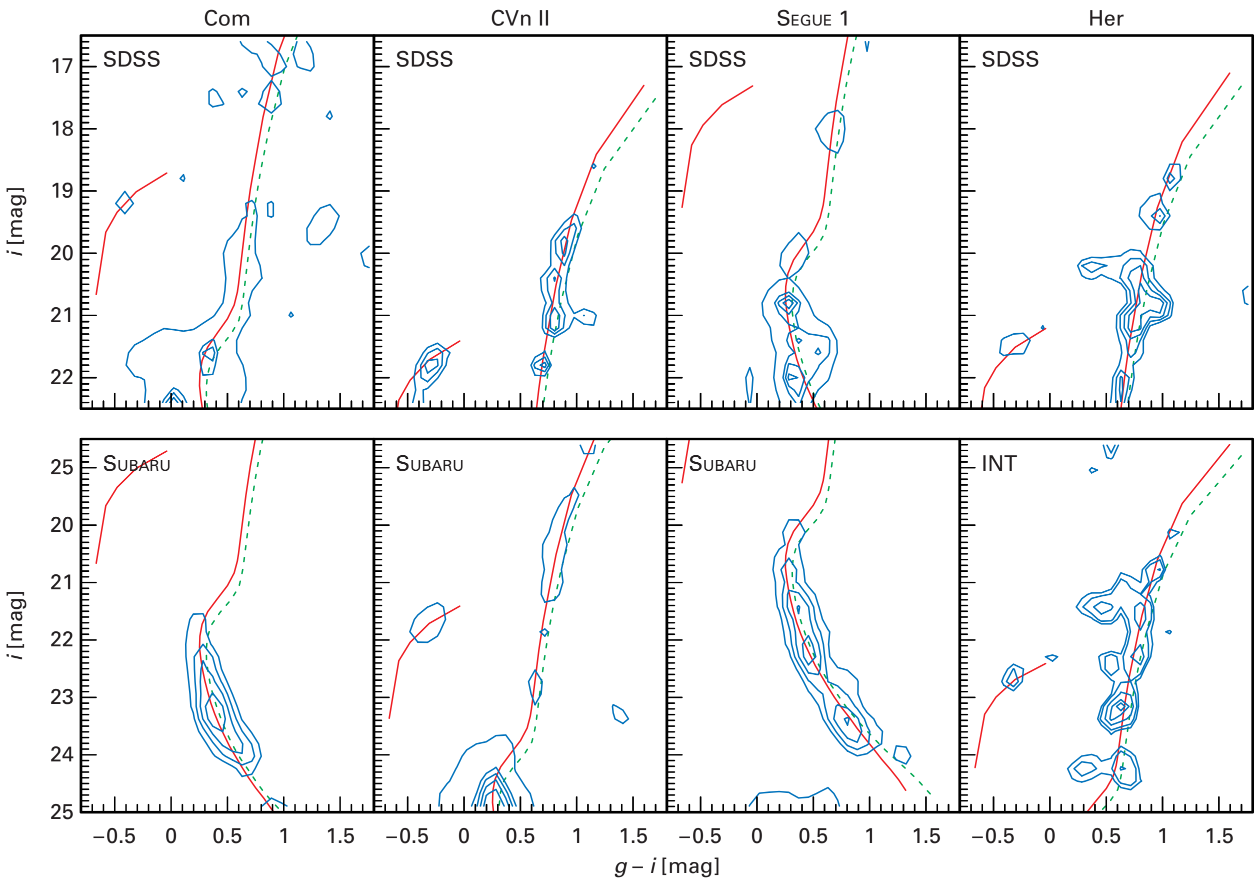


Fig. II.7.4: *Left column:* SDSS images of indicated objects as well as the positions of the SUBARU and INT fields. *Right column:* Images filtered with a 4′ kernel.

As a compromise, a kernel of 4 arc minutes was used where the red limiting magnitude lay around 22.0 mag. In the program's trial runs, it turned out additionally that HII regions and clusters of galaxies were erroneously identified as dwarf galaxies (Fig. II.7.2). This problem could be eliminated through a comparison to existing catalogues of these objects.

Through this method, MPIA astronomers and their colleagues were able to identify four as yet unknown dwarf galaxies: Coma Berenices (Com), Canes Venatici II (CVn II), Leo IV, and Hercules (Her). The fifth object,



named Segue 1, is probably a globular cluster. A look at Fig. II.7.1 shows that all dwarf galaxies recently discovered through the SDSS that are located at distances beyond 100,000 light years are at the detection limit. This shows the enormous efforts required to track down these faint dwarf galaxies among the large dataset.

Fig. II.7.5: *a)* Contour representation for the color-brightness diagrams, *dotted line:* Data of both globular clusters M 92 and M 13;

Comparison with Models and the Missing Satellite Problem

These nine objects now also permit the determination of a luminosity function (that is, the number of objects per brightness interval) for dwarf galaxies, which can be compared with theoretical predictions. This allows, for the first time, the ascertainment of a distribution of faint objects.

In Fig. II.7.3, volume corrected data for a maximal distance of 900,000 light years are listed. The open circles that are connected with a solid line show the distribution in the normally utilized brightness limit of $r = 22.0$ mag; the data in the dotted curve show a brightness limit of $r = 22{,}5$ mag for which a strong correction was necessary. The red and blue lines show the results of two theoretical models, which both require that star formation in satellite halos of the young universe be suppressed due to strong UV radiation. The solid circles represent the known bright dwarf galaxies of the Milky Way System and the Andromeda galaxy. They complement the luminosity function for bright objects.

It is clear that the models do not sufficiently describe reality: One model overestimates the number of faint satellite galaxies (blue curve) while the other underestimates the number of bright ones (red curve). Further efforts are required to create a consistent model for dwarf galaxies. The progress in the observation of faint dwarf galaxies is, however, significant. It allows for the first time a comparison between models and observations of these satellite systems.

The “missing satellite problem” does not seem so serious in light of these new discoveries. With the SDSS, so far a total of eight new dwarf galaxies have been discovered. Because the survey only comprised a fifth of the entire sky, one may assume 40 potentially existing satellite systems to which one can add the nine objects that were already known. This total number of 50 satellite systems brings observations very close to the models, also considering that there could still be many fainter systems beyond SDSS’s detection limit.

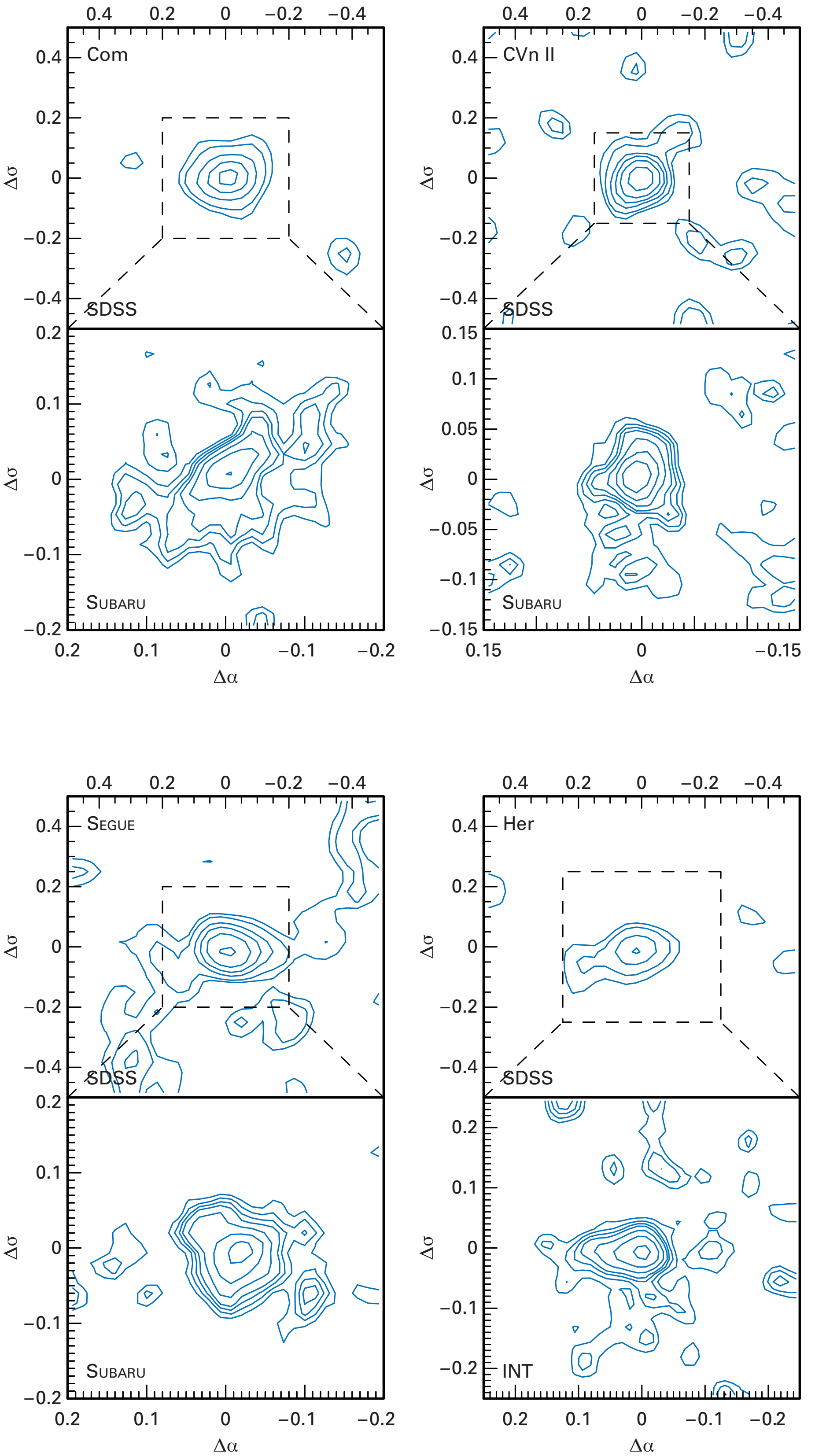


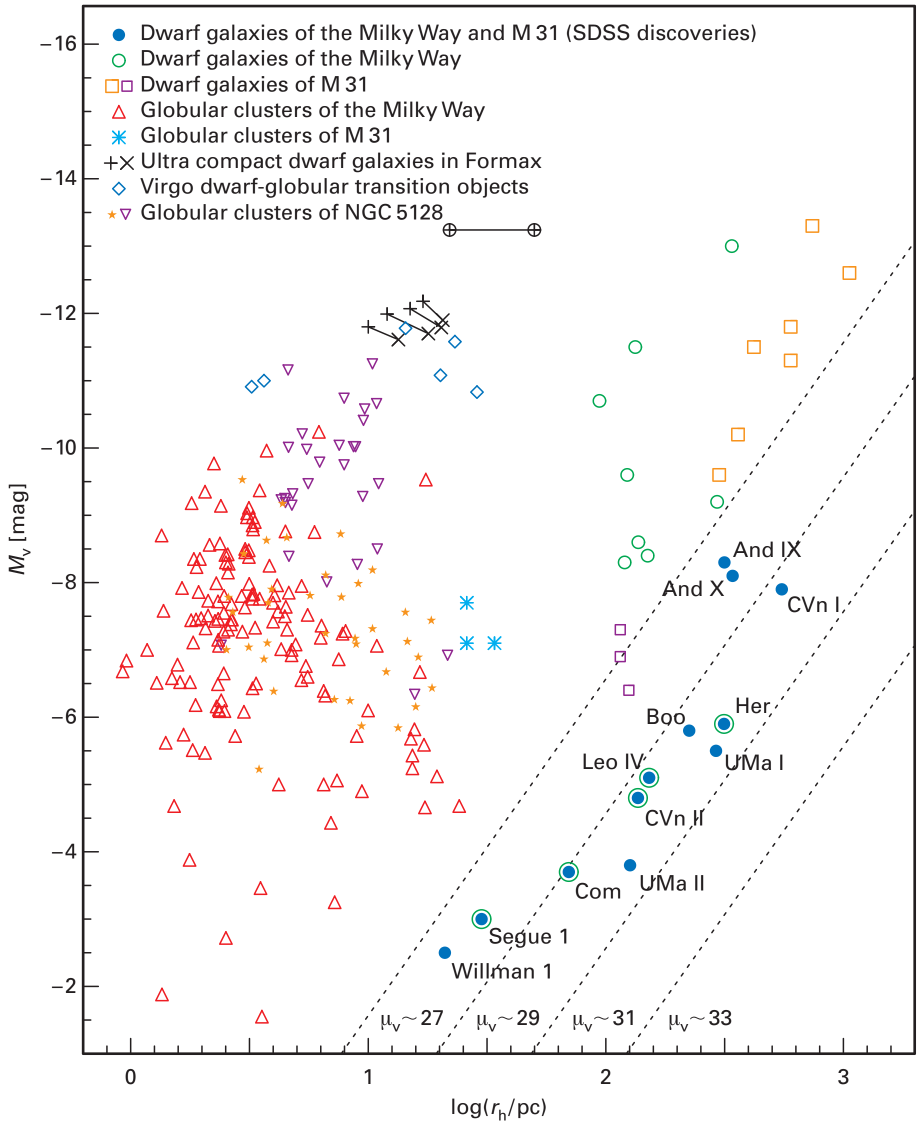
Fig. II.7.5: *b)* Distribution of indicated objects, derived from the SDSS data (*top*) or, alternatively, from the Subaru images (*bottom*).

Follow-up Observations relating to Dwarf Galaxies and the new Globular Cluster

The astronomers observed the newly discovered dwarf galaxies (with the exception of Leo IV) in detail with the Subaru telescope on Hawaii and the Isaac Newton telescope (INT) on La Palma. Fig. II.7.4 shows in the first column the SDSS images of the corresponding objects as well as the positions of the Subaru and INT fields. The second column shows filtered images with a kernel of 4′. The dotted circles indicate those regions in which the color-brightness diagram of stars was established. Contour lines indicating the color brightness diagrams as well as the distribution of stars are shown in Fig. II.7.5. The derived characteristics are summarized in the following Table.

Object	Distance (kpc)	radius (pc)	Ellipticity
Com 3.m7	44	70	0.5
CVn II	150	140	0.3
Her	140	320	0.5
Leo IV	160	160	0.25
Segue 1	23	30	0.3

Fig. II.7.6: Comparison of the absolute luminosity and size of different satellite systems.



Here a comparison between absolute brightness and size of various satellite systems is interesting (Fig. II.7.6). Noticeable is a bipartition among the objects. There is a gap between objects with radii of 130 light-years and 320 light-years. This gap seems entirely real and not dependent on observation techniques, because the new SDSS survey should have permitted objects to be found in this interim region. This gap especially separates globular clusters from dwarf galaxies: For a given absolute luminosity, globular clusters are more compact than dwarf galaxies. This could be a sign that there is no evolutionary connection between these classes of stellar systems. Supporting this is the fact that all objects located left of the gap showed no indications for larger amounts of dark matter, while the dwarf galaxies – as far as is known – are dynamically dominated by it.

Nevertheless, there are no spectra available for the newly discovered dwarf galaxies. Thus nothing is known about their dynamic characteristics and their dark matter content. Spectroscopic data are therefore also important, because a second explanation is also possible for the existence of these dwarf galaxies: They could be remains of a galaxy that merged into our Milky Way system in earlier times. In this case, one would not expect to find large amounts of dark matter in these dwarf galaxies.

Therefore, spectroscopic studies of the newly discovered dwarf galaxies are urgently needed. They should provide information regarding the dynamic composition of the stellar systems and thus also about their formation history. Furthermore, spectra contain information regarding the content of heavy elements. The dwarf galaxies known so far are very “metal poor”: this points to the fact that they belong to old components of the Milky Way which formed in its halo, as is predicted by the hierarchical formation scenario. Further studies will have to show whether this is also true for the recently discovered faint dwarf galaxies. This is already indicated in the good correspondence between their color-magnitude diagrams and those of M 92 and M 13.

Finally, Fig. II.7.6 shows an additionally significant detail: The dotted lines show the location of objects in this diagram with a constant surface brightness μ, where μ is the surface brightness in magnitudes per square arc second. All objects with $\mu > 27$ mag were found within the scope of the SDSS – this demonstrates once again the strength and the significance of this sky survey.

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Lick Observatory, Ohio State University,
Pennsylvania State University,
Michigan State University,
Apache Point Observatory,
Subaru Telescope, Gemini Observatory (all in the USA),
Mt. Suhora Observatory, Cracow Sternberg
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II.8 Unique Galay Portraits with THINGS

Under MPIA's leadership using the Very Large Array (VLA), an international team of astronomers studied a total of 34 nearby galaxies in the light of atomic hydrogen's 21 cm line. The VLA is a radio interferometer located near Socorro (New Mexico). The project was designated "The HI Nearby Galaxy Survey" (THINGS) and has been the largest program of this type at the VLA. It delivered data that are unique from many points of view and which will be the foundation for many systematic studies. In an initial series of publications, MPIA astronomers and colleagues from other institutions studied the rotation curves of spiral and dwarf galaxies in order to understand more about the puzzling dark matter halos. In a subsequent study, they researched the connection between the density of interstellar matter and star formation.

Observations of atomic hydrogen's (HI) 21 cm line have been considered for decades to be one of the best methods to study the structure and kinematics of the interstellar medium – both in our Milky Way system as well as in other galaxies. Compared to other radiation, this has a series of advantages. HI emission experiences no extinction through interstellar dust and is in almost all cases optically thin, so that one can immediately derive the density of the hydrogen gas from the measured intensity. In addition, the kinematics of the hydrogen gas can be ascertained by looking at the Doppler effect.

Selecting Galaxies for THINGS

Because of the comparatively large wavelength, one needs large telescope apertures to obtain a sufficient spatial resolution. The VLA interferometer (Fig. II.8.1) offers unique possibilities in this regard. The VLA worked for THINGS in three different configurations with antenna separations of between 35 m and 11.4 km. A high spectral resolution between 1.3 and 5.2 km/s and a high spatial resolution of 6 arc seconds was decisive for the project. Thus, astronomers had to go to the technical limits of the instrument.

The principal goal of THINGS is to study key characteristics of galaxies across the entire HUBBLE sequence (with the exception of starburst galaxies). Galaxy morphology, star formation and evolution, as well as mass distribution are the main areas of interest (compare 2005 Annual Report, p. 82).

The selection of galaxies followed several criteria. They cover a wide range in their star formation rates, absolute luminosities, and metallicities. Almost all galaxies are targets of the SPITZER Infrared Nearby Galaxies Survey (SINGS) project's catalogue in which the MPIA is also participating. So far, the NASA SPITZER space telescope is the most efficient infrared observatory. SINGS studies the near and middle infrared dust characteristics of galaxies. At the same time, for many of the THINGS galaxies, observations by the American GALEX space telescope and CO observations from the IRAM telescope are available. Thus, star formation rates can be ascertained and compared with the characteristics of neutral hydrogen (see below). Most of these observation data have about the same angular resolution of 6 arcseconds and can therefore easily be compared to each other.

There were also other criteria in selecting the galaxies. For example, all of them are in a distance range of 6 to 50 million light years, resulting in a spatial resolution of 300 to 1600 light years – which is significantly better than earlier observations. Galaxies from the Local Group were not included because their angular size in the sky is too large. In the end, 34 galaxies were selected requiring 500 hours observing time for the detailed study of their light on the 21cm line (Fig. II.8.2). On the following pages we present two already published results.

Rotation Curves and Models for Dark Matter Halos

Since the 1970s, there have been more and more indications that galaxies are embedded in extended clouds (halos) of dark matter. This was derived from the galaxies' rotation curves. If the galaxies consisted exclusively of visible matter, then the stars and gas clouds would orbit the center in Keplerian orbits on which the orbital velocity would decrease as the distance from the center grew. Yet, after a certain radius, one observes an almost constant velocity extending into the outskirts of the galaxies, our Milky Way also has such a rotation curve. This phenomenon is explained by the gravitational effect of the dark matter halo.

This dark matter must have already played a decisive role in the formation of galaxies. In the early universe it created potential troughs in which normal, baryonic material accumulated and further condensed into galaxies. Modern computer simulations take into account the gravitational effect of the dark matter, though its further physical characteristics are widely unknown. However, a problem has recently emerged in these cosmological calculations: The theory predicted that the density, and thus also the gravitational potential of dark matter halos, increases very steeply toward the center (with r^{-1} to $r^{-1.5}$). This is known as the "cuspy core" model. Galaxy rotation curves however can best be explained with a very moderately enhanced central density. Accordingly, the density of the dark mass halo in the central region is nearly constant or increases slightly toward the midpoint. This is described as the "soft core".

So far, galactic rotation curves were partially obtained from HI observations. These had, however, the disadvantage that their spatial resolution of at least 3200 light years was rather coarse and that the velocity resolution was low. Thus, several astronomers saw the possibility that non-circular movements would appear in the central regions which were not correctly captured by the observations and which smear out the measured radial velocity values. The data would then simulate a "soft core", where in reality a "cuspy core" is present.

Erwin de Blok's team at the University of Cape Town (South Africa) and Fabian Walter's team at the MPIA used the THINGS data to understand this problem. These measurements finally had a sufficient spatial and spectral resolution to be able to recognize non-circular components in the movement of gas clouds.

To perform their research, however, the list of THINGS galaxies had to be restricted. The inclination angle of the galaxies against the line of sight would have to be between 40 and 80 degrees. This is because, if one looks almost vertically at the disk, then the gas also moves perpendicular to the line of sight and corrections to the measured radial velocities become too large. If, in contrast, one looks nearly toward the edge, then the line of sight traverses regions of the galaxy that are too large, so that there are too many overlayered velocities. Finally, 19 galaxies with average inclinations were left remainng, among which were the large spiral galaxy M 81 and the dwarf galaxy IC 2574 (Fig. II.8.2).

From the Doppler shift of the 21 cm line, the astronomers determined the galaxies' rotation curves. This can be done in principle in several ways. For example, one can simply determine the position of the line maximum or fit a Gaussian curve to the line. All methods, however, present difficulties when the form of the line is asymmetrical due to the influence of non-circular movements. De Blok and Walter's team therefore decided to fit the 21 cm line with the aid of the so-called Gauss-Hermite Polynomial, which allows for a certain "skewness" to the profile of the line. Fig. II.8.3 shows how strong the effects from the application of these different methods are on the velocity determination.

The THINGS galaxies cover a large range of luminosities and morphologies. This is shown in a variety of rotation curves, as demonstrated in Fig. II.8.4. These were ordered such that the position of the origin was adjusted to the absolute brightness MB. Here it becomes clear that the rotation curves of brighter galaxies increase and

Fig. II.8.1: Areal view of the Very Large Telscope (VLA) in New Mexico.

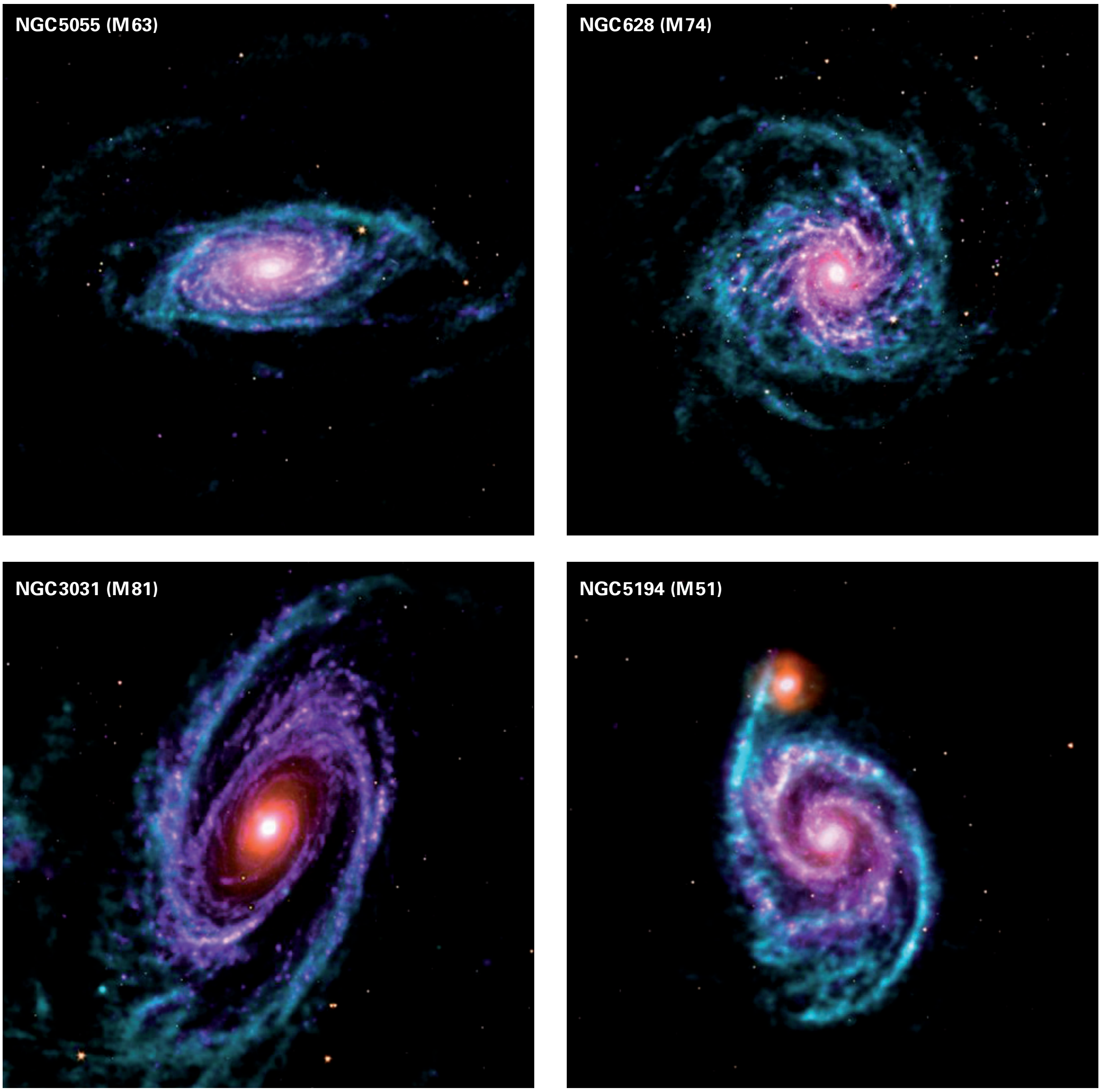


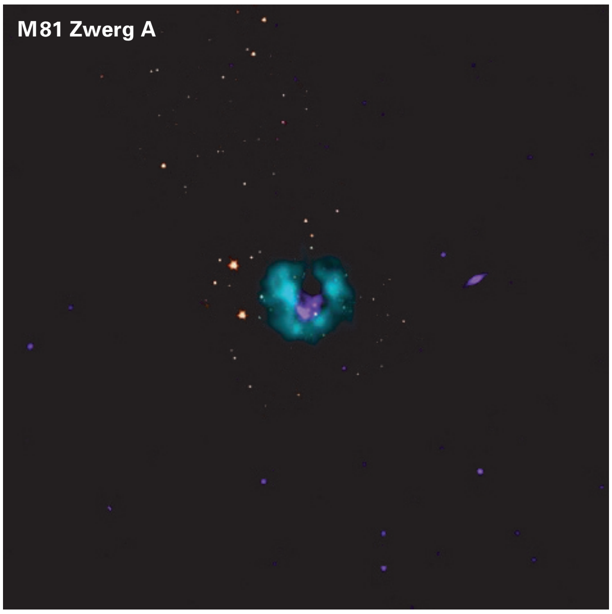
Fig. II.8.2: Several examples of the galaxies observed within the THINGS project; *left (this page):* Spiral galaxies; *right (Page 59):* Dwarf galaxies. The radio maps are coded in blue; with an overlay of infrared images (coded in yellow, they show the distribution of the old stars) and a combination of infrared and ultraviolet (coded in violet, they show the distribution of the star formation regions).

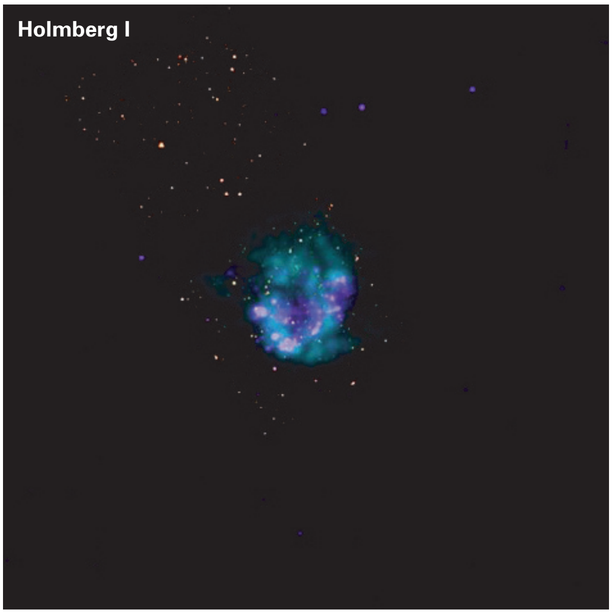
then approximate a constant value as the distance to the core region grows. The curves of faint galaxies slowly increase and do not reach a constant level within the HI area.

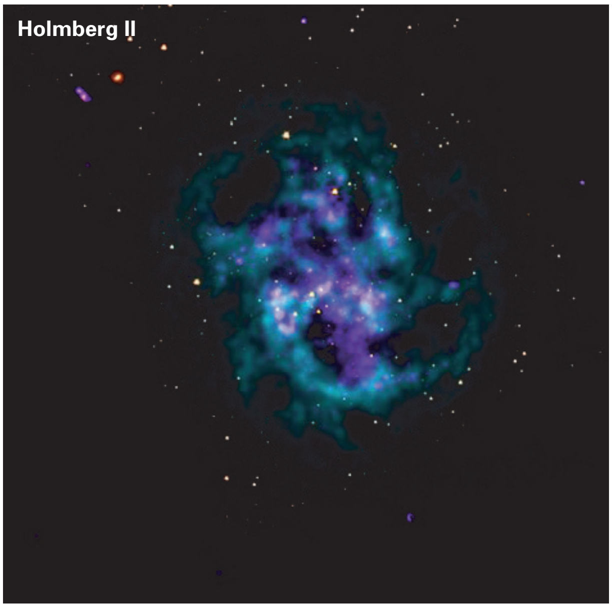
Mass models of the galaxies, including dark matter, could be obtained from the measured rotation curves and these could be related to the baryonic masses derived from the SPITZER data. Here it became clear that in bright galaxies the influence of dark matter increases as the radius grows but that the ratio of dark to baryonic matter is never as large as in faint galaxies. Bright galaxies are thus not so strongly dominated by dark matter as faint galaxies, and in particular dwarf galaxies. In the latter, the dark matter comprises over 90 percent of the total matter.

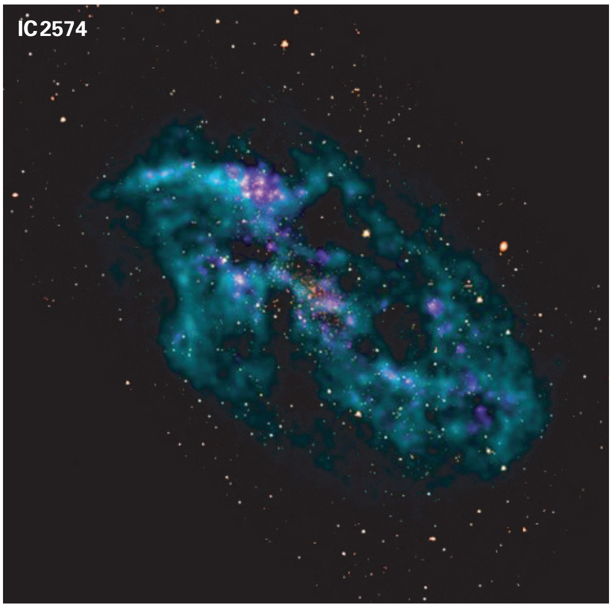
With the existing data, the group then approached the question of the mass distribution of dark matter. Would it be possible to distinguish between the "cuspy core" model and the "soft core" model as was suggested by observations?

Fig. II.8.5 shows all rotation curves (grey) as well as an averaged curve (black squares). Furthermore, the









results of several cosmological models are represented (dotted). All theoretical curves decline with larger radii, while the measured curves do not have this characteristic. The density of the empirically ascertained halo of dark matter is about a factor two less than what was theoretically expected. Furthermore all models always provide velocities that are too high for the central regions. That is, theory and observation do not match.

As a result, the astronomers were able to dismiss the possible explanation that had existed thus far: that is that the "soft cores" which were always observed were simulated through insufficiently resolved observations. The THINGS data had spatial and spectral resolution sufficient to exclude this. Thus a significant discrepancy continues to exist between cosmological simulations of dark matter halos and reality.

Star Formation and Gas Density

A decisive factor in the evolution of galaxies is their star forming activity. A quantitative measurement of the connection between the star formation rate (*SFR*) and gas density (*p*) is therefore a significant input parameter for all cosmological models of the evolution of galaxies. Maarten Schmidt already established in 1959 the relation for the Milky Way System according to which the number density of forming stars quadratically increases with gas density. Schmidt supported his findings through observations of HI gas. Subsequent observations of other galaxies in which the column density of the gas was established, however, provided no uniform picture. A variety of studies led to the power law SFR $\sim p^N$ with $1 < N < 3$. Theoretical studies established approximate values for N of between 0.72 and 2.

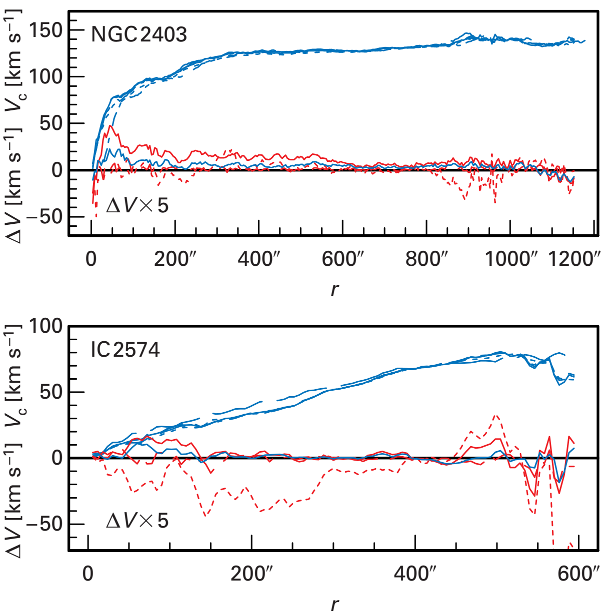


Fig. II.8.3: These rotation curves (*blue*) demonstrate how strongly the derived radial velocities vary depending on the method applied; *above:* the rotation-dominated galaxy, NGC 2403; *below:* IC 2574, in which strongly asymmetrical line profiles appear.

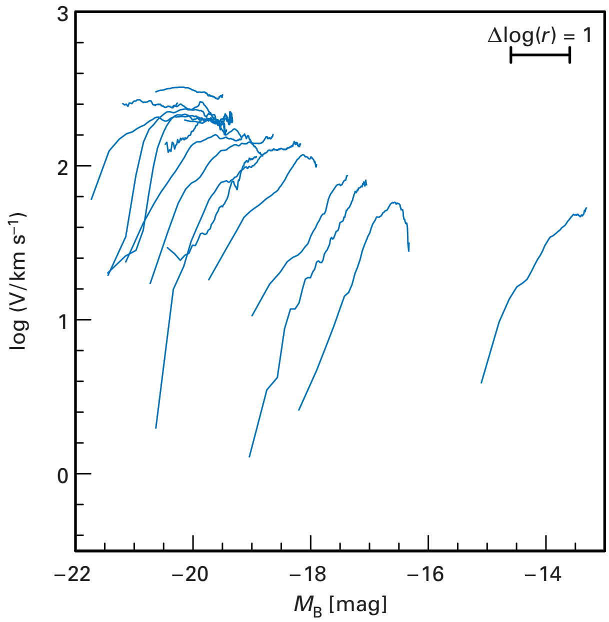


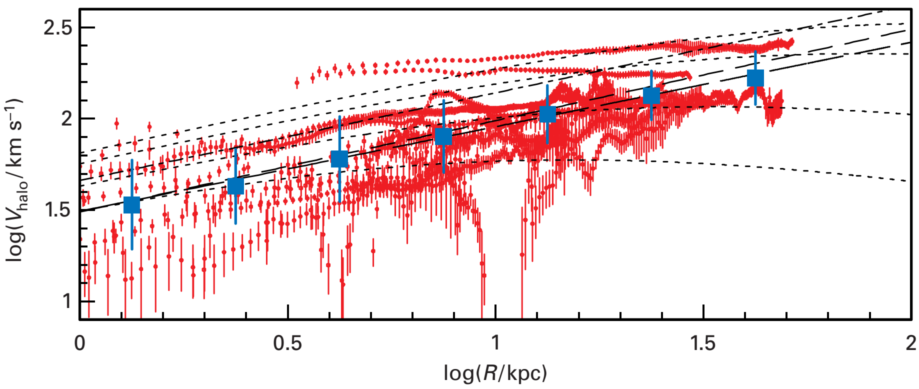
Fig. II.8.4: The rotation curves of all galaxies, sorted by absolute luminosities of the galaxies with a logarithmic representation of the rotation velocity.

It is still unclear today whether all galaxies or at least each galaxy type follows a universal "Schmidt Law" or whether varying external conditions significantly influence the relationship between star formation rate and gas density. This question is of great significance for theories and models of galaxy evolution.

If one experimentally pursues the question, then it turns out to be useful to distinguish between the density of atomic (HI) and molecular gas (H_2). THINGS is especially suitable because of the high spatial resolution that it can achieve and its homogenous sensitivity. An astronomer team with Frank Bigiel, Adam Leroy, and Fabian Walter discussed this question by using data from the GALEX Nearby Galaxy Survey and SINGS. From these the star formation rate could be derived. In addition, CO observations with the 30 m IRAM telescope were available which permitted the derivation of the molecular hydrogen's (H_2) density.

Fig. II.8.6 shows the results (above) for spiral galaxies with H_2-dominated central areas as well as (below) for late spiral and dwarf galaxies. The values are listed in relation to averaged radius and azimuth. One sees how star formation rates and H_2-density decrease in spiral galaxies with growing distance, while the HI density does not follow this trend. In Fig. II.8.7, these measurements for the spiral galaxies were then plotted such that the SFR can

Fig. II.8.5: The studied galaxies' rotation curves. THINGS measurements (*red*), their averages (*blue squares*), cosmological models (*dotted curves*), as well as a theoretical result by S. S. McGaugh et al. from 2007 (*upper dotted curve*).



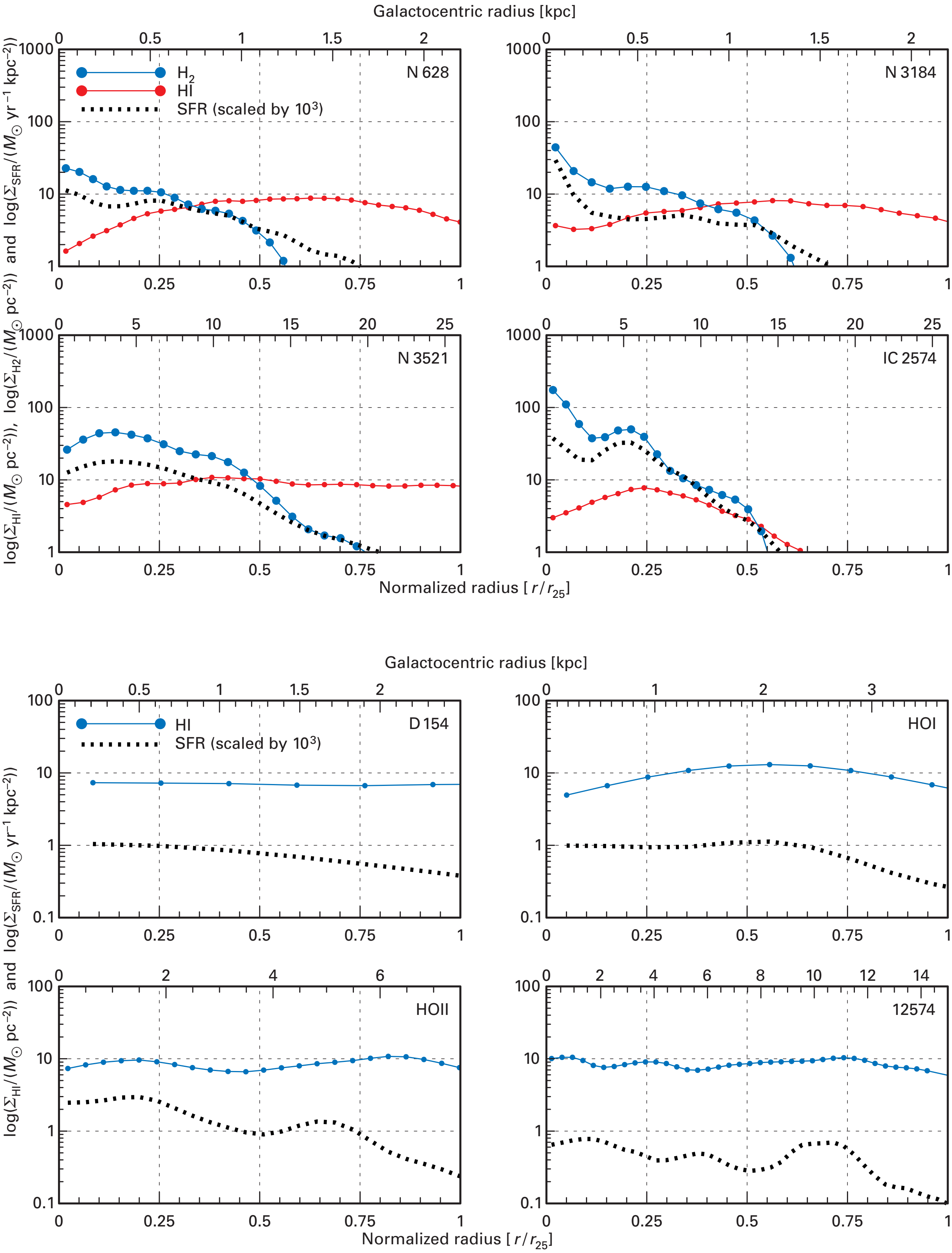


Fig. II.8.6: The radial dependence, averaged over azimuth, of HI and H_2 surface density Σ, as well as star formation rate, *above:* in spiral galaxies with H_2-dominated central regions, *below:* in HI dominated galaxies (faint spiral and dwarf galaxies).

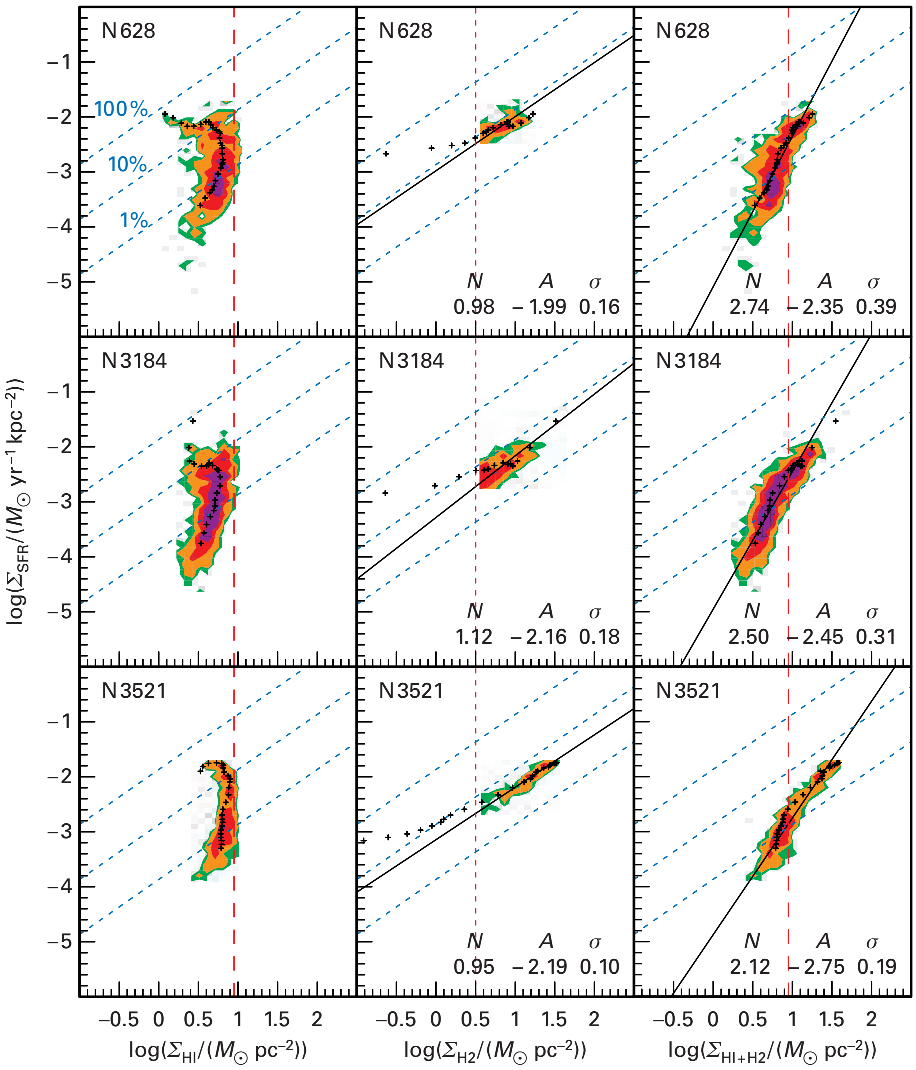
be directly compared in dependence on HI, H_2 as well as to the total gas density of HI plus H_2. In addition, a further quantity – the so-called star formation efficiency (SFE) – plays a role in this diagram. It is defined as the ratio of the star formation rate to gas density and indicates the time span in which the interstellar gas is used up at the actual star formation rate. The diagonal dotted lines correspond from bottom to top to consumption periods of 10^{10}, 10^9 and 10^8 years.

That the HI and H_2 components behave differently is obvious. While the star formation rate (SFR) grows almost exactly linearly ($N = 1.02 \pm 0.12$) with the density of the molecular hydrogen (H_2), the HI density within the galaxy remains almost constant. It is interesting that the dependence even kinks with higher star formation rates. If one forms the sum of HI + H_2, then very differing power laws with exponents of $1 < N < 2.9$ result. Often the dependence within a galaxy cannot even be described with a single power law. Because this behavior is significantly different from galaxy to galaxy, one has to assume that there exists no universal connection between the SFR and the total gas density (HI + H_2), but that it does exist in the case of H_2 density.

There also is no uniform behavior for star formation efficiency. In dwarf galaxies it is nearly constant, while in spiral galaxies it sinks with increasing distance from the center. In the outer regions of the spiral galaxies it then reaches values that are typical for dwarf galaxies.

Fig. II.8.7 allows an interesting behavior of HI gas to be seen: In no case does the density increase above a value of approximately 10 solar masses per square parsec. This is true both for large spiral galaxies and for dwarf galaxies. This degree of saturation, which does not occur with molecular hydrogen, is somewhat surprising because it was assumed that in some galaxies a transformation of atomic to molecular hydrogen is not

Fig. II.8.7: The star formation rate per unit area as a function of the densities of HI, H_2 , as well as the total gas density in spiral galaxies for three galaxies. Green, orange, red, and magenta colored dots respectively represent 1, 2, 5, and 10 data points.



favored – for example, in dwarf galaxies with low metallicity, where less dust is expected be present. (The reaction of two hydrogen atoms to form H_2 takes place on the surface of dust particles.)

In Fig. II.8.8, the values of all spiral galaxies are collected. The saturation limit very clearly comes to light here (left bottom), the gas reservoir is used up within two billion years on average.

The new observational data from THINGS thus support clearly the notion that star formation is linked directly to molecular hydrogen density. The transition from atomic to molecular hydrogen and the star formation that then follows is not a pure function of the total gas density. Very obviously, other physical influences determine the ratio of HI to H_2.

All in all, the data confirm the classical idea according to which stars form when a molecular cloud collapses under the influence of its own gravity. A simple model suggests that star formation then begins only above a certain gas density. In this case, one would expect a linear correlation between the star formation rate and the H_2 density, that is an exponent of $N = 1$, as is suggested by the recent THINGS study.

This result has considerable implications for the theory of galactic evolution. The exponent N today is assumed in the models to have a value of 1.4 – that is, a non-linear relationship. Yet, this value was determined by averaging over entire galaxies. With THINGS one was able thus to ascertain for the first time exponents on a spatial scale of less than 3200 light years. Here is where it was found that $N = 1$. This is an important indicator for theoreticians who in the future must assume a linear relationship in models of the evolution of galaxies with high spatial resolution – which compared to current models makes a significant difference.

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Observatories of the Carnegie Institution of Washington, Pasadena USA),
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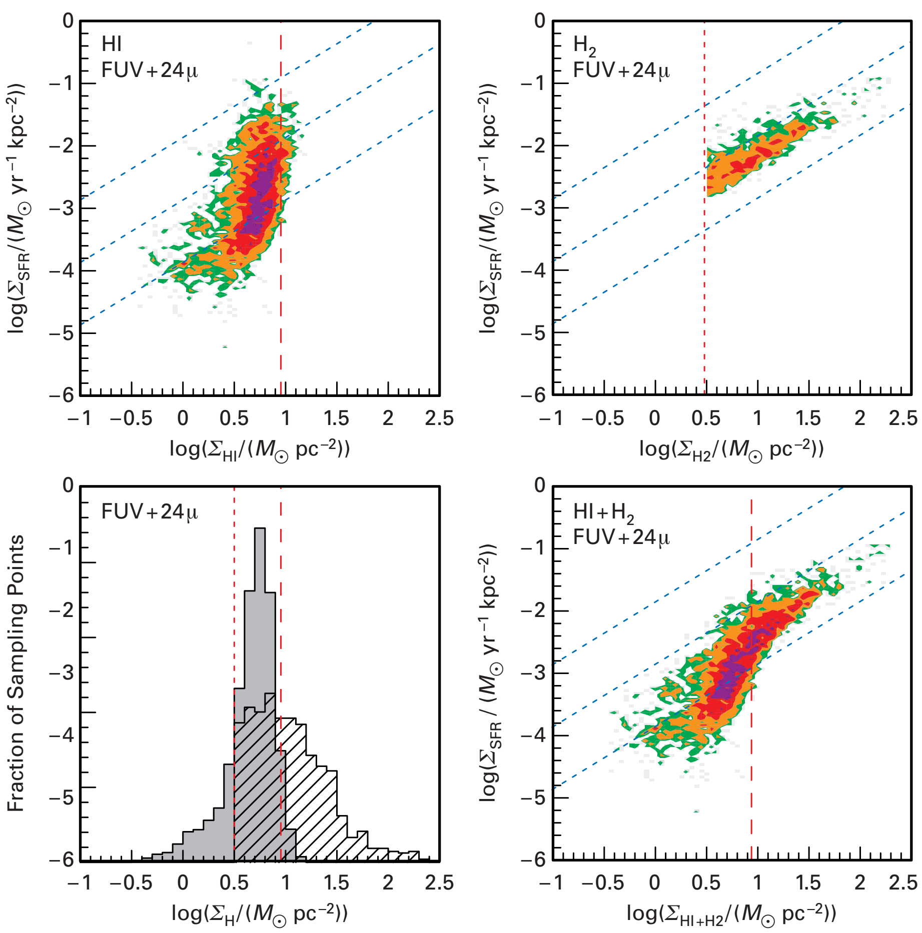


Fig. II.8.8: Results for all spiral galaxies. Clearly visible is the linear increase in star formation rate with H_2 density (*right top*) and the saturation limit for HI gas at about ten solar masses per square parsec (*left bottom*).

III. Selected Research Areas

III.1 Gas and Dust in Nearby Galaxies

From the combination of surveys carried out by space-based telescopes like Spitzer and Galex with large ground-based observing programs, our view of nearby galaxies has sharpened and expanded over the last few years. Researchers at the MPIA are harnessing these new data to study the interplay between galactic structure, the interstellar medium, and star formation in nearby galaxies. Highlights in 2007 included: a stunning range of science produced from The HI Nearby Galaxy Survey, based at the MPIA; impressive first science results using the Large Binocular Telescope to constrain the effect of stellar feedback on the ISM; and the undertaking of a large new observing program to map the molecular gas content of the Things sample using the Iram 30 m telescope.

Studies of nearby galaxies occupy a unique niche in the astronomical landscape. They link the detailed understanding of star formation and the interstellar medium (ISM) built up in the Milky Way to the process of galaxy evolution, studied via surveys of distant galaxies and challenging observations of high redshift objects. As locales to test astrophysical theories, they offer a clarity of view and a range of physical environments not found in the Milky Way combined with a proximity that allows good sensitivity and spatial resolution at a wide range of wavelengths.

In the Milky Way, phenomenal progress has been made understanding how stars form from molecular clouds. Observations with unprecedented resolution and sensitivity offer an exquisitely detailed view of the nearest star forming regions. At millimeter and infrared wavelengths, astronomers can now resolve star formation in progress on the smallest scales, including exciting snapshots of outflows from individual young stars and disks that may host planet formation. Maps of dust and gas in molecular clouds may very well reveal the origins of the stellar mass distribution imprinted in cloud substructures.

However, our position within the disk of the galaxy makes it challenging for local observations to achieve a 'zoomed out' view. The processes by which molecular clouds form, how long they live, how they behave in different environments, and the effects wrought by the ensuing star formation on the surrounding ISM are difficult to study in our own galaxy. Distance ambiguities, extinction from interstellar dust, and line of sight crowding all conspire to limit the most thorough studies to the nearest star forming regions.

Studies of galaxy evolution, on the other hand, can now harness stunning statistics, bringing tens or hundreds of thousands of galaxies to bear in order to measure the demographics of galaxy populations with exquisite precision. At the same time, combining powerful numerical simulations with observations appears to have yielded a robust understanding of how large scale structures form and evolve. Using the most powerful radio and optical telescopes, astronomers can now detect vast reservoirs of gas and vigorous star formation less than a billion years after the big bang. As a result, we now have an impressive understanding of the origin and evolution of galaxy populations on cosmological scales.

Galaxy surveys and high redshift observations, however, typically do not resolve scales on which individual star-forming clouds assemble and these same processes take place 'below the grid' of most numerical simulations. Further, the combination of detailed infrared and radio measurements needed to characterize the ISM are difficult to achieve even nearby. At large distances, resolving the distributions of dust and gas on the scales relevant to star formation is simply not possible with present technology. As a result, the processes of cloud formation, star formation, and stellar feedback are usually not directly observed beyond the vicinity of our own Local Group.

Studies of nearby galaxies fit neatly into the middle ground between these two fields (and so, in many ways link the two departments at the MPIA). Our view of these systems, particularly of face-on galaxies, is largely free of the ambiguities in distance and interstellar extinction that bedevil observations of galactic objects. As a result, it is possible to assemble a picture of the mass budget, the cycle of star birth and death, or the different phases of the ISM with some certainty that, e.g., gas and stars seen along the same line of sight are probably associated. This makes these systems the natural place to study galactic-scale processes in some detail, for example the formation of star-forming molecular clouds, the interplay between spiral arms and star formation, the effects of star death on the surrounding gas, the small scale distribution of dark matter, or the 'feeding' of the super-massive black holes often found in the centers of galaxies.

Further, many environments not readily accessible in the Milky Way can be found even in nearby galaxies. Blazing starbursts harbor conditions similar to galactic star-forming clouds over kiloparsec scales and form super star clusters, likely young analogs to the globular clusters only observed as fossils in the Milky Way. Dwarf galaxies harbor sprawling distributions of gas largely unenriched by previous generations of star formation. Both dwarf and starburst galaxies may offer windows into the distant past: mergers and prodigious star formation rates are frequently observed at high redshift, while the apparently ‘primitive’ state of dwarf galaxies suggests that they may be windows into how star formation proceeded in the first systems in the young universe. More fundamentally, this range of environments allows basic observations to constrain how factors like dust abundance, gas density, the radiation field, stellar bars, or spiral structure impact star formation and feedback. In the local universe we have, in essence, a vast laboratory where we can test “how does process X depend on parameter Y?” by observing “process X” across a suite of nearby systems.

Finally, as hinted by the analogy to more distant systems, nearby galaxies play a critical ‘calibration’ role in our understanding of galaxy populations and interpretation of high redshift data. In particular, to model how galaxies form and evolve it is necessary to have a quantitative understanding of how gas turns into stars in various environments and of the impact of stellar feedback on the surrounding ISM. Lacking an analytic theory of galactic-scale star formation, the usual approach is to empirically calibrate these relations and then tune models and simulations to match them. These calibrations necessarily take place in nearby galaxies, where all of the necessary data (particularly measurements of the ISM) can be assembled. The same quantitative relationships are often used to interpret observations of distant systems, including galaxy surveys, high redshift observations, and studies of the Lyman alpha forest.

Multiwavelength Surveys

Despite their proximity, it has still proven observationally challenging to assemble a complete picture of the distribution of matter in nearby galaxies. Extended, high resolution maps of the ISM require a large investment of telescope time and an accurate inventory of recent star formation ideally includes infrared and ultraviolet observations, wavelengths that are largely inaccessible from the ground. As a result, most studies have either focused on a uniform sample observed at one or two wavelengths or in depth, multiwavelength case studies. In the last five years this has changed dramatically. A series of surveys using space-based and radio telescopes have made uniform, high-resolution, high-sensitivity, multiwavelength data available for dozens of nearby galaxies. It is now possible to study a sample of galaxies using high quality data from radio to ultraviolet wavelengths.

The Spitzer Infrared Nearby Galaxy Survey (Sings), led by R. Kennicutt at Cambridge University and involving some current and past MPIA researchers, mapped 75 nearby galaxies at near- to far-infrared wavelengths using the Spitzer Space Telescope and assembled a rich suite of ancillary data. Sings maps and spectra captured light from old stars, small dust grains heated by nearby star formation, and the larger dust grains that permeate the ISM.

At the same time, the Galaxy Evolution Explorer (Galex) undertook the Galex Nearby Galaxies Survey, which yielded, among other data products, extended, wide-field maps of far-ultraviolet and near-ultraviolet light for more than a thousand nearby galaxies. The maps offer a direct view of recently formed O and B stars. They reveal a wealth of star formation and structure, including the surprising finding that star formations extends at low levels well into the outskirts of many galaxies.

Maps of interstellar gas are key to studies of galactic kinematics, star formation, or stellar feedback, and the MPIA is playing a major role in this field. Here we will single out two programs based at the MPIA: The HI Nearby Galaxy Survey (Things) and a complementary program now underway to make extended, sensitive maps of molecular line emission from the same sample.

The combined view offered by Things, Sings, and the Galex NGS is shown in Figure II.8.2 on page 58-59: Four nearby spirals (left panel) and four dwarf galaxies (right panel). Blue shows the distribution of atomic hydrogen, mapped by Things. Red shows the distribution of old stars, inferred from near-infrared maps by Sings. Pink shows the location of current star formation, estimated from ultraviolet and infrared light mapped by Sings and Galex.

The HI Nearby Galaxy Survey

Based at MPIA, Things used the Very Large Array (VLA) to map the atomic gas distribution of 34 nearby galaxies. Begun in 2003, with data acquisition and reduction completed in 2006, Things is one of the largest programs ever undertaken by the VLA.

Things mapped the 21-cm transition of atomic hydrogen (HI), obtaining sensitive, high resolution measurements of how the mass of HI is distributed in each galaxy. With an angular resolution of 7 arcseconds (typically 200 to 300 parsecs), the data are perfectly suited to comparison with ultraviolet maps from Galex and mid- to far-infrared maps from the Spitzer Space Telescope. Because the Things targets were chosen to match those of the Sings survey, this sort of comparison is a mainstay of the resulting science which focuses on combining data from many wavelengths to form a more complete picture of stars, gas, and dust than was previously attainable.

The 21-cm line also carries velocity information, and wherever Things observed atomic gas, it also measured the line of sight velocity with an accuracy of 5 km/s. Thus, in addition to maps of the gas distribution, Things has yielded maps of gas motion. This enables a large range of science, from searching for holes and shells in the atomic gas distribution to detailed studies of the distribution of dark matter via its gravitational influence.

With all data in hand, the THINGS team focused on science in 2007. The data is now fueling more than a half dozen PhD theses and the first round of research includes over a dozen science papers now at or near submission. A sample of the questions being addressed by the THINGS team:

- What is the dark matter distribution in each galaxy? From the motions of the gas measured by THINGS, one can infer the distribution of mass in each galaxy and, after comparison with starlight and the gas distribution, infer the distribution of dark matter.
- Where do galaxies end? THINGS maps are both extremely sensitive and very big, allowing team members to measure where a galaxy's gas reservoir ends. This yields clues to both the origins of galactic structure and the conditions, particularly the radiation field, in the space between galaxies.
- What is the distribution of holes and shells in the ISM? A casual inspection of the THINGS maps reveals a wealth of such structures and systematically measuring their properties may offer a clue to their origins, for example from comparison to the distributions of young stellar clusters.
- Do the deepest hydrogen absorption lines seen along the line of sight towards high redshift quasars come from galaxies like those around us? By simulating the effect of random lines of sight drawn through the THINGS galaxies, one can hope to explain the distribution of these so-called "damped Lyman alpha systems".

In addition to the four MPIA-based projects described in detail later in this chapter a half-dozen more projects are nearing completion. Even with this rich first round of science, the potential of THINGS is only beginning to be tapped. The second round of projects are already underway, complementary molecular line data are being collected, and the sample will be targeted as part of a HERSCHEL Space Observatory legacy program.

A New Atlas of Molecular Gas Maps Using the IRAM 30 m telescope

The atomic hydrogen probed by THINGS is a key component of the ISM but does not represent a complete inventory of the gas. Particularly in the centers of spiral galaxies, molecular (rather than atomic) gas is often the dominant component of the ISM. This is also the phase observed to relate most directly to star formation. Therefore any study hoping to understand why stars form where they do must take into account the molecular gas.

Unfortunately, the H_2 that makes up most of the molecular phase lacks a dipole moment and is therefore not readily observed under the conditions where it is found in the ISM (cold, dark clouds). Therefore emission from other molecules is often used to infer the distribution and abundance of molecular gas. The most common and commonly used of these tracer molecules is CO. Although relatively abundant and bright, mapping CO still remains a challenging undertaking and the lack of extended, sensitive maps of CO emission have remained a serious gap (although the pioneering BIMA Survey of Nearby Galaxies took a major step forward in this regard).

Following a pilot project in the winter of 2006, 2007 saw an MPIA-lead team undertake a large project using the IRAM ~30 m telescope to map the molecular gas in a subset of the THINGS/SINGS sample. The project will use more than 300 hours of telescope time to map CO line emission from 20 THINGS galaxies. The enabling technology is the HERA focal plane detector array, a 9-element dual-polarization receiver array. HERA allows fast on-the-fly mapping of the CO ($2 \rightarrow 1$) transition, making it possible to obtain sensitive maps of CO emission over wide areas while still yielding an excellent angular resolution of 11 arcseconds. Because it simultaneously maps emission from nine positions on the sky, HERA offers almost an order of magnitude increase in efficiency, making it possible to accomplish in only 300 hours a project that would have required almost 3000 hours just five years ago.

The HERA survey will wrap up in the early spring of 2008 but is already yielding exciting results. In particular, one already observes a striking, nearly one-to-one correspondence between CO line emission and the rate of star formation inferred from ultraviolet and infrared maps. The result suggests that molecular gas may form stars in roughly the same way in all of the spiral galaxies that the team studied.

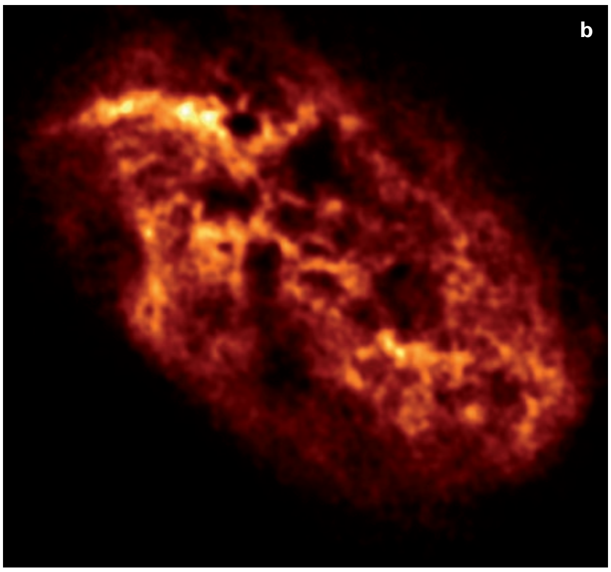
Science Highlights

First Science With the LBT: Stellar Feedback in IC 2574

The Large Binocular Telescope (LBT), with its large aperture, wide field of view, and excellent sensitivity to blue light, will be a powerful tool to study star formation in nearby galaxies. Some of the first science results to come out of the LBT already demonstrate this capability. MPIA researchers led an effort using the LBT to make sensitive maps of *U*-, *B*-, and *V*-band light from the nearby dwarf irregular galaxy IC 2574, also a target of THINGS. With extended star formation and an HI distribution characterized by dozens of known holes and shells, IC 2574 is an ideal locale to study the interaction between star formation as viewed by the LBT and the ISM seen by THINGS.

From the LBT data (Fig. III.1.1a), the researchers were able to estimate the number of young stars at each location in the galaxy and how recently these stars were formed. They also calculated how much energy these stars create in the form of winds, supernova explosions, and ionizing photons. Comparing this information to the

Fig. III.1.1: *a)* The LBT view of the dwarf irregular galaxy IC 2574. This three color image shows *U*-band light in blue, *B*-band light in green, and *V*-band light in red. The extended, irregular distribution of star formation is evident. *b)* The distribution of atomic hydrogen in IC 2574, measured by the VLA as part of the THINGS survey. Many holes and shells are evident. However, based on the energy output from young stars inferred from the LBT data one would expect even more such structures.



atomic hydrogen map of IC 2574 (Fig. III.1.1b) revealed that these stars generate plenty of energy to create the observed wealth of holes and shells (Fig. III.1.2). Indeed, the stars can easily account for all of the random motions seen in the gas. The surprising observation is – if anything – that there are so few holes.

The researchers translated the comparatively low energy in the holes and gas into constraints on what fraction of stellar feedback and ionizing photons are deposited into the atomic gas. They found both values to be only about 10 – 20 %. Further, they found it difficult to identify specific young stellar populations responsible for most of the observed holes. These results support an emerging picture that the coupling between stellar feedback and atomic gas may in fact be quite weak. This kind of quantitative constraint on the channel followed by stellar output is critical because feedback remains an often-invoked but still poorly constrained aspect of the star-ISM life cycle. The success of the project also demonstrates the promise of the LBT as a tool to study the evolution of nearby galaxies.

Using THINGS and SINGS to Measure the Timescale for Star Formation

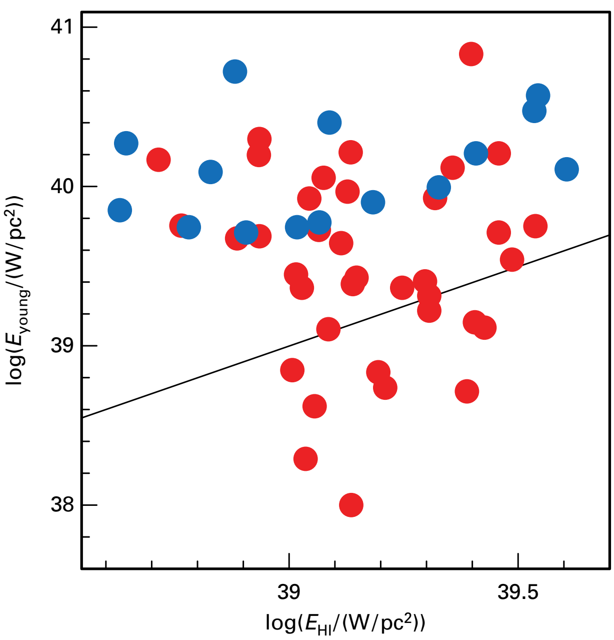
One of the most poorly constrained aspects of star formation is also one of the simplest: how long does a star-forming molecular cloud live? Evidence exists to support lifetimes ranging from a collapse time (a few million years) to thirty to forty million years; indeed, there are suggestions that clouds may live even longer.

MPIA scientists combined data from THINGS and SINGS to make an innovative measurement of the timescale for star formation in nearby spiral galaxies. The scientists considered regular massive galaxies that have well-defined structures both within and between spiral arms in both atomic hydrogen (mapped by THINGS) and mid-infrared maps from SINGS. The atomic hydrogen emission may represent the material from which stars form, while mid-infrared emission is often an indicator of embedded star formation and thus suggests that star formation has already taken place. Therefore, the spiral patterns observed at these two wavelengths reflect two sequential phases – the onset of the cloud collapse and the formation of massive star clusters. The researchers reasoned that if they could measure the angular offset between these two proxies of distinct epochs and the speed with which the spiral pattern has rotated, they could estimate a characteristic timescale for star formation in spiral galaxies.

By cross-correlating HI and infrared data within a series of concentric rings, the MPIA researchers were able to successfully measure the offset between the infrared and atomic gas spiral pattern even though it was below the resolution of either data set. Because spiral density waves are assumed to move with a fixed pattern speed, the offset between the two patterns is a well-defined function of radius (the same angular speed corresponds to larger real velocities and thus larger offsets at larger radii) and the scientists fit this function to derive the pattern speed of the spiral waves.

The results (see Fig. III.1.3 for an example) imply that the time between the peak of the HI distribution until the peak of embedded star formation was only a few million years, on average. This value is in line with values proposed for the lifetimes of short-lived molecular clouds and represents a measurement of the timescale for star formation that is orthogonal to many frequently used methods (e.g. association with stellar features) and again demonstrates the depth of science achievable with the present generation of multiwavelength surveys.

Fig. III.1.2: The energy output from young stars, inferred from the LBT data shown in Fig. III.1.1a, as a function of the energy observed in the atomic hydrogen gas. The solid line shows equality, blue points show locations where holes are observed in the HI, and red points show locations where there are no holes. Even where there are no holes, the points usually lie well above the line. This means that the energy output of young stars is more than enough to account for all of the energy in the atomic gas.



The Relationship Between Gas and Star Formation

Measuring the quantitative relationship between gas and star formation in nearby galaxies has been a fundamental goal of THINGS, SINGS, and the new IRAM survey. The most common observational approach to this topic is to relate the amount of atomic and molecular gas per unit area to the area-averaged star formation rate. This observed relationship is used as a benchmark for galaxy simulations, a tool to interpret observations at high redshift, and a key constraint that must be explained by any theory of galactic scale star formation.

Previous work comparing gas to star formation has found a striking correlation between gas surface density and star formation per unit area on large scales. These studies have usually either averaged over whole galaxy disks or considered very large areas, often averaging together data to make a radial profile of the galaxy. A central goal of both SINGS and THINGS, therefore, was to extend this measurement to smaller scales, closer to those on which individual molecular clouds form and produce stars.

MPIA scientists combined data from the GALEX Nearby Galaxies Survey, THINGS, SINGS, and the IRAM 30 m survey to make one of the first uniform measurements of this relationship below kiloparsec scales. They estimated the rate of recent star formation by combining ultraviolet and infrared light, thus counting both directly visible young stars and those obscured by dust.

The scientists found that the amount of molecular gas in a given part of a galaxy was, on its own, a very

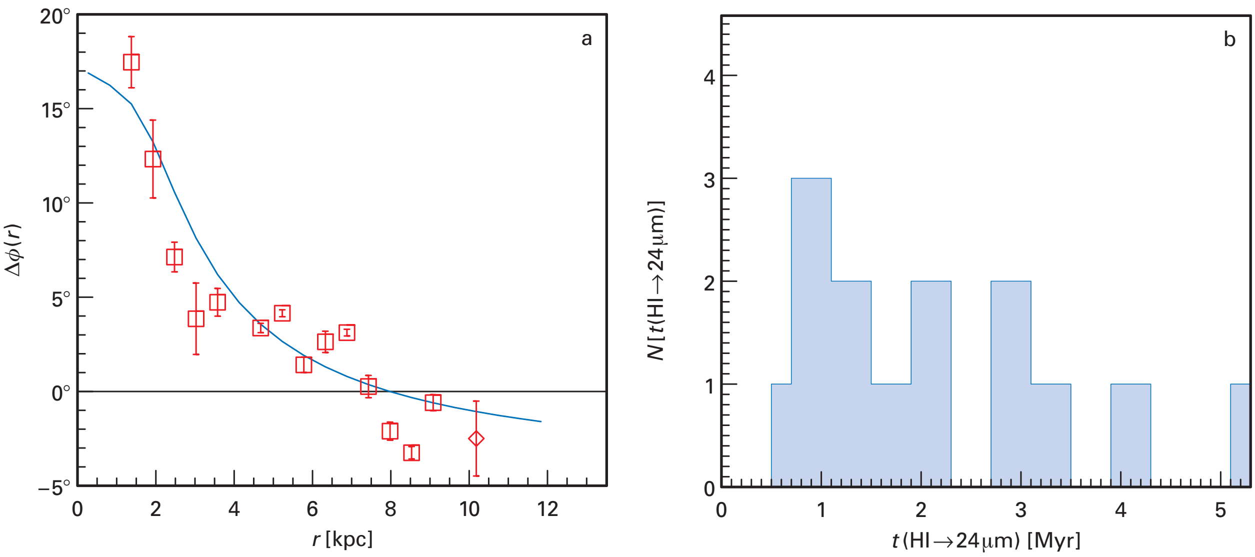


Fig. III.1.3: *a)* The angular offset measured between the infrared and HI arms in one spiral galaxy (NGC 3627) as a function of increasing radius. The solid line shows a fit corresponding to a fixed time lag between the two arms. *b)* The distribution of time lags between HI and infrared arms for all spiral galaxies studied. The typical value is a few million years, implying that once the material for star formation (the atomic gas) is assembled, star formation (traced by the infrared light) occurs fairly quickly.

good indicator of star formation (Fig. II.8.8). The plots show how the rate of star formation along a line of sight through a galaxy (*y*-axis) depends on the amount of atomic gas (*x*-axis in the upper left plot) and molecular gas (*x*-axis in the upper right plot) along the same line of sight. The star formation is inferred from combining FUV data from the GALEX NGS and 24 µm data from SINGS. The atomic gas is measured from the THINGS maps, while the molecular gas is estimated from the IRAM 30 m CO maps. The right panel shows that H_2 and star formation obey an almost one-to-one relation, while the left panel shows that the amount of HI along a line of sight has little bearing on the rate of star formation.

Further, they found little evidence of variation in the number of stars that form out of each parcel of molecular gas. Although molecular gas under extreme pressure, such as that found in starburst galaxies, is known to form stars very efficiently, the galaxies studied here were mostly ordinary spiral galaxies forming stars at only moderate rates. The researchers therefore suggested that the apparent uniformity in the number of stars formed per unit molecular gas indicates that most star formation in spiral galaxies takes place in molecular clouds that look largely the same everywhere and are probably not so different from those seen in our own Milky Way.

The team found a sharply different conclusion when they look at the atomic gas. The ratio of atomic gas to molecular gas and the rate of star formation per parcel of atomic gas vary dramatically both within and among galaxies. Depending on where it is found, the same parcel of atomic gas may host either a wealth of star formation or a virtually none at all. The team interpreted these results to mean that while stars forming out of molecular clouds may be a fairly universal process, the formation of these clouds depends rather strongly on conditions in the galaxy. They highlighted the role that old stars play in the process: compressing gas via their gravitational influence so that gas found in the presence of a deep stellar potential well is more dense than that in the outskirts of galaxies.

Dust and Gas in the Extreme Environments of Dwarf Galaxies

We have already mentioned in an offhand way that nearby galaxies host a variety of environments that may hinder or aid the formation of stars and their parent clouds. Indeed, we mentioned the often-made argument that dwarf galaxies, in particular, will have conditions like those found in the early universe: low heavy element abundances, intense radiation fields, a wealth of atomic gas, but relatively little dust. Dust is particularly important to star formation because dust helps to shield molecular clouds and serves as the site of most molecular hydrogen formation. These claims are often made, but measuring the physical conditions even in nearby dwarf galaxies is both challenging and necessary to understand star formation in extreme environments.

MPIA researchers combined the THINGS and SINGS surveys to do exactly that. They used infrared emission to measure the properties of dust in the dwarf irregular galaxies of the nearby M 81 group. They found them to be even more deficient in dust than their low heavy element abundances would imply and observed evidence of intense radiation fields heating the dust to higher temperatures than are typically found in spiral galaxies. The team also found that the emission from small dust grains, via the mid-infrared continuum and the PAH emission features, varies dramatically even among dwarfs with otherwise similar properties. Though a small constituent of galaxies by mass, these small grains account for a large fraction of the light-absorbing area of dust and so their presence or absence can substantially affect the thermal balance of the ISM.

AGN Feeding in Nearby Galaxies

Star formation is not the only important process fed by gas. Inflow of gas also fuels active galactic nuclei, feeding the supermassive black holes at the centers of (AGN) galaxies and in the process generating some of the most luminous and energetic phenomenon in the universe. Quasars – distant, more luminous cousins to local AGN (Seyferts and LINERS) – are seen at extremely high redshift but it is only possible to resolve the dynamical processes in the nearest AGN host galaxies. Up to now a general picture for these fueling processes is missing: What mechanisms are responsible for the different types of AGN observed locally? How to remove angular momentum from material far away from the gravitational influence of the central black hole?

Researchers at the MPIA engaged in active research on this front as well. As part of the Nuclei of Galaxies collaboration (NUGA), MPIA scientists used the VLA to map the atomic gas distributions and kinematics of 16 nearby spiral galaxies. These maps complement existing molecular gas data obtained by the NUGA collaboration using the IRAM PdBI. The researchers found a link between the distribution of atomic gas and the type of nuclear activity and are now focusing on modeling how the gas is brought in to the centers of their sample.

In order to trace the gas flow on various spatial scales, ranging from a few 10 pc in the very center to the outer disk at several kpc distance, the researchers computed gravity torque maps based not only on the stellar luminosity distribution but also on the distribution and kinematics of the atomic and molecular gas. Since gravity torques are defined as the rate of angular momentum exchange, they can be utilized to predict gas inflow rates as a function of the radial distance from the center. This novel approach allows the researchers to assess timescales and efficiencies for fueling galactic centers and will likely provide new insight into the growth of black holes and bulges.

Future Prospects

In the immediate future, THINGS promises to continue fueling a wide range of research. Efforts are already underway to study the random motions of the atomic gas and star formation in the outskirts of spiral galaxies. With the completion of the IRAM CO survey in the spring of 2008, a whole new array of projects oriented towards understanding the formation and evolution of molecular gas will commence. As the scientific capabilities of LBT continue to come online, its role will expand; observations are already taken or planned to extend the work in IC 2574 to both larger and smaller galaxies.

In the slightly longer term, most of the targets for THINGS and the IRAM survey will be observed as part of the HERSCHEL Space Observatory's KINGFISH key program (PI: R. Kennicutt, Cambridge University). HERSCHEL, scheduled for launch in 2008, promises to open new windows into the ISM. It will observe infrared radiation with unprecedented resolution, map the submillimeter emission that is key to assembling an accurate inventory of interstellar dust, and perhaps most excitingly provide extensive observations of the most important ISM cooling lines. In combination with gas maps (including THINGS and the IRAM survey), these observations will give the best constraints yet on the energetics of the neutral ISM and new insights into the physics that govern the conversion of gas into stars.

Early next decade, the Atacama Large Millimeter Array (ALMA) will come online. ALMA promises to revolutionize millimeter and submillimeter astronomy and with them our knowledge of dust and molecules. At the end of the decade, the Square Kilometer Array is planned to begin full operations, triggering a similar leap in radio astronomy. With these telescopes the study of gas and dust at high redshifts will become common and observations of nearby galaxies will achieve resolution now possible only in the Milky Way. Via the projects described here, the MPIA is helping to lay the groundwork for these new institutions and thus to set the stage for studies of star formation and the ISM in the coming decade.

Adam Leroy, Frank Bigiel, Sebastian Haan, Anna Pasquali, Eva Schinnerer, Domenico Tamburro, Fabian Walter and the THINGS-Collaboration

III.2 In What Type of Galaxies Do Quasars Live?

Why is there a fixed relationship between the mass of a galaxy's extended bulge and the much smaller mass of its almost point-like, although supermassive, central black hole – as if the black hole "knew" something about the galaxy in which it lives? Why is there a division between elliptical and spiral galaxies with rather few other types of galaxies inbetween?

Both of these questions could have a common answer: The energy that a supermassive black hole emits in the form of radiation during its growth phase is basically sufficient to tear apart the galaxy in which it is located. Even if this does not happen, interstellar gas can by blown out of the galaxy by the radiation emitted during the accretion process, thus suppressing not only further star formation within the galaxy but also the continued growth of the central black hole. With such feedback, the growth of central black holes could be connected in self-regulating fashion with the formation of stars in their host galaxies. One of the most exciting phases in the life of galaxies is therefore the one during which its central black hole grows: the quasar phase. But what makes galaxies so special during this brief phase to permit this growth? What conditions are prerequisites for quasar activity? That is, in what types of galaxies do quasars live?

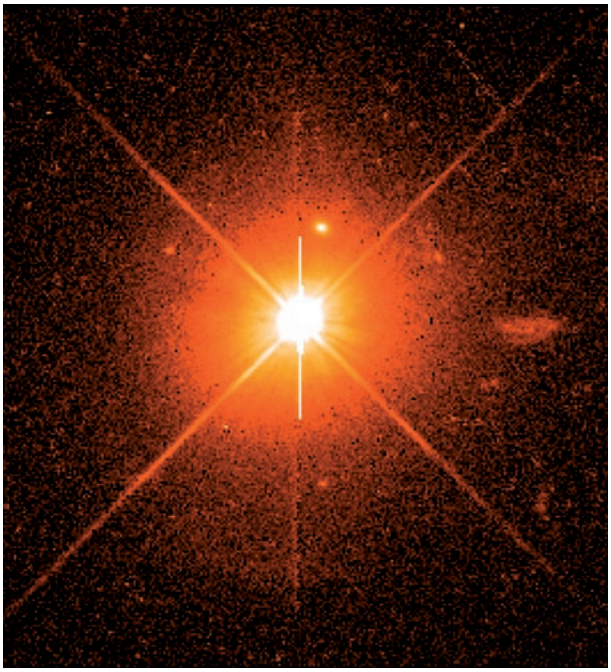


Fig. III.2.1: Example of a galaxy in the quasar phase: HE 1029 – 1401 is an elliptical galaxy at redshifting $z = 0.086$ with a bright point source in its center. Only the transformation of gravitational energy can be responsible for all of the AGN's light emissions. (Observed with HST/WFPC2)

Black Holes in Luminous Galaxies

The most persistently luminous sources in the universe are galaxies in which significant amounts of material are actively falling into their central supermassive black hole. This so-called "quasar" phase in the evolution of galaxies – in the case of black holes one also talks of active galactic nuclei (AGN) – lasts for several hundred million years. During this relatively short period, vast amounts of gravitational energy from material falling into the black hole is transformed into radiation energy (Fig. III.2.1). In order to plummet into the black hole, the invading material must give up its angular momentum. This happens during the last part of its journey, when angular momentum can be dissipated through friction against dense so-called accretion disks surrounding the central black hole, the diameter of which is no more than a few light minutes or hours.

The total emitted potential energy of the material falling into the deep potential pit of the black hole during the quasar phase exceeds the gravitational binding energy of all stars in the galaxy. It would thus have – assuming a corresponding coupling – the ability to destroy the galaxy. We know, however, that this does not happen; and this raises questions about how strong the influence of quasar activity actually is on the surrounding galaxy and what conditions have to exist in the galaxy for a quasar to be formed.

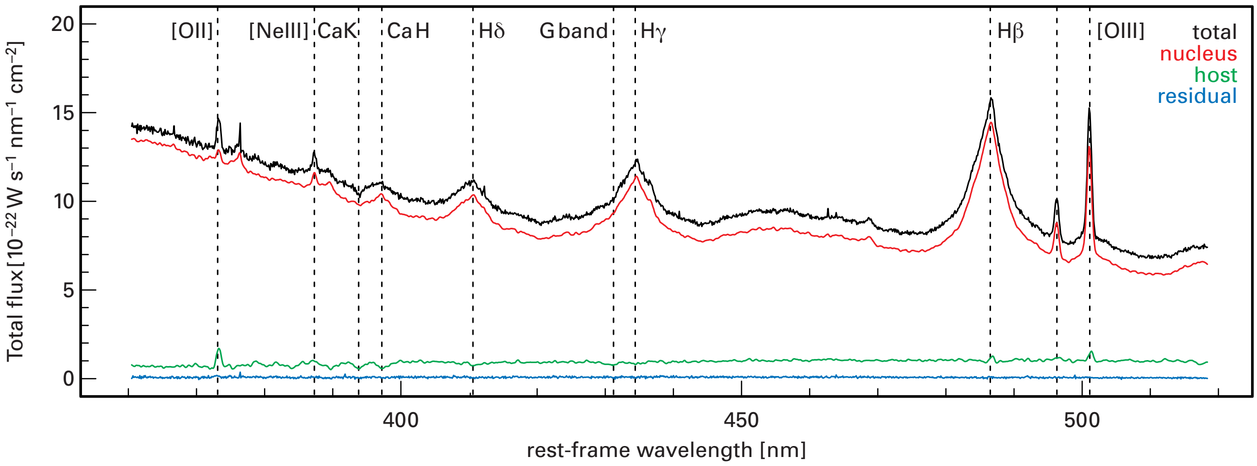
Since initial examining of the first large sample of quasar host galaxies in the near universe, which started about ten years ago, it has become clear that AGNs – of which quasars are only the most extreme expression– can appear in all galaxies that have a stellar "bulge". Presumably, each galaxy, the central bulge of which consists of more than approximately one million solar masses, hosts a black hole in its center – though below this threshold uncertainty continues to exist. Because with growing AGN or quasar luminosity and assuming a constant relative accretion rate, the mass of the black hole – and thus also the mass of the bulge – must also grow, it follows why the most luminous quasars only appear in mass-rich elliptical galaxies: These galaxies consist solely of a bulge and are the only ones to achieve the necessary bulge masses. At lower luminosities it is then possible for even later galaxy types, with smaller bulges – that is, S0- or Sa-galaxies or even later spirals – to host quasars or AGNs.

As a result only the question regarding the possible underlying parent population of galaxies that host supermassive black holes is explained; but not the question regarding the circumstances required for quasar activity. Observational approaches include spectroscopy and direct imaging of quasars in the visible and near-infrared light. To achieve this, the team of astronomers at the MPIA availed themselfes of two powerful and unique tools: the HUBBLE Space Telescope (HST) with its unparalleled resolution and the European Very Large Telescope (VLT) with its enormous light collecting power.

Spectroscopy with the VLT

There is, however, a complication to be overcome when using spectroscopy. For the analysis of host galaxies it is necessary to isolate the light from the quasar core. In the case of highly luminous quasars, which only start to appear in larger numbers at redshifts of $z = 0.1$ to 0.2, a galaxy diameter of ten kiloparsec corresponds to only about three to five arc seconds. In an atmospheric "seeing" of one arc second, one can of course locate the spectrograph's slit such that it captures the light from the inner part of the galaxy – where it is most likely to find indications of what influences quasar activity and to what extent it influences the galaxy – but one will also simultaneously collect a large part of the quasar light which can exceed the light of the galaxy by ten or hundred fold. Thus, a method is needed to separate out the light of the quasar after the measurement is completed.

Some time ago the MPIA team developed such a method through which the components can be numerically separated by taking advantage of information regarding the different spatial distribution of the light emitted from extended galaxies and pointlike quasars. With these techniques, one can now – at least given a contrast of 10:1 – extract and separately analyze the



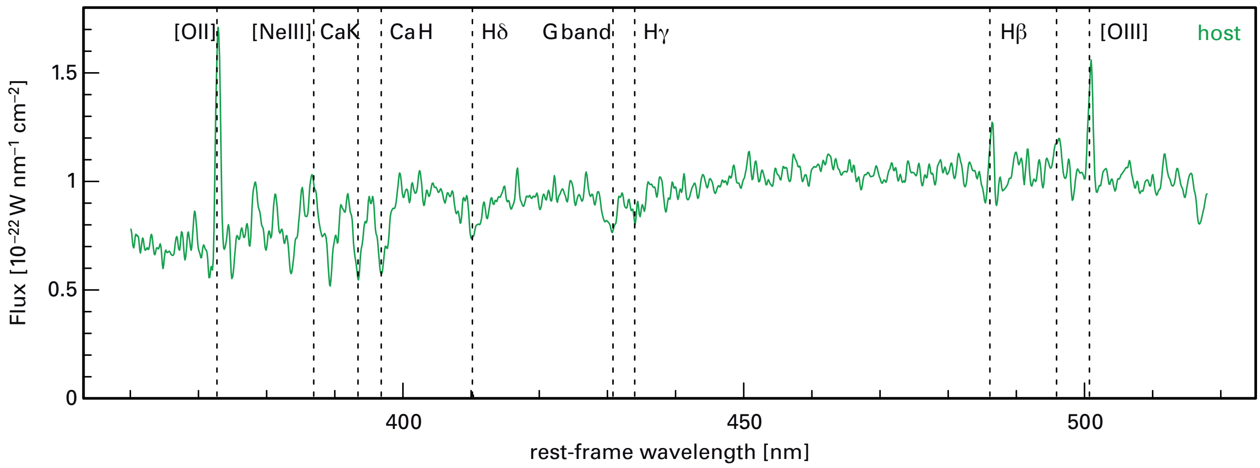
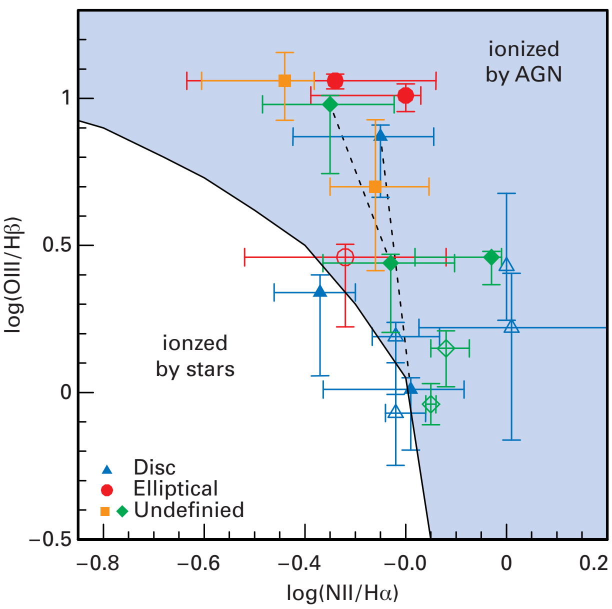


Fig. III.2.2: Separation of the spectra of the quasar HE 1503 + 0228 and its host galaxy. *Above:* Full spectrum (*black*), the extracted spectrum of the quasar (*red*), and of the host galaxy (*green*), and the residual left after subtraction of both these components (*blue*). The host galaxy spectrum, shown enlarged in the *lower diagram*, shows all characteristics of a normal galaxy spectrum with emission and absorption lines that, together with the continuum, point to a rather young, one to two billion year old stellar population. (Jahnke et al. 2007, MNRAS, 378, 23).

spectra of quasar and galaxy. As an example, Fig. III.2.2 shows results for the quasar HE 1503 + 0228 at redshift $z = 0.135$. Together with Belgian and Swiss colleagues, who use a different technique, the MPIA astronomers were able to examine a larger sample of near ($z < 0.3$) quasar host galaxies with Fors spectra gathered from the VLT in regard to their stellar populations and interstellar gas.

The results show that the quasar's energetic radiation often causes the ionization of all the interstellar gas in the host galaxy. The ionizing source can be established with the help of a so-called BPT diagram: Due to the differing spectral distributions of emissions from star forming regions and quasar accretion disks, depending on the source, the strength of different emission lines varies depending on ionization potential so that a dividing line can be drawn in this diagram between regions of dominating star formation and those of quasar accretion. In the case of quasars, the emission of hot young stars is never entirely responsible for the ionization: The quasar is always involved to some extent. Independent of a galaxy's morphological type, both in the spiral as well as in the elliptical host galaxies a mixture of light from starforming regions and quasar light – or even the quasar light alone – dominates. Yet there seems to also be an additional trend: In quasar systems that are more heavily disturbed through gravitational interaction or galaxy collisions, the interstellar matter is ionized solely by the quasar light (Fig. III.2.3).

Fig. III.2.3: Diagnostic "BPT Diagram" to identify the dominating ionization mechanism in the host galaxies of a sample of near quasars in galaxies of varying morphological type: spiral galaxies (*triangles*), elliptical galaxies (*circles*), interacting galaxies (*filled symbols*), undisturbed systems (*open symbols*). From: Letawe et al. 2007, MNRAS, 378, 83.



The presence of a quasar in the galaxy also has effects on its stellar composition. The team of astronomers at the MPIA was already able to show through the analysis of broadband colors that stellar populations in quasar host galaxies always contain a portion of young stars. This is true not only for spiral galaxies but also, surprisingly, for elliptical or S0-galaxies in which there is normally little to no star formation. Even here more details could be obtained through VLT spectroscopy. The stellar populations of examined quasar host galaxies are on average one to two billion years old; more than 90 percent of their stellar populations are old and they contain a few percent of roughly hundred million years old or even younger stars. Here too, there is a tendency toward younger and bluer galaxies in strongly disturbed systems.

Cosmic Collisions and Galactic Tidal Tails

For twenty years astronomers have suspected that galactic collisions are the driving force, or at least an important one, behind the supply of material accreting onto black holes. In a collision and subsequent merging of two galaxies, the influencing tidal forces create chaotic interstellar gas turbulences. Parts of these will end in an orbit of vanishing angular momentum with respect to the black hole and can thus later fall into the black hole. For some of the most luminous infrared galaxies (ultraluminous infrared galaxy, Ulirg), which carry a quasar hidden by dust within them, this suspicion seems to be confirmed to a high degree of significance. At the opposite extreme are Seyfert galaxies which are less luminous, but identical in terms of their core structure. These are principally spiral galaxies that are often undisturbed and symmetrical; they were not subjected to stronger galaxy collisions in their recent past. Here instabilities and the accretion of small companions play the dominating role.

How strongly a galaxy collision can affect a quasar is shown in Fig. III.2.4 with the example of the quasar HE 0450 – 2958 and its environs. At $z = 0.285$, this system contains a very luminous quasar and was classified as early as the 1980s as a Ulirg. Observerd in visible light with the HST/ACS, the companion galaxy shows not only strong tidal arms to the South-East in the direction of the quasar, but also "holes" in its middle. The HST image in the near infrared (HST/Nicmos) shows that these holes are not due to lacking emission but that the emitted light was absorbed here by dust. In neither case is an extended host galaxy visible, but only the luminous, dusty companion galaxy as well as tidal tails. This provides, together with the 10.3 µm image in which only the quasar core but neither companion galaxy nor stars are visible, a consistent picture according to which both the quasar and the companion galaxy are just colliding and, in the companion galaxy, all radiation is due to massive star formation of approx. 300 solar

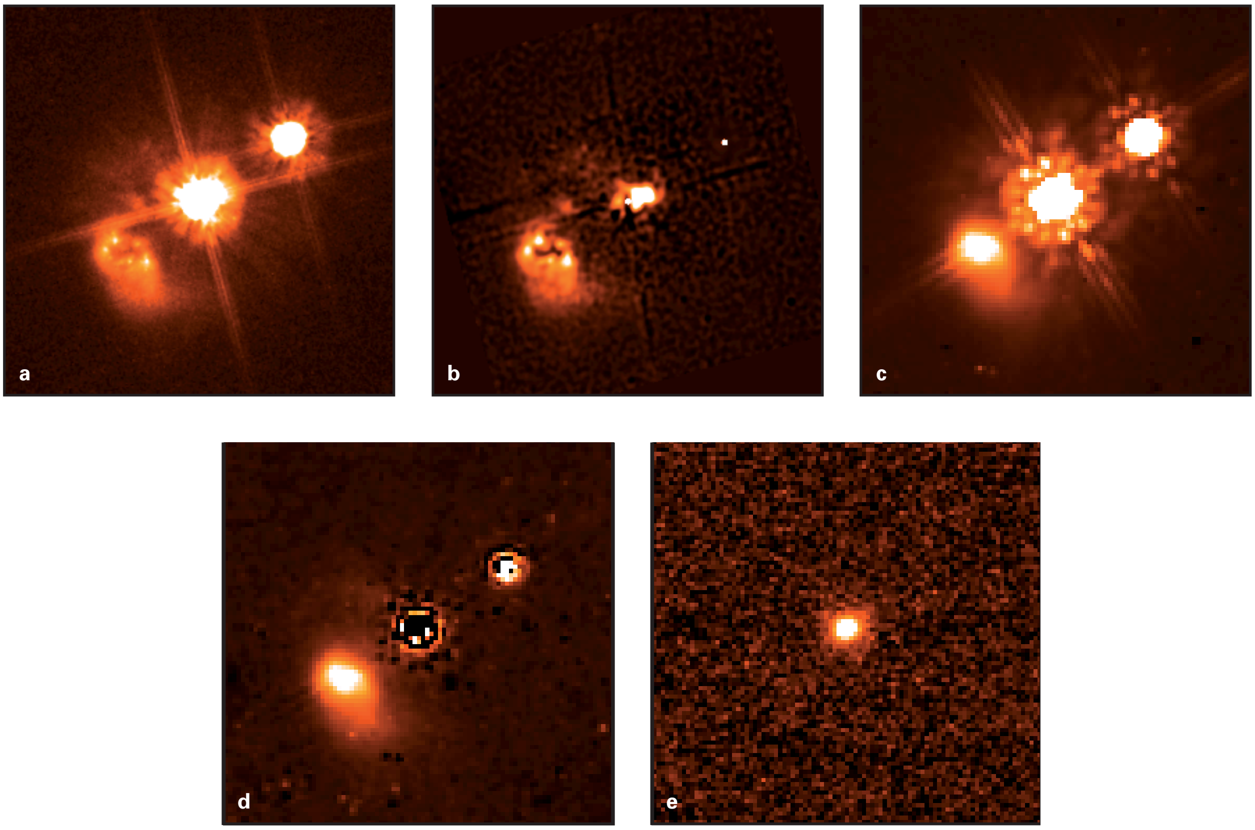


Fig. III.2.4: The quasar HE 0450–2958 spatially resolved at three wavelengths *a)* in the visual (V-band, taken with the HST ACS-HRC camera), *c)* in the near infrared (H-band, taken with the HST NICMOS-NIC2 camera), *e)* in the mid-infrared (N-Band, taken with VISIR on the ESO VLT). The HE 0450–2958 system at $z = 0.285$ consists of a quasar in the middle, a neighboring galaxy interacting with the quasar on the left, and a foreground star belonging to our milky way on the right. The *b)* and *c)* images were derived from *a)* and *c)* respectively after subtraction of a modeled point source for quasar core and fore-ground star (Jahnke et al. 2008).

masses per year while the quasar emission is primarily fed through accretion.

These data, together with information relating to CO emission, show that both the quasar and also the companion galaxy possess a ULIRG type luminosity: The quasar is surrounded by some dust and a rather mass-poor host galaxy and its direct environment emits reprocessed quasar light at the ULIRG level. For its part, the companion galaxy is rather dust-rich and produces roughly 300 solar masses in new stars per year. The luminosity emitted hereby and the large amount of dust also provide for ULIRG strength infrared emission. In such a system, the interaction of the quasar with the companion galaxy plays an important role, both in triggering the massive star formation as well as in its core activity. Only the combination of the highest level of spatial resolution by HST and VLT and multi-wavelength data allowed for an analysis of these most diverse physical processes.

HST and COSMOS

After the MPIA GEMS project led by Hans-Walter Rix, COSMOS (Cosmic Evolution Survey) is the next and largest HST project with, among other things, the goal of tracking down the nature of quasars and their host galaxies. More than one hundred scientists from the USA, Italy, France, Germany, Switzerland, and other countries are a part of COSMOS. With the HST, an image of a two square degree sized area of the sky was taken in the I-Band with the highest possible angular resolution (0.04 arc seconds per pixel). This core data set is flanked by X-ray images of the XMM / Newton and CHANDRA satellites, infrared images from SPITZER, earth-bound images in more than 30 optical and near-infrared filter bands up to the millimeter and radio range, the latter again with the Very Large Array under MPIA direction (led by Eva Shinnerer), and spectroscopy with the VLT and with Magellan.

One of numerous aspects of the COSMOS project, the examination of quasar host galaxies is carried out principally through X-ray and HST images of a large sample of several hundred AGN and quasars. Fig. III.2.5 shows several examples at redshifts between $z = 0.35$ and $z = 2$. At these highest redshifts, the images reach their limits because the observed rest wavelength interval lies in the ultraviolet in which only regions of strong star formation, but no old stellar populations, can be seen. After subtracting the quasar core, the galaxy images frequently show asymmetrical, and in rare cases strongly disturbed, systems. An initial comparative analysis with inactive normal galaxies shows no significant over-frequency of disturbances in quasars with these midlevel luminosities.

The (M_{BH} : M_{Gal}) Relationship between the Masses of the Black Hole and of the Bulge

In the meantime it has been broadly established, which galaxies are homes to quasars: All mass-rich galaxies with a bulge possess a central mass-rich black hole and can appear in a quasar phase or are likely already in one. The only requirement is the existence of accretable gas which must reach the center. The exact physical processes which lead to the accretion from the galaxy into its central black hole remain unclear. Simulations of the $M_{BH} \sim M_{Gal}$ relationship are not based on fundamental physics but continue to contain ad hoc assumptions.

One of the best diagnostic possibilities to constrain existing models is to examine how the relationship between black hole and galaxy bulge masses changed over cosmic time. Varying physical mechanisms are required to, for example, maintain the constant $M_{BH} : M_{Gal} = 1:700$ ratio observed in the local universe or to allow for the earlier evolution of black holes or galaxies. It is already difficult to determine this $M_{BH} : M_{Gal}$ ratio in the local Universe and at larger redshts it turns out to be a real challenge. At larger redshifts the only galaxies in which the mass of the black hole can be determined are quasar host galaxies. The quasar's broad emission lines permit, in combination with its luminosity, an $M_{BH} : M_{Gal}$ estimate within a factor of 3 – 4. This presupposes, however, that the galaxies can only be analyzed with the complications for spectroscopy described above which equally apply to imaging data.

In one of the first and best attempts in this direction, the luminosity of quasars of host galaxies enhanced by the gravitational lens effect are used to estimate their masses subject to assumptions about their stellar populations (Fig. III.2.6). Up to $z = 1.7$, no strong indications of a change in the $M_{BH} : M_{Gal}$ ratio are found. The ratio

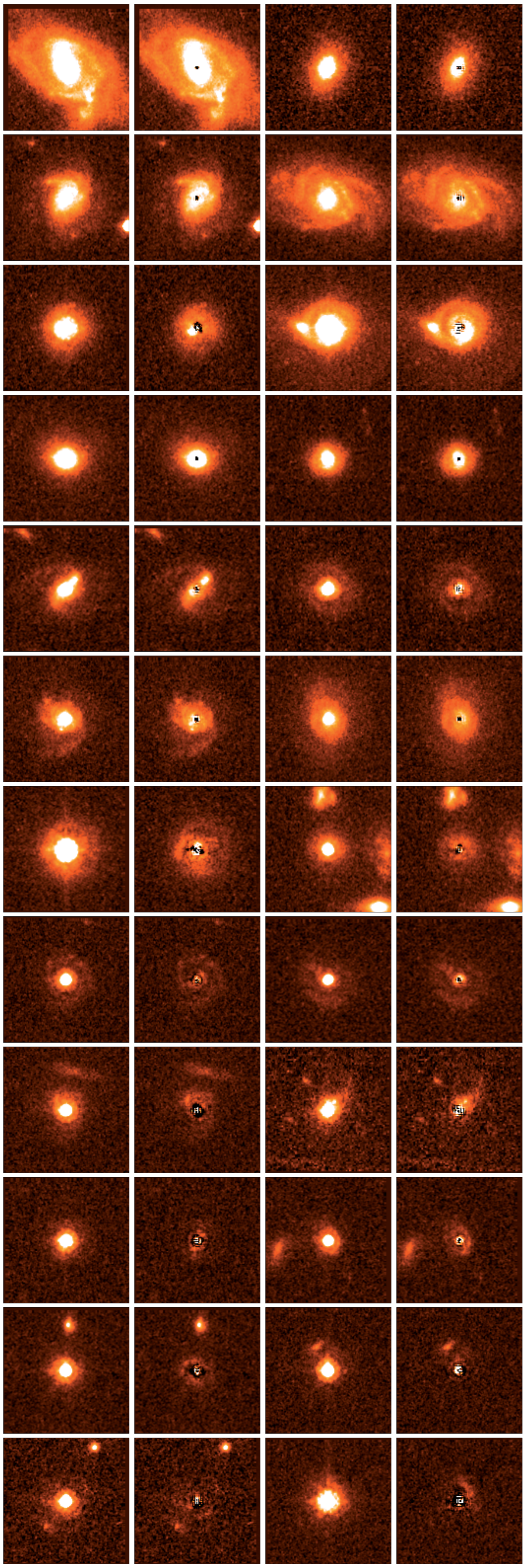


Fig. III.2.5: Quasars and their host galaxies taken with the HST as part of the COSMOS project. This selection of 24 of of approx. 300 quasars shows objects at redshifts $z = 0.35$ (*top*) to $z \approx 2$ (*bottom*). In each image pair, the left one is the original image and the right one shows the host galaxy after removal of a point source. The quasars were taken in I-Band with the HST ACS/WFC camera. (Jahnke et COSMOS et al. 2008, in prep.)

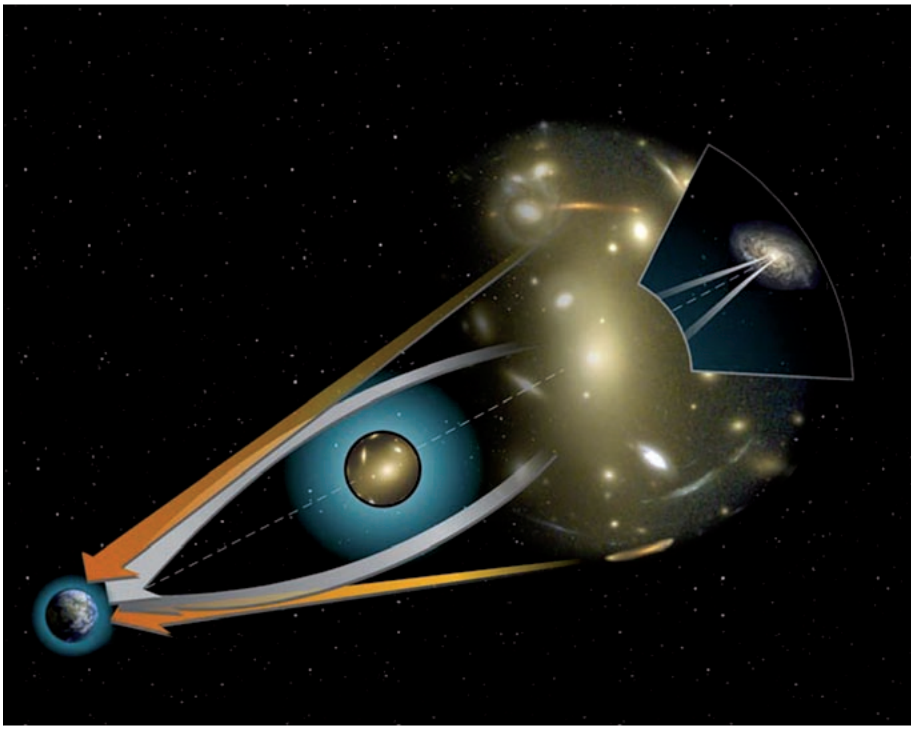


Fig. III.2.6: The gravitational lens effect. The mass of a galaxy or a cluster of galaxies diverts the light of a background galaxy (*top right*) on its path to the observer (*left*) such that multiple images are created. Thus the gravitational lens effects an increase of brightness and a magnification of the angular scales. As a result weaker and smaller systems become accessible.

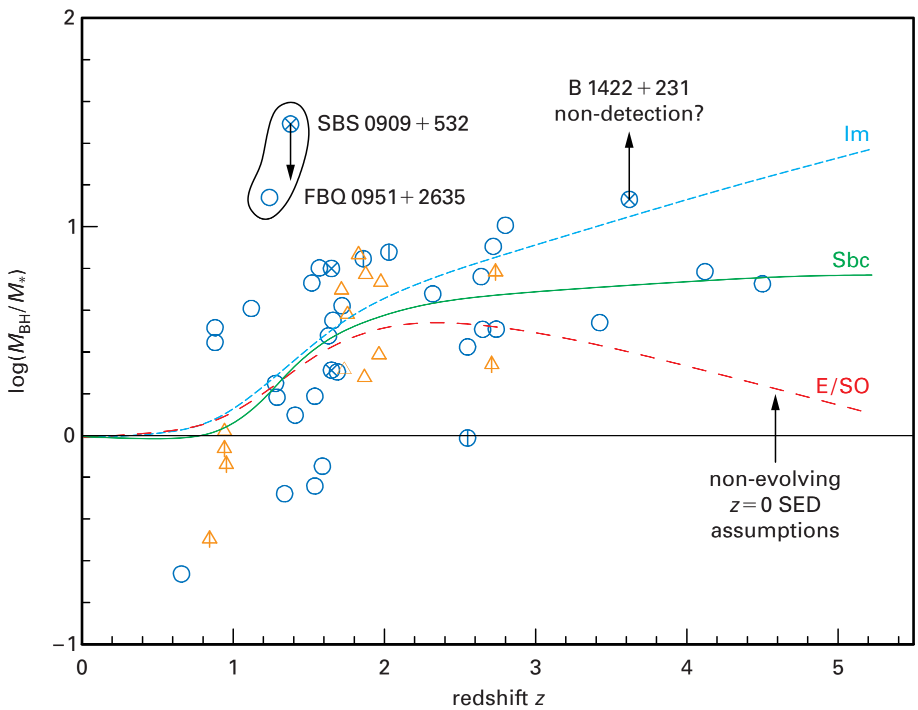
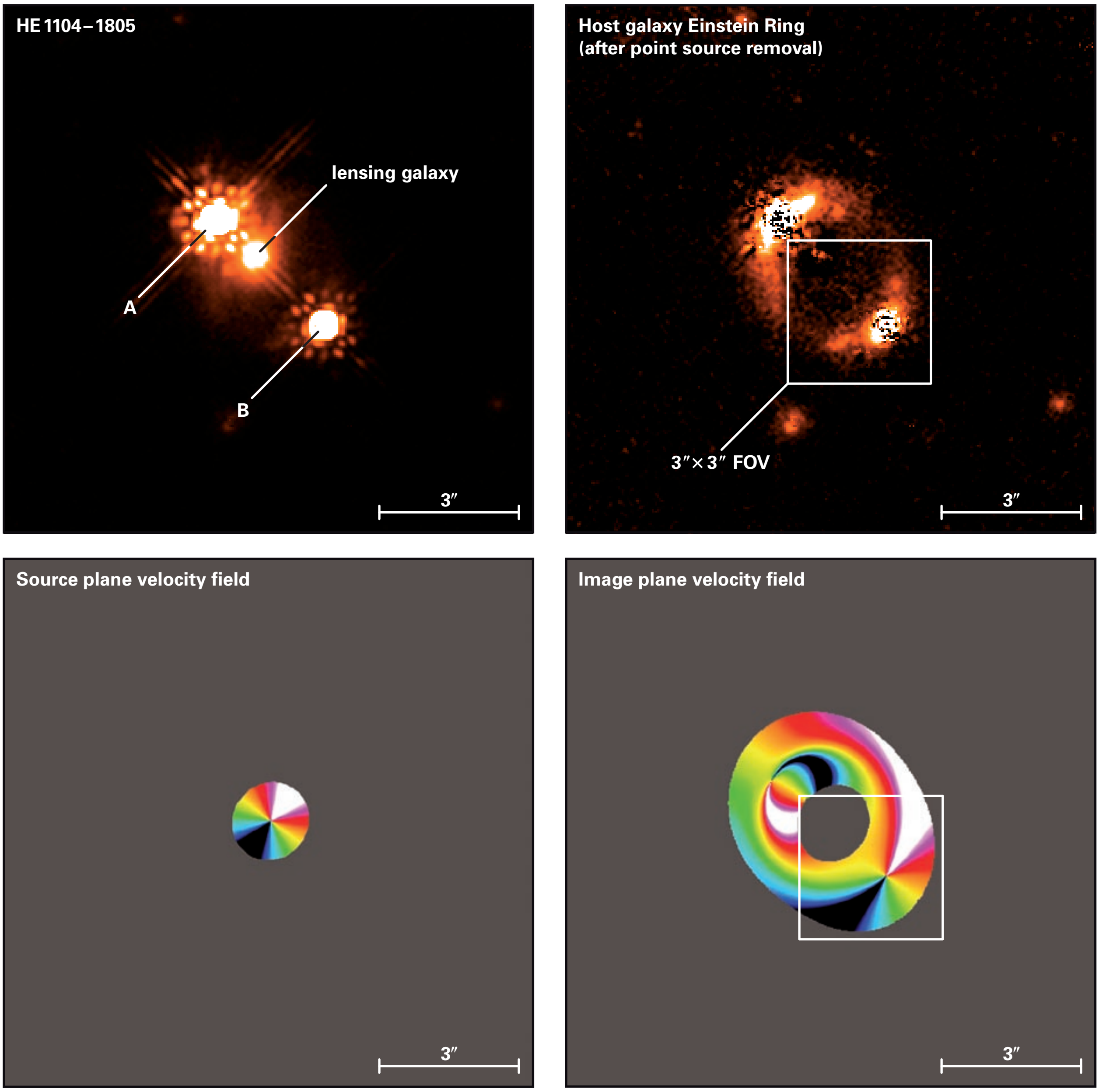


Fig. III.2.7: First results on the evolution of the $M_{SL} : M_{Gal}$ ratio with time (Peng et al., 2006, ApJ, 649, 616) for gravitationally lensed quasars while making assumptions about their stellar populations: According thereto, the ratio does not significantly change up to $z = 1.7$, but beyond this period, there are indications of an evolution toward more massive black holes in galaxies of given masses as compared to today.

seems consistent with the present value. Only beyond $z = 1.7$ are there indications that black holes were more massive than today relative to their galaxies in the early universe. Accordingly, the black holes would have first grown quickly – their galaxies building their masses only later and more slowly.

However, because of selection effects, the uncertainties of this method are still so high that these results could possibly be insignificant. Further, methodically independent approaches are necessary in order to obtain a coherent picture at these and other redshifts. To achieve this, the MPIA astronomers have started among other things an observing program using the VLT and Sinfoni (the near infrared integral field spectrograph with camera), for which they make use of MPIA's guaranteed observing time from building the Parsec laser guidance system that supports Sinfoni. The initial goal is to determine dynamic galaxy masses for four quasars, three of which are gravitationally lensed. Through Sinfoni, extended line emission in the host galaxy is measured in order to derive the velocity field present there and thus dynamically determine the included masses. This method differs in principle from the above-described approach and is also complementary to the mass determinations based on the

Fig. III.2.8: The lense system HE 1104-1805. *Top left*: the optical image (HST), *top right*: the image of the host galaxy after subtraction of the quasar core pulled apart near an Einstein ring, *right bottom:* a velocity field likely observed according to the lens model, and *left bottom:* the velocity field calculated back into the source plane.



estimate of the mass / luminosity ratio which is in parallel attempting as a part of the COSMOS project.

Representing one of the lensed systems, Fig. III.2.7 shows HST images of lensed quasars for which detailed lens models already have been derived. These models permit the calculation of a measured velocity field back into the source plane and thus a dynamic determination of the masses. The first data for this project have already been taken and are currently being analyzed. They reveal that, as calculated during planning, the observations are a challenge even for an 8 m telescope such as the VLT and that a very precise calibration is required before reliable results can be obtained. The redshift range, through which the mass of the host galaxies can be determined by means of this method, will certainly not exceed $z = 2$ given today's telescopes.

A Look toward the Golden Future

While it can be predicted that in the next few years one will be able to effectively constrain the evolution of the $M_{BH} : M_{Gal}$ ratio at least up to $z = 2$, the fact is that black holes in high-mass galaxies date from an earlier period. For a mass-dependent analysis of this relationship, a view of clearly higher redshifts is thus required –presumably around $z = 6$ to 7, to a time when the first supermassive black holes were formed. While there are currently very few, although highly interesting, reference points from CO observations of these time periods (compare annual reports 2004 and 2006), the coming years will provide very interesting instruments just for this purpose.

The Atacama Large Millimeter Array (ALMA) is currently being built in stages and will begin operation as of 2009 reaching resolutions of up to 0.005 arc seconds in the submillimeter wavelength range. Starting in 2013, the successor to the HST, the James-Webb Space Telescope, will permit, even at very large distances, new insights into the centers of active galaxies due to its as yet unachieved spatial resolution and sensitivity in the near infrared. And at the Large Binocular Telescope, the LINC/NIRVANA imaging interferometer developed by the MPIA will achieve the spatial resolution of a 23 m telescope.

In summary, over the next five years, completely new types of instruments will become available, thus allowing for new insights. One will thus be able to find out which came first – the super-massive black holes, or the galaxies in which they reside.

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together with researchers at the
Astrophysikalischer Institut Potsdam,
Universität Liege, EPFL Lausanne,
Space Telescope Science Institute
and the GEMS and COSMOS-Projects

III.3 Chemistry in Protoplanetary Disks

In this chapter we review recent advances in our understanding of the chemical evolution of protoplanetary disks and the Solar nebula obtained by radio-interferometric observations and theoretical models. Current observational constrains on physical structure and chemical composition of gas and dust in such disks are presented. We discuss a few recent results obtained at the MPIA.

First, we study the genesis of pre-biotic organic molecules in the planet-forming zone at the verge of planet formation. We predict that some CO-bearing species such as H_2CO can be underabundant in the inner regions of accreting protoplanetary disks around low-mass stars due to the high-energy stellar radiation and chemical processing on dust grain surfaces. Second, we predict how protoplanetary disks around low-mass young stars would appear in molecular lines observed with the ALMA interferometer. Molecules and transitions that can be used to probe and distinguish between chemical stratification and physical disk structure are identified and the necessary requirements for ALMA observations are specified.

Introduction

The origin and evolution of life as we know it are tightly related to the chemistry of complex carbon-bearing molecules. While the transition from macromolecules to the simplest living organisms is likely to have proceeded on Earth, we do not yet know the complexity of organic molecules that were available during the build-up phase of the primordial / secondary Earth atmosphere and oceans. During the last few decades a multitude of species, including alcohols (e.g. CH_3OH), ethers (e.g. CH_3OCH_3), and acids (e.g. HCOOH) have been discovered in interstellar space, with atomic masses up to a few hundred (for a recent review see Snyder 2006). A precursor of amino acids, amino acetonitrile, and the simplest sugar, glycolaldehyde, have been found toward the star-forming region Sagittarius B_2 (N) (Hollis et al. 2004, Belloche et al. 2008). Thus, many simple "blocks" of prebiotic molecules do exist in space. It is natural to ask what happens to these species during the prestellar / hot core phase, passage of an accretion shock, and inside a protoplanetary disk. Are organic molecules present in large amounts in circumstellar disks at the verge of planet formation? Could they form and survive in such a harsh environment as an accretion disk?

Despite the variety of "interstellar" molecules, only formaldehyde (H_2CO) and a few other non-organic species have been detected and spatially resolved with interferometers in several nearby protoplanetary disks (e.g., Dutrey et al. 1997, Kastner et al. 1997, Aikawa et al. 2003, Qi et al. 2003, Dutrey et al. 2007 b). These multi-molecule, multi-transition studies allowed the constraint of basic disk parameters such as radii, masses, kinematics, temperature and density profiles, ionization degree and depletion factors (e.g., Dartois et al. 2003, Semenov et al. 2005, Qi et al. 2006, Piétu et al. 2007, Qi et al. 2008). Using advanced chemical models and indirect observational evidence, one can attain clues about the presence of other, yet undetected organic molecules in disks and estimate their abundances.

It is now commonly believed that the formation of complex (organic) molecules begins in cold dense cloud cores on dust grain surfaces serving as catalysts for many exothermic reactions between radicals and light atoms, with formaldehyde being one of the precursors for complex organic molecules. The newly produced species can eventually be returned into the gas phase, either during the slow heat-up phase after the formation of a central star (Garrod & Herbst 2006) or due to some thermal/ non-thermal desorption mechanisms, like cosmic rays, X-rays, and UV heating of grains (d'Hendecourt et al. 1982, Leger et al. 1985, Shalabiea & Greenberg 1994, Najita et al. 2001, Garrod et al. 2007).

Transformation of a cloud into an actively accreting disk caused by gravitational collapse and angular momentum transport further modifies the composition of gas and dust as it passes through a shock front (Lada 1985, Hassel 2004). Furthermore, dynamical transport in accretion disks can also be efficient for enriching the gas with complex species through evaporation of icy mantles in warmer, less opaque regions (Willacy et al. 2006, Semenov et al. 2006). The UV radiation from the star and interstellar radiation field plays a major role in disk chemistry by dissociating and ionizing molecules, and heating the gas above the midplane where many molecular lines get excited (e.g., van Zadelhoff et al. 2003). Disk chemistry by itself can lead to the production of complex organic molecules.

The recent detection of NeII line emission from several protoplanetary disks by SPITZER (Pascucci et al. 2007) supports theoretical predictions of Glassgold et al. (2007) that the upper disk parts can be ionized and heated by the intense X-ray radiation from a young star. This thermal bremsstrahlung radiation is likely produced in reconnection loops in stellar corona at a distance of up to 0.1 AU from the star and is capable of penetrating deeply into the disk inner region – the zone where planets form (e.g., Igea & Glassgold 1999). This X-ray radiation ionizes helium atoms, which destroy CO and replenish the disk gas with ionized atomic carbon. This leads to the formation of heavy cyanopolyynes and long carbon chains, partly on grain surfaces, which may lock a significant fraction of elemental carbon in the inner disk region (Semenov et al. 2004). Thus it is of utmost importance to reveal which mechanisms and processes are important during various stages of protoplanetary disk evolution, using advanced theoretical modeling and high-quality observational data.

In the framework of the "Chemistry In Disks" (CID) collaboration between groups in Heidelberg, Bordeaux, Paris and Jena, astronomers from the MPIA have initiated a program to study and characterize chemical evolution and physical properties of nearby protoplanetary disks surrounding young stars of various masses and ages (see, e.g., Dutrey et al. 2007 b). Among the various goals of the project, they searched for emission lines of precursors to complex organic molecules and detected and resolved the disk around the low-mass star DM Tau in the H_2CO (3–2) line with the Plateau de Bure interferometer (though with the modest signal-to-noise ratio of 3 to 5). They found that the H_2CO emission is not centrally peaked like the dust continuum, but shows an asymmetric, ring-like structure with a large inner "hole" of 100 AU. The high-resolution observations of DM Tau with the IRAM interferometer by Dartois et al. (2003) and Piétu et al. (2007) did not reveal the presence of a central depression either in CO lines or in dust continuum.

The difficulty of resolving nearby protoplanetary disks in molecular lines with high signal-to-noise ratio will be greatly diminished when the Atacama Large Millimeter Array (ALMA), equipped with 50 12-m antennas, comes into operation in 2012. ALMA will be capable of imaging protoplanetary disks at spatial resolutions up to $0\overset{''}{.}04$ — $0\overset{''}{.}005$ in a frequency range between 100 and 950 GHz. This will allow direct detection and characterization of disk instabilities, resulting in clumpy structures (vorticities, "spiral arms", etc.) as well as inner gaps and holes induced by forming giant planets (Wolf et al. 2002, Wolf & Klahr 2002, Narayanan 2006). The large-scale chemical structure of protoplanetary disks will become accessible through the rotational lines of many abundant molecules. As demonstrated by Pavlyuchenkov et al. (2007), excitation of molecular lines in disks with strong gradients in physical conditions and chemical structure can be a complicated process and may be hard to interpret.

In this chapter the MPIA team reviews the current knowledge about chemistry in disks and predict that the H_2CO inner hole, if it really exists, should likely be caused by *chemical effects*. Also, they study the potential of ALMA to distinguish between various temperature and chemical effects in protoplanetary disks, with an emphasis on discerning the spatial resolution and integration time needed.

Observational Facts

Up to now more than 150 molecules have been discovered in space. Among them only a small fraction have been detected in planet-forming disks with the aid of millimeter interferometry: CO and its isotopes, CN, HCN, DCN, HNC, H_2CO, C_2H, CS, HCO^+, $H^{13}CO^+$, DCO^+, and N_2H^+ (Dutrey et al. 1997, Kastner et al. 1997, Aikawa et al. 2003, Dutrey et al. 2007 a, Qi et al. 2008). A few bright and large disks like the ones surrounding DM Tau, LkCa 15, and MWC 480 have been investigated in detail in a dozen of molecular transition lines and dust continuum. Combined analysis of these line and continuum data allowed the astronomers to derive disk sizes, orientation, kinematics, distribution of temperature, surface density, and molecular column densities (e.g., Dartois et al. 2003, Qi et al. 2006, Isella et al. 2007, Piétu et al. 2007).

The lines of the abundant CO molecule serve as a probe of disk geometry as well as thermal structure and surface density distribution and kinematics. Due to selective photodissociation, disks appear increasingly larger in the dust continuum and the $C^{18}O$, ^{13}CO, and ^{12}CO lines, with a typical radius of 300 – 1000AU (Dutrey et al. 2007 a). An important finding is the presence of vertical temperature gradients in many disks, as predicted by physical models, while a few disks with large inner cavities do not show evidence for such a gradient (e.g., GM Aur). Furthermore, disks around hotter Herbig Ae/Be stars are systematically warmer than those around cool Sun-like T Tau stars. Recently, Qi et al. (2006) have found that the observed intensity ratios of the CO low- to high-level lines in the TW Hya disks require an additional heating source, which could be the X-ray stellar radiation.

The observed lines of C_2H, CN, and HCN are sensitive to the properties of the impinging UV radiation, in particular to the fraction of the total UV luminosity emitted in the Ly line (Bergin et al. 2003). The observed ratio of the CN to HCN column densities in disks is typical of photon-dominated chemistry, as predicted by the chemical models (Chapillon et al. 2008, in prep.). Molecular ions (HCO^+ and N_2H^+) are the dominant charge carriers at intermediate disk heights and their observations allowed the constraint of the ionization fraction in these regions, with a typical value of 10^{-8} (Qi et al. 2003, Dutrey et al. 2007 b). The observed ratios of DCO^+ to HCO^+ and DCN to HCN column densities have much higher D/H value than the cosmic abundance of 0.01% and thus deuterium fractionation is effective in disks (Qi et al. 2008).

In general, the observed molecular abundances are lower by factors 5 – 100 in protoplanetary disks compared to the values in Taurus molecular cloud, likely due to efficient freeze-out and photodissociation. A puzzling observational fact is that a significant reservoir of very cold CO and HCO^+ gas exists in the disks of DM Tau and LkCa 15, at temperatures 13 – 17 K, which are below the freeze-out temperature of CO (20 K). Conventional chemical models cannot explain this without invoking a non-thermal desorption mechanism that works in the dark disk midplane, like efficient turbulent diffusion and UV-photodesorption driven by cosmic ray particles (Semenov et al. 2006, Oeberg et al. 2007).

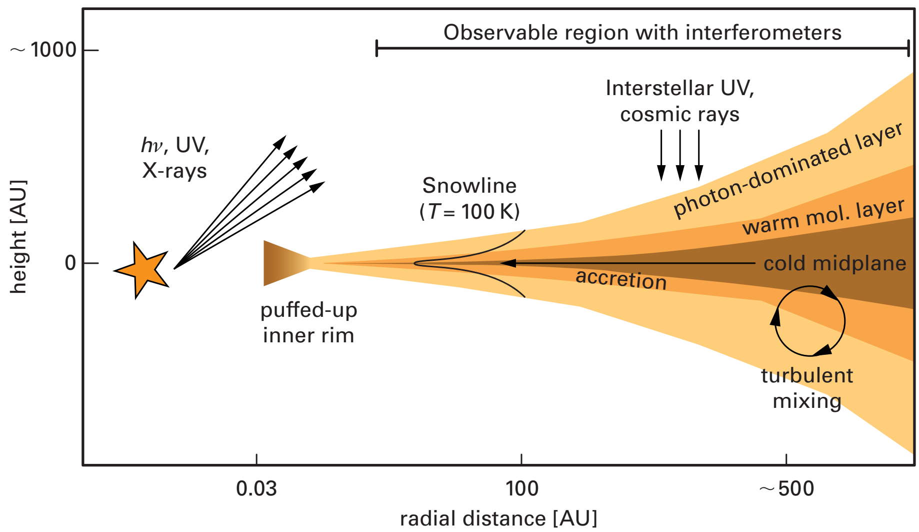
Observations of dust thermal emission at (sub-) millimeter and centimeter wavelengths are used to measure the slope of the wavelength dependence of the dust opacities, which is a sensitive indicator of grain growth and sedimentation in disks (e.g., Rodmann et al. 2006). There is strong evidence that in many evolved disks, with ages of a few Myrs, dust grains grow until at least pebble-like sizes. The results from the Infrared Space Observatory (Iso) and Spitzer reveal the presence of a significant amount of frozen material and a rich variety of amorphous and crystalline silicates and PAHs in disks (e.g., van den Ancker et al. 2000, van Dishoeck 2004, Bouwman et al. 2008). The PAH emission features at near-and mid-infrared wavelengths are excited by the incident stellar radiation field and as such depend on disk vertical structure and turbulent state (Dullemond et al. 2007). These lines are more easily observed in disks around hot, intermediate-mass Herbig Ae / Be stars than cool, Sun-like T Tauri stars (e.g., Acke & van den Ancker 2004, Geers et al. 2007, Sicilia-Aguilar et al. 2007).

Various solid-state bands observed at 10 – 30 μm in emission belong to amorphous and crystalline silicates at temperatures betwwen 100 and 300Kelvin with varying Fe/Mg ratios and grain topology/sizes (e.g., van Boekel et al. 2004, Natta et al. 2007, Bouwman et al. 2008, Voshchinnikov&Henning 2008). The composition of the hot gas in the inner disk as traced by ro-vibrational emission lines from CO, CO_2, C_2H_2, HCN and recently water and OH, suggests that complex chemistry driven by endothermic reactions is at work there (Brittain et al. 2003, Lahuis et al. 2006, Eisner 2007, Salyk et al. 2008). At larger distances from the star the disk becomes colder and most of these molecules stick to dust grain, forming icy mantles. The main mantle component is water ice with trace amount of other more volatile materials like CO, CO_2, NH_3, CH_4, H_2CO, HCOOH and CH_3OH (Zasowski et al. 2007). Typical relative abundances of these minor constituents are about 0.5 to 10 percent of that of water.

Chemical Structure of a Disk

The chemical evolution of protoplanetary disks has been investigated in detail by using robust chemical models (Willacy et al. 1998, Aikawa & Herbst 1999, Willacy & Langer 2000, Aikawa et al. 2002, Bergin et al. 2003, van Zadelhoff et al. 2003, Ilgner et al. 2004, Semenov et al. 2004, Willacy et al. 2006, Ilgner & Nelson 2008). The current theoretical picture based on a steady-state prescription of the disk structure divides the disk into three zones, see Fig. III.3.1. Before planets have formed and disk gas is dispersed, the dense

Fig. III.3.1: Physical and chemical structure of a protoplanetary disk. In the dark, dense and cold midplane most molecules reside on dust grains, and chemical evolution is dominated by ion-molecule and surface reactions; this region has the lowest ionization degree, with dust grains being the most abundant charged species. A warmer intermediate layer is located above midplane, heated by mild UV radiation. Many reactions with barriers can occur and a rich variety of molecules exist in the gas phase; this is the zone where most of the molecular lines are formed. The ionization fraction in the intermediate layer is determined by a multitude of molecular ions, in particular HCO^+. Further above, a hot, highly ionized disk atmosphere is located, where only the simplest radicals and ions (apart from H_2) survive; this is the region where ionized carbon is abundant and C^+ emission lines are excited.



midplane is well shielded from stellar and interstellar high-energy radiation. While its inner part can be heated up by accretion, the outer zone is cold, between about 10 and 20 Kelvin. The only ionization sources are cosmic ray particles and decay of radionuclides with short lifetimes, and thus matter remains almost neutral with a low degree of turbulence. The molecular complexity in the midplane is determined by ion-molecule and surface reactions, with most molecules attached to the grains. A warmer zone adjacent to the midplane is partly shielded from stellar and interstellar UV / X-ray radiation. The complex cycling between efficiently formed gas-phase molecules, accretion onto dust surfaces, rapid surface reactions, and non-negligible desorption result in a rich chemistry (see Bergin et al. 2007 for a review). The inner part (10 – 20 AU) of this region in the disks around T Tauri stars can be substantially ionized by stellar X-ray radiation. The intermediate molecular layer is dense enough (about $10^5 – 10^6$ cm^{-3}) to excite most of the observed emission lines. A hot and heavily irradiated surface layer is located above this, where C^+, light hydrocarbons, their ions, and other radicals like C_2H and CN are able to survive. This is the region where PAH and silicate emission features are produced.

Modeling of Disk Chemical Evolution

The Plateau de Bure interferometric image of the DM Tau disk at the 1.″5 resolution in the H_2CO (3–2) line is shown in Fig. III.3.2 (left panel). Despite the high noise level, the H_2CO emission appears as an asymmetric ring-like structure, with a dip in the southern direction. To make a proper analysis of these data, a consistent combination of disk physical and chemical models along with radiative transfer in molecular lines is used. To simulate the physical structure of the disk the MPIA astronomers utilize a 1 + 1 D flared disk model which is similar to the model of D'Alessio et al. (1999) with a vertical temperature gradient. The dust grains are modeled as compact amorphous silicate spheres of uniform 0.1 µm radius, with the opacity data taken from Semenov et al. (2003) and a dust-to-gas mass ratio of 100. The accretion rate is assumed to be $2 \times 10^{-9}\, M_\odot\, yr^{-1}$, $\alpha = 0.01$, and the disk outer radius is 800 AU. We focus on the observable disk structure beyond the radius of about 10 AU. The total disk mass is $0.07\, M_\odot$ and the disk age is 5 Myr (Piétu et al. 2007). The thermal and density disk structure is shown in Fig. III.3.3 (left and middle panels). To mimic the case when the vertical temperature gradient is weak or absent, the astronomers also consider the same disk model with a vertical temperature distribution fixed to the value at one pressure scale height.

They assume that the disk is illuminated by UV radiation from the central star with an intensity $x = 410\, x_0$ at 100 AU and by interstellar UV radiation with intensity x_0 in plane-parallel geometry (Draine 1978, van Dishoeck et al. 2006, Dutrey et al. 2007 b). They model the attenuation of cosmic rays (CRP) by Eq. (3) from Semenov et al. (2004) with an initial value of the ionization rate $\zeta_{CRP} = 1.3 \times 10^{-17}$ s^{-1}. In the disk interior ionization due to the decay of short-living radionuclides is taken into account, assuming an ionization rate of 6.5×10^{-19} s^{-1} (Finocchi & Gail 1997). The X-ray ionization rate in a given disk region is computed according to the results of Glassgold et al. (1997 a), Glassgold et al. (1997 b) with parameters for their high-metal depletion case and a total X-ray luminosity of $\approx 10^{23}$ J cm^{-2} s^{-1} (Glassgold et

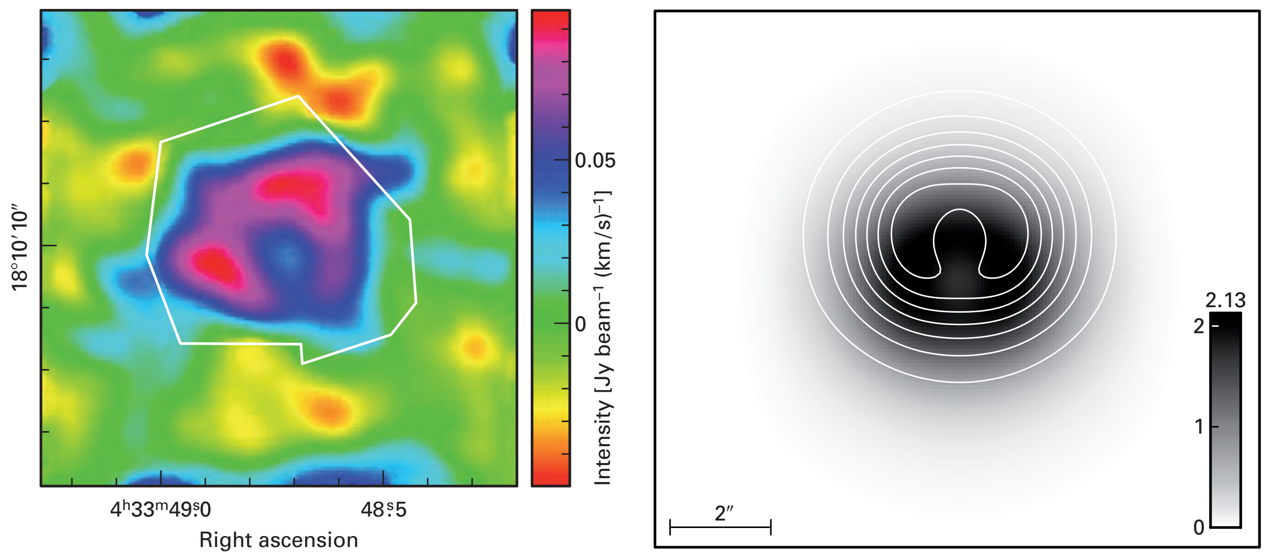


Fig. III.3.2: (*Left*) The observed integrated intensity map of H_2CO (3 – 2) in the disk of DM Tau shows an asymmetric shell-like distribution with a chemical inner "hole" of 100 AU in radius. (*Right*) The same features are present in the synthetic integrated intensity map of para-H_2CO (4 – 3) that is produced with a realistic physical and chemical disk model and line radiative transfer.

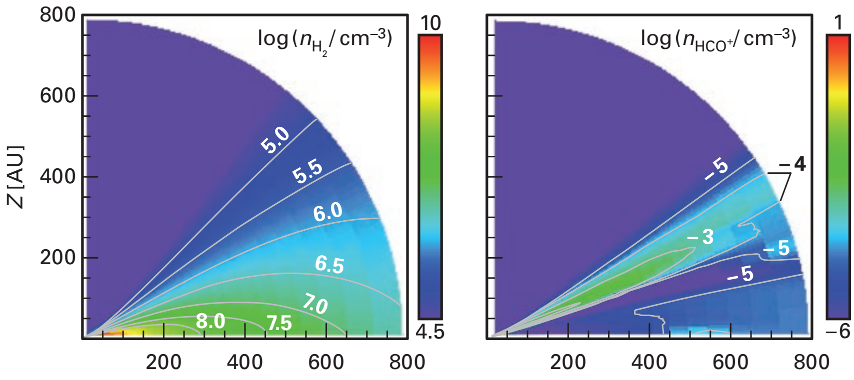


Fig. III.3.3: Distributions of molecular densities (*left*) and temperature for the DM Tau disk model.

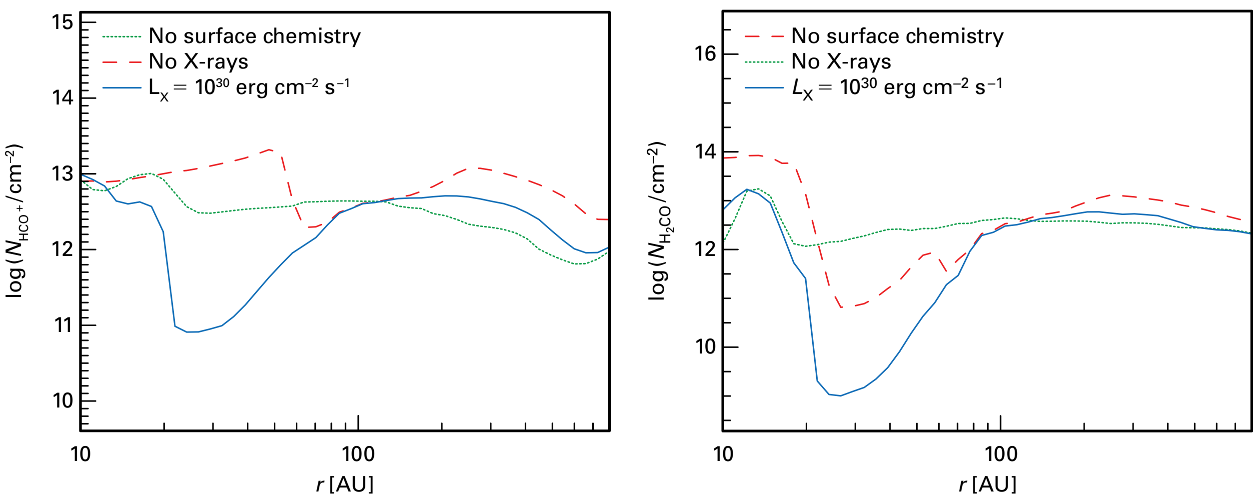
al. 2005). The gas-phase reaction rates are taken from the RATE 06 database (Woodall et al. 2007), while surface reactions together with desorption energies are adopted from the model of Garrod & Herbst (2006). A standard rate approach to the surface chemistry modeling, but without H and H_2 tunneling was utilized (Katz et al. 1999).

Using the time-dependent chemical code "ALCHEMIC", the MPIA astronomers simulated 5 Myr years of evolution in the DM Tau disk, followed by 2D non-LTE line radiative transfer modeling with "URANIA" (Pavlyuchenkov et al. 2007), see Fig. III.3.4. The observed ring of H_2CO emission with a depression is fully reproduced by our model. We found two possible explanations why such a large-scale chemical hole can exist in the disk around DM Tau. The 100AU hole in the H_2CO emission is fully reproduced by both a disk model with X-ray driven chemical processes and somewhat less markedly in the model without surface chemistry. These two models predict different spatial distributions of molecular species, which can be tested by future interferometric observations.

Destruction of formaldehyde has important consequences for organic chemistry. The X-ray chemical model leads to the clearing of an inner hole of about 100 AU radius in all chemically related CO-bearing species, including HCO^+, by converting gas-phase CO into heavier CO2-containing and chain-like hydrocarbon molecules. In contrast to CO, these heavier species are locked on dust surfaces in the inner disk region, where temperatures are lower than about 35 – 50 K (Fig. III.3.4, solid line). This implies substantially different initial conditions with respect to the presence of complex organic molecules inside the planet-forming zone of protoplanetary disks, if this X-ray driven chemistry is important.

The less realistic model without surface chemistry shows the inner depression in column densities of highly saturated molecules only, like H_2O, NH_3, and to some extent H_2CO (see Fig. III.3.4, dashed line). These species are

Fig. III.3.4: (*Left*) The radial distribution of the HCO^+ column density in the DM Tau disk as computed with 3 different chemical models: 1) the stellar X-ray luminosity is assumed to be close to the observed value of 10^{23} J cm^{-2} s^{-1} (*solid line*), 2) no X-ray radiation penetrates into the inner disk (*dotted line*), and 3) the model without surface reactions but with X-ray radiation included (*dashed line*). (*Right*) The same calculations but for the chemically related H_2CO molecule.



formed on dust surfaces in a sequence of hydrogen addition reactions. Though at the current stage one cannot fully distinguish between these two scenarios, for the understanding of the evolution of organic species in protoplanetary disks it will be of great importance to verify which of these explanations are valid. With the aid of the high resolving and collecting power of ALMA the MPIA astronomers hope to get a distinct answer on this question.

Predictions for ALMA

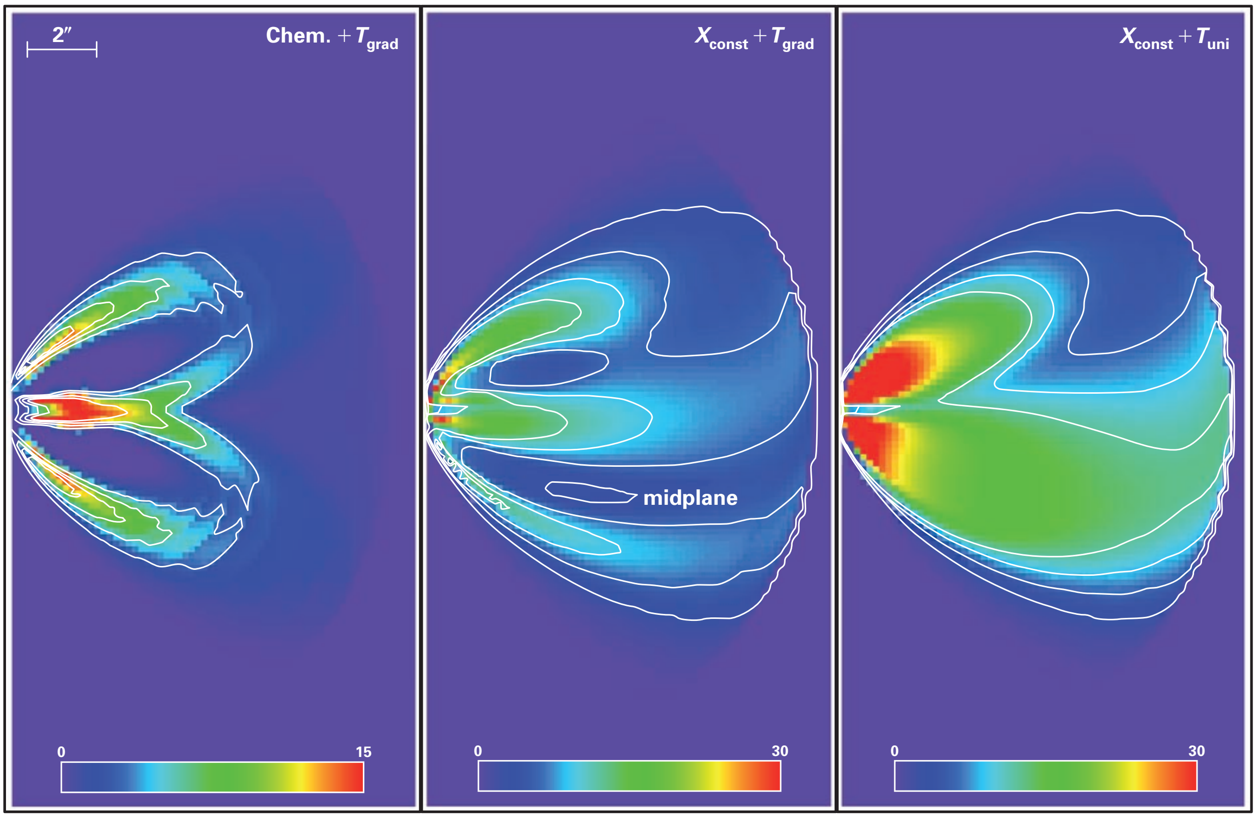
Though in the previous section we discussed the evolution of complex chemical species in protoplanetary disks which would require the use of ALMA to fully understand, first one has to understand if ALMA will help to discriminate between chemical stratification and thermal gradients in disks. For that the astronomers will use HCO^+ as a representative abundant molecule that traces the ionization fraction and possesses strong rotational transitions, and which is readily observed in disks (Dutrey et al. 2007). The HCO^+ abundances have a layered structure with the maximal HCO^+ concentration of $\sim 10^{-8}$ reached at intermediate disk heights. Many observed species have a similar stratification, e.g., CO, CS, HCN, etc. (Aikawa & Herbst 1999; Vasyunin et al. 2007).

Strong turbulent mixing and/or global advection flows can smooth these abundance gradients, leading to more uniformly distributed abundances (Willacy et al. 2006; Semenov et al. 2006). Therefore, the astronomers also consider a model with an uniform HCO^+ abundance of 10^{-9} relative to H_2. Thus, the ALMA study is based on three disk models: (1) the model with chemical stratification and vertical temperature gradient, (2) the same model but with uniform abundances, and (3) the model with uniform abundances and no vertical temperature gradient.

Using these three DM Tau-like disk models, and the 2D non-LTE line radiative transfer code of Pavlyuchenkov et al. (2007) with thermal dust continuum included, the MPIA astronomers synthesize "ideal" (beam-unconvolved) channel maps. At the 60° inclination the integrated HCO^+(4–3) line width is about 3 km s^{-1}, with a peak intensity reached at about 0.8 km s^{-1}. The corresponding 0.1 km s^{-1} wide velocity channel at $V = 0.77$ km s^{-1} of the continuum-subtracted HCO^+(4–3) map is shown in Fig. III.3.5.

This close to edge-on orientation is particularly favorable as the layered and uniform disk chemical structures can be clearly distinguished in the channel maps, if suffi-

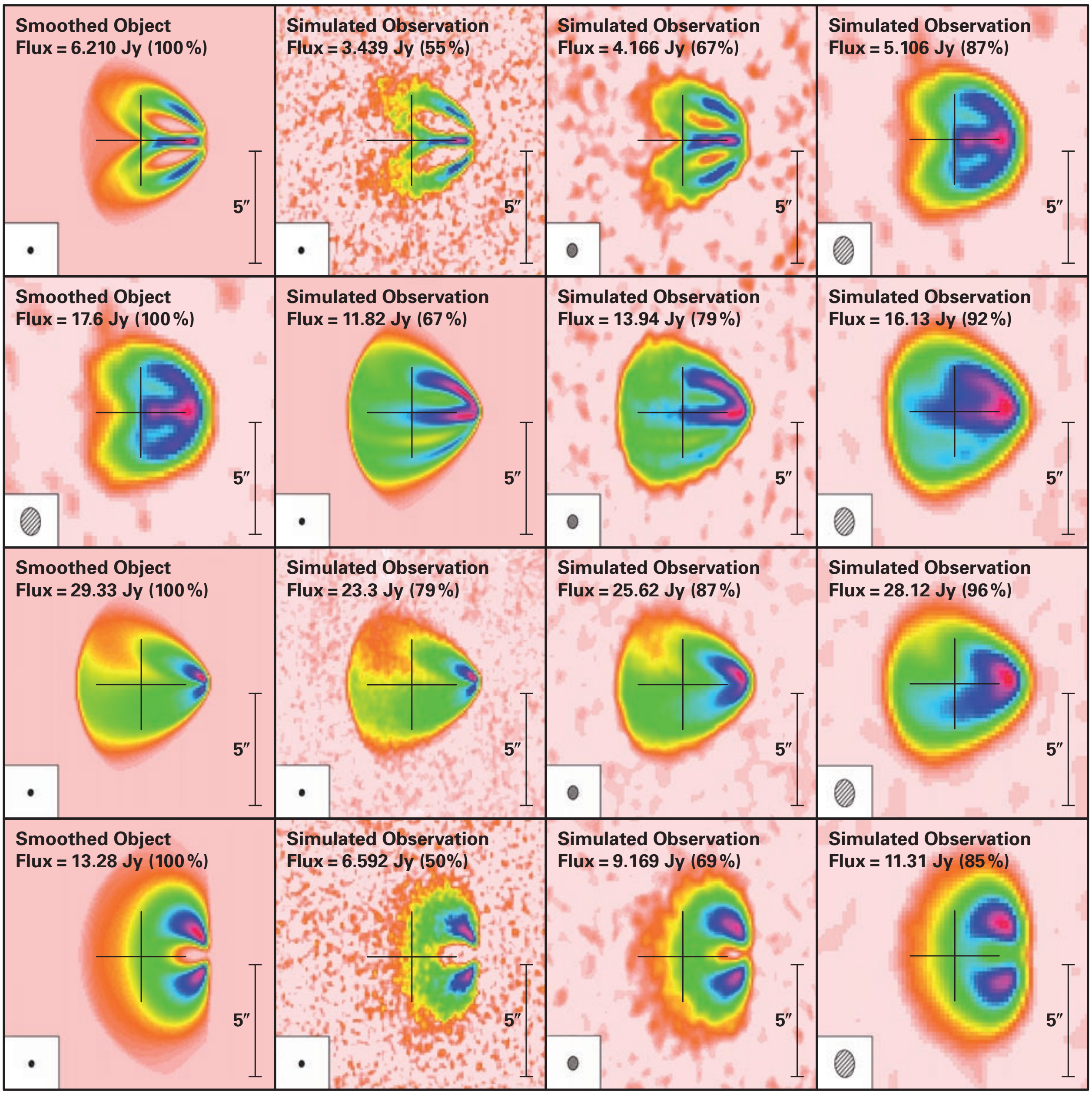
Abb. III.3.5: (*Left to right*) The continuum-subtracted HCO^+ (4–3) synthetic map at the $V = +0.77$ km s^{-1} velocity channel for the three disk models: the model with chemical stratification and temperature gradients, the same model but with uniform abundances, and the model with uniform abundances and no vertical temperature gradient. The inclination angle is 60°. Intensity is given in units of radiative temperature (Kelvin).



ciently small channel widths of 0.1 – 0.2 km s $^{-1}$ are used. All synthetic channel maps reveal a complex pattern and are asymmetric. The model with both non-zero temperature and abundance gradients has a remarkable "omega" shape, where the cold midplane with low HCO^+ concentration appears as two intensity "holes" (Fig. III.3.5, left panel). A steep temperature gradient in the radial direction toward the inner disk region is clearly visible, while the vertical temperature gradient cannot be fully traced with the HCO^+ lines due to strong chemical stratification of this species. The HCO^+ (4–3) emission is thermalized and optically thin in this case.

The two models with uniform abundances have relatively high HCO^+ column densities so that self-absorption becomes important. In the model with fixed vertical temperature this effect leads to a layer with low intensity in the upper part of the map (Fig. III.3.5, right panel). However, the overall intensity of the HCO^+ (4–3) emis-

Fig. III.3.6: (*From first to third row*) The same as in Fig. III.3.5 but processed with the GILDAS ALMA simulator for the three array configurations and 64-antennas: "zoom-c" (~0.25″ beam size, integration time is 2 hours), "zoom-b" (~0.5″ beam size, integration time is 0.5 hours), and "zoom-e" (~1″ beam size, integration time is 0.5 hours). (Bottom row) The HCO^+(4 – 3) channel map at the $V = +0.3$ km s^{-1} velocity channel for the disk model with chemical gradients and the inclination angle of 20°.



sion is higher compared to the model with layered abundances. The radial temperature gradient is also prominent in this case.

The model without chemical stratification but with a vertical temperature gradient also reveals the self-absorption layer in the upper part of the channel map. The excitation temperature of the HCO^+ (4–3) transition changes strongly with the disk height and has the lowest value in the midplane. This zone of low intensity appears as a fake "spiral arm" in the lower part of the map (marked as "midplane" in Fig. III.3.5, middle panel). Note that such a pattern somewhat resembles the "omega" structure for the model with chemical stratification of HCO^+. While only one representative channel is shown, one should bear in mind that analysis of the interferometric data is more reliable when all channels and dust continuum emission are taken into account.

Despite the fact that all the models considered can be distinguished in the synthetic channel maps, it is important to study whether ALMA is able to disentangle the effects of thermal and chemical structure in disks. To simulate the observations with ALMA, use of the synthetic HCO^+ (4–3) channel maps is made as an input to the GILDAS simulation software. The focus lies on the 0.77 km s^{-1} channel (with 120 kHz bandwidth or 0.1 km s^{-1} velocity width). Typical weather conditions at the Chajnantor plateau are assumed, with the following main types of errors leading to noise: 1) receiver temperature is 80 K, system temperature is 230 K (at n = 357 GHz, see Guilloteau 2002), 2) random pointing errors during the observation are 0.60″, 3) relative amplitude errors are 3 % with a 6 % hour-1 drift, 4) residual phase noise after calibration is 30°, 5) anomalous refraction. The object is assumed to pass the meridian in the middle of a single observational run. 30 minutes of integration time is used or increased such, that the deconvolved maps look similar to the input model with chemical gradients. In contrast to modern interferometric facilities there will be no difficulty achieving a good uv-coverage with ALMA in a fraction of an hour.

The simulated ALMA channel maps of HCO^+ (4–3) at various spatial resolutions for the three adopted models and the inclination angle of 60° are presented in Fig. III.3.6 (upper 3 rows). All significant features that are present in the "ideal" molecular emission spectra appear clearly at the resolution of 0.25″ ("zoom-c" array configuration) and some are still visible at half the resolution ("zoom-d" configuration). The use of even lower resolution ("zoom-e") makes it difficult to disentangle the chemical and thermal features without extensive modeling. The DM Tau disk model with layered HCO^+ abundances and 2D temperature gradient has the lowest line intensities and hence requires the longest observation of 2 hours, while for the models with uniform HCO^+ abundances it can be as short as 30 minutes or less.

In addition, we perform a similar analysis for a face-on orientation with i = 20°. At such low inclination channel maps for distinct disk models look similar and multi-line, multi-molecule analysis become a must. The corresponding V = 0.3 km s^{-1} channel of the HCO (4–3) channel map is presented in Fig. III.3.6 (bottom row). This channel map has a ring-like shape with two emission peaks located around the low-intensity midplane. The intensity in this channel is a factor of 2 stronger than for the disk model with i = 60° and thus the observational time required to detect all these features is only 1 hour with the 0.25″ beam size and less than 30 minutes at lower resolutions. All major features in the i = 20° channel map are resolved even with the compact "zoom-e" array configuration.

Given the importance of multi-line observations and ability of ALMA to simultaneously observe several transitions of several species in various frequency bands,

Table III.3.1: Requirements for ALMA to study protoplanetary disks in molecular lines in order to discriminate between thermal structure and chemical stratification.

Species	Frequency GHz	Bandwidth kHz	R_{Disk} = 800 AU		R_{Disk} = 250 AU	
			i = 20°	i = 60°	i = 20°	i = 60°
$HCO^+(1-0)$	89	30	zoom-c (4°h)	zoom-c (10 h)	zoom a/b (> 12 h)	zoom a/b (> 12h)
$C^{18}O(2-1)$	220	75	zoom-d (1h)	zoom-e (> 12 h)	zoom-c (4 h)	zoom-c (10 h)
$^{13}CO(2-1)$	220	75	zoom-d (< 0.5 h)	zoom-d (< 0.5 h)	zoom-c (2 h)	zoom-c (3.5 h)
$CS(5-4)$	245	80	zoom-e (3 h)	zoom-d (12 h)	zoom-b (> 12 h)	zoom-b (> 12 h)
$HCN(3-2)$	266	90	zoom-e (< 0.5 h)	zoom-d (1 h)	zoom-c (4 h)	zoom-b (> 12 h)
$HCO^+(4-3)$	357	120	zoom-d (< 0.5 h)	zoom-e (< 0.3 h)	zoom-c (2 h)	zoom-d (12 h)
$HCO^+(7-6)$	624	210	zoom-e (< 0.5 h)	zoom-e (1.5 h)	zoom-c (12 h)	zoom-d (< 12 h)
$^{13}CO(6-5)$	661	220	zoom-e (< 0.5 h)	zoom-e (1 h)	zoom-d (1 h)	zoom-c (6 h)

we continue our study for other observationally important molecular tracers (CS, HCN, CO isotopes) as well as a smaller disk with a radius of 250 AU. All results are summarized in Table III.3.1. The channel maps for other transitions at millimeter wavelengths and for molecules located in the intermediate layer are similar to that of HCO^+, though their intensities are vastly different. We find that smaller disks are better studied at high frequencies of 400–700 GHz with moderately extended array configurations leading to smaller beam sizes than at millimeter wavelengths, though longer integration times are required. The contamination of the high-lying emission lines by the optically thick dust continuum from the disk inner regions and non-LTE excitation can be an issue for the analysis of these high-frequency data.

Summary

The MPIA team briefly overviews recent progress in the understanding of chemical evolution in protoplanetary disks, from both the theoretical and observational perspective. A puzzling observation of the chemical inner hole visible in the spatial distribution of the H_2CO emission in the disk of DM Tau is addressed theoretically. They found that such a hole can be explained either by the absence of efficient hydrogenation reaction on dust surfaces or efficient processing of disk matter by stellar X-ray radiation in the inner disk region, which was overlooked in previous studies. In future, when the Atacama Large Millimeter Array will become operational, the planet-forming zone of disks will be observable and this hypothesis can be verified. The ALMA interferometer will allow to distinguish the effects of temperature gradients and chemical stratification in disks through molecular line observations, in particular for highly-inclined objects. The MPIA team found that moderately extended array configurations (with baselines of 1 km) and 0.5–10 hours of integration time will be necessary to pursue such goals. In general, chemo-dynamical models of disks together with interferometric observations will lead to a comprehensive understanding of the molecular inventory of protoplanetary disks.

Dmitry Semenov und Thomas Henning

III.4 Starburst Clusters in the Milky Way

The majority of stars are born not in isolation, but in stellar clusters and associations. Interacting galaxies like the Antennae galaxies are the birthplaces of massive stellar clusters with several 100,000 to millions of stars. Over time, these super star clusters are expected to evolve into globular clusters quite similar to the 150 or so that constitute the Milky Way globular cluster system, which formed about 13 billion years ago. Among the most extreme star formation environments in the present-day Milky Way are starburst clusters with several 10,000 to 100,000 stars. As the stellar population in starburst clusters contains stars with masses from 0.1 to 120 solar masses, starburst clusters are ideal testbeds to study star formation and early stellar evolution across the entire range of stellar masses.

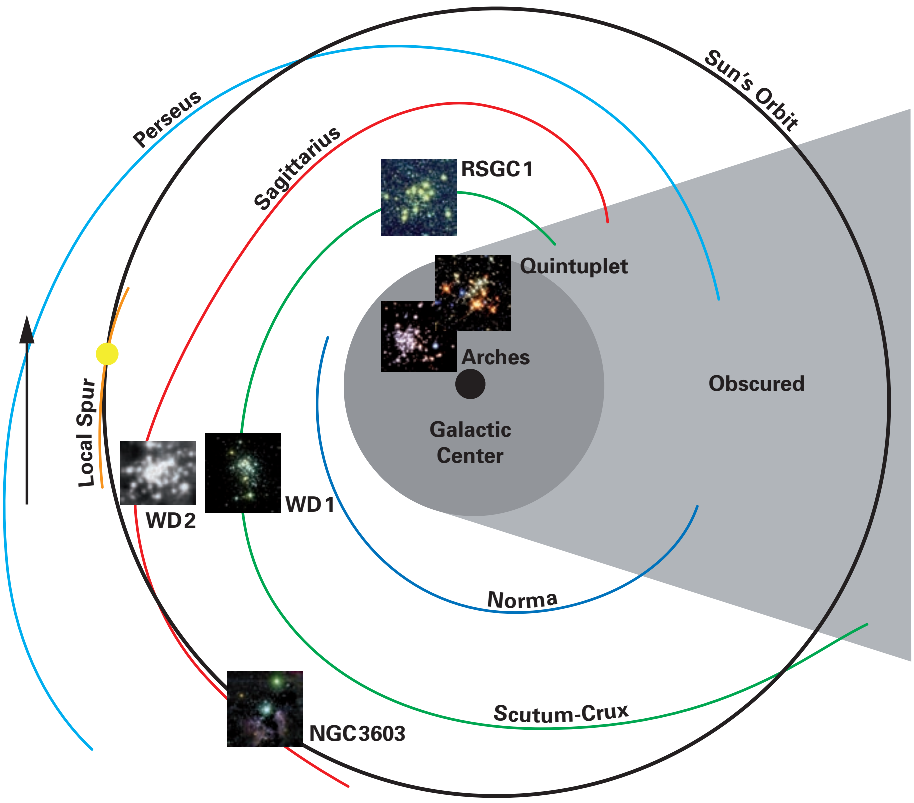
Starburst clusters with ages of a few million years represent unique astrophysical laboratories, because they contain, in a rather homogeneous environment, stars across the entire stellar mass range from the upper mass cut-off in the mass function down to the hydrogen burning limit (and possibly beyond) and with the same metallicity and age.

As such, starburst clusters are the ideal places to study star formation and to test theories on formation and evolution of stars and clusters. Unlike interacting galaxies such as the Antennae galaxies, where hundreds of super star clusters have been identified, the Milky Way houses only a handful of starburst clusters. Starburst clusters in the Antennae, however, are barely resolved, restricting study to the integrated properties of hundred thousands of stars. In the Milky Way, on the other hand, starburst clusters can be resolved into thousands to tens of thousands of stars, and the properties of each star can be derived individually.

Galactic Starburst Clusters

Milky Way starburst clusters can be found either in the galactic center region or in spiral arms. Because of strong

Fig. III.4.1. Location of the presently known starburst clusters plotted on a map (courtesy of Wikipedia) of the Milky Way spiral arm structure. The Sun's orbit is indicated by a black circle, and the present-day position of the Sun by a yellow dot. The small inserts show near-infrared observations of the individual starburst clusters.



extinction and crowding due to the high stellar density in the galactic plane, our census of galactic starburst clusters is most likely incomplete, as all known spiral arm starburst clusters are located on the near side of the galaxy (see Fig. III.4.1). The incompleteness is also highlighted by the recent discovery of two embedded red supergiant clusters in the Scutum-Crux spiral arm. Five to ten million years ago, these red supergiant clusters would have qualified as starburst clusters.

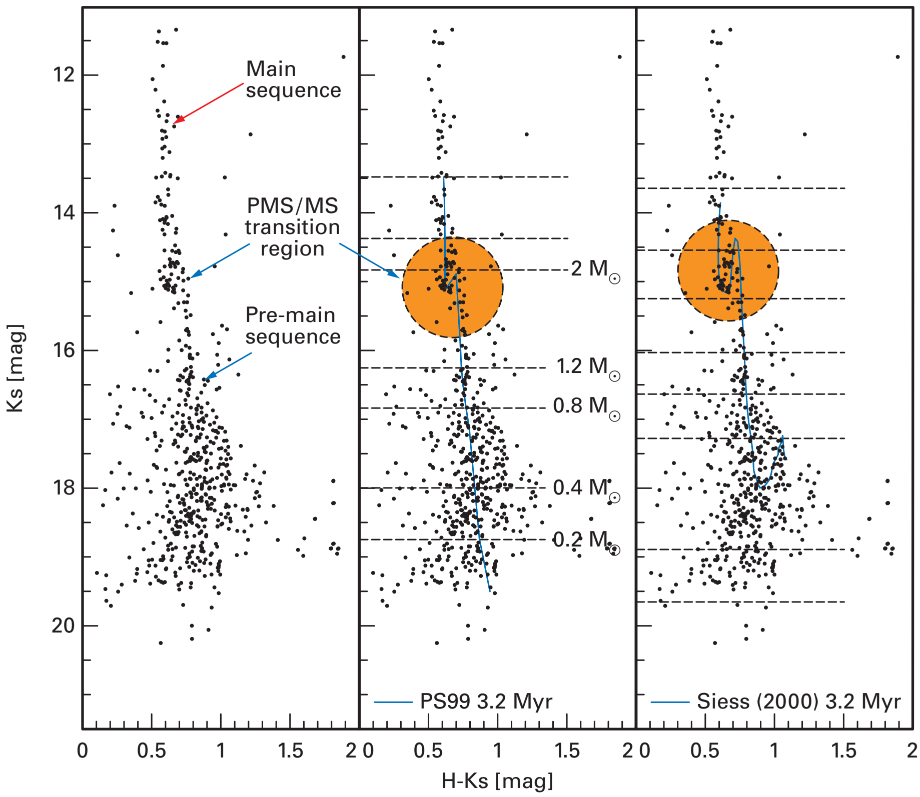
Advantages of studying Spatially Resolved Starburst Clusters

There are several advantages in studying local, and hence spatially resolved star-burst clusters. First, the large number of stars is crucial for a statistically sound determination of the mass function and dynamical properties of the clusters. Second, unlike less extreme star formation environments, starburst clusters initially house the most massive and luminous O-type main sequence stars. Fast stellar winds disperse any remnant interstellar material leftover from the formation of the cluster. UV photons from the most massive stars lead to rapid photo-evaporation of any remnant circumstellar material around the low-mass members of the cluster. The resulting advantages are twofold: star in the cluster suffer little to no differential extinction and IR excess, which results in a well constrained colour-magnitude sequence for the cluster members (Fig. III.4.2); further, the absence of circumstellar material means that non-accreting pre-main sequence tracks can be used to compare theory with observations. The presence of on-going accretion alters pre-main sequence evolutionary tracks quite drastically.

Westerlund 1 – Testing Evolutionary Tracks

The following analysis is based on near-infrared observations of Westerlund 1, which is located in the Scutum-Crux spiral arm at a distance of 3.5 kpc from the Sun. With an initial stellar mass in excess of 50,000 solar

Fig. III.4.2: Near-infrared color-magnitude diagram of the central region of Westerlund1 obtained with adaptive optics (Naco) at the Eso VLT. *Left*: the pre-main sequence and main sequence population as well as the PMS/MS transition region are identified. *Center*: the best fitting isochrone PS99 from Palla and Stahler (1999) is overplotted. It provides both a good fit to the transition region and yields the same value for the foreground extinction as has been determined by a comparison of main-sequence stars with a Geneva isochrone. *Right*: this figure highlights that an isochrone by Siess et al. (2000) does not fit the transition region as well. The offset in infrared intrinsic colours for the lower mass MS stars when compared with Geneva isochrones indicates a potential problem in the transformation from the theoretical to the observational plane for the Siess tracks.



masses Westerlund 1 is the most massive starburst cluster identified in the Milky Way to date. Seeing-limited wide-field data obtained with the ESO NTT and SOFI cover an area of about 5 pc × 5 pc centered on Westerlund 1. This is supplemented by adaptive optics high-resolution imaging of the cluster center obtained with NACO at the ESO VLT.

Starburst Clusters Going Bust – or are they Proto-Globular Clusters?

Given a total stellar mass of at least several 10,000 solar masses, starburst clusters must have formed out of giant molecular clouds. Once the most massive stars appear on the main sequence, they rapidly ionize and disperse the remaining gas. Simulations by a number of research groups indicate that, in general, a star formation efficiency (SFE) of at least 30 percent is required for a stellar cluster to re-main bound, though under special circumstances a SFE as low as 10 percent might suffice for clusters to survive for a hundred million years.

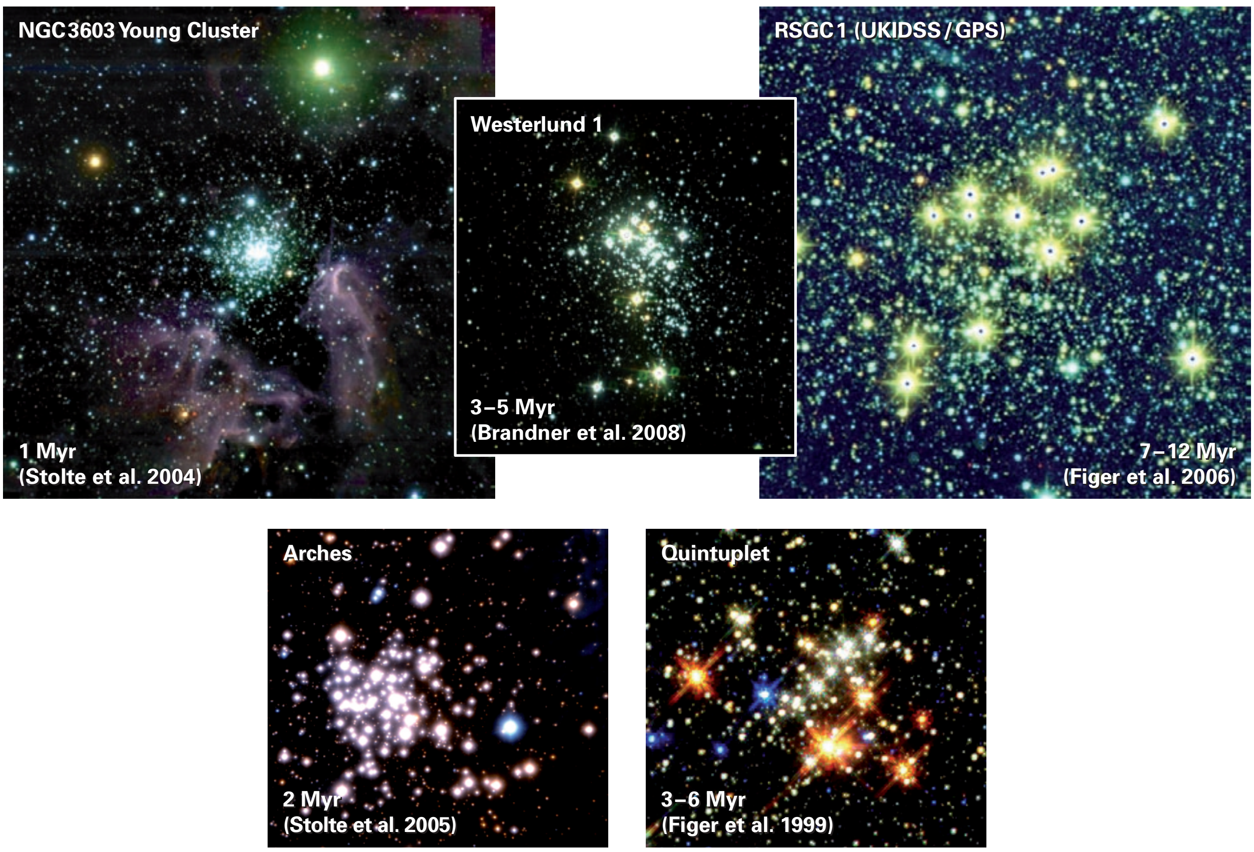
To answer the question whether any of the local starburst clusters constitutes a proto-globular cluster, observation of the cluster kinematics are required. Thus far 1d velocity dispersions derived from radial velocity measurements of a handful of the brightest cluster members in Arches and Westerlund 1 have been obtained, and – assuming virial equilibrium – employed to estimate an upper limit of the total mass in each of the two clusters.

Of the Galactic starburst clusters shown in Fig. III.4.3, all plotted to the same physical scale, and ordered according to age from left to right, only NGC 3603 YC and Arches, the two youngest clusters in the sample, exhibit compact cores with half-mass radii of less than 0.5 pc, whereas the already slightly more evolved Westerlund 1 and Quintuplet clusters have half-mass radii of 1 pc. The two recently discovered red supergiant clusters with ages of around 10 Myr have still larger half-mass radii.

For the spiral arm clusters, which are experiencing only weak tidal force fields, this could be evidence that dynamical evolution is accelerated by the gas expulsion. For the starburst clusters in the Galactic center region, strong tidal shear could result in rapid cluster dispersal.

Thus there are hints that the current generation of Milky Way starburst clusters is not long-lived, and hence is different from proto-globular clusters.

Fig. III.4.3: Five near-infrared images of Galactic starburst clusters are all shown to the same physical scale, ordered according to their age from left to right. The apparent increase in cluster size as measured by the half-mass radius with increasing age is suggestive of a rapid dynamical evolution (and dissolution in the general Galactic field) of the starburst clusters.



Outlook

Recently, Stolte et al. (2008) compared multi-epoch high-resolution adaptive optics observations of Arches, and derived an upper limit on the two-dimensional velocity dispersion in agreement with the radial velocity measurements. They also discuss that astrometric follow-up observation should yield the true velocity dispersion of Arches.

Ongoing multi-epoch astrometric monitoring of Milky Way starburst clusters will thus provide considerably improved constraints on the internal velocity dispersion, which in turn will be valuable for comparison with theoretical models.

The next generation of high-precision astrometric instruments like Gravity for the Eso VLTI should reveal the kinematics of stars in the very cores of the starburst clusters, provide dynamical mass estimates for the most massive stars, and possibly even trace intermediate mass blackholes hidden in the very centers of these clusters.

Wolfgang Brandner, Boyke Rochau,
Felix Hormuth,
in collaboration with Andrea Stolte (UCLA)

IV. Instrumental Developments and Projects

IV.1 Instruments for the LBT

LUCIFER I/II: Two Multi-Mode Instruments for the Near Infrared

The first of two identical infrared instruments, LUCIFER I and II, will be delivered mid 2009 to the Large Binocular Telescope (LBT) near Tucson. The complex systems consist in each case 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 first tests of the entire system were performed at the end of 2007 after LUCIFER I's assembly at the MPIA. Simultaneously, at the MPI for Extraterrestrial Physics the unit for multi-object spectroscopy (MOS) was produced and tested. At the end of 2007 it was installed at the MPIA in LUCIFER I. Essentially the MOS unit consists of a cryogenic mask changer: A robot system enables long-slit or MOS masks to be exchanged out of a loader. The loaders can be exchanged during the day without having to warm the cryostats. The second LUCIFER instrument should follow in about one year.

Fig. IV.1.1: Both LBT individual telescopes will be equipped with an IR camera spectrograph.

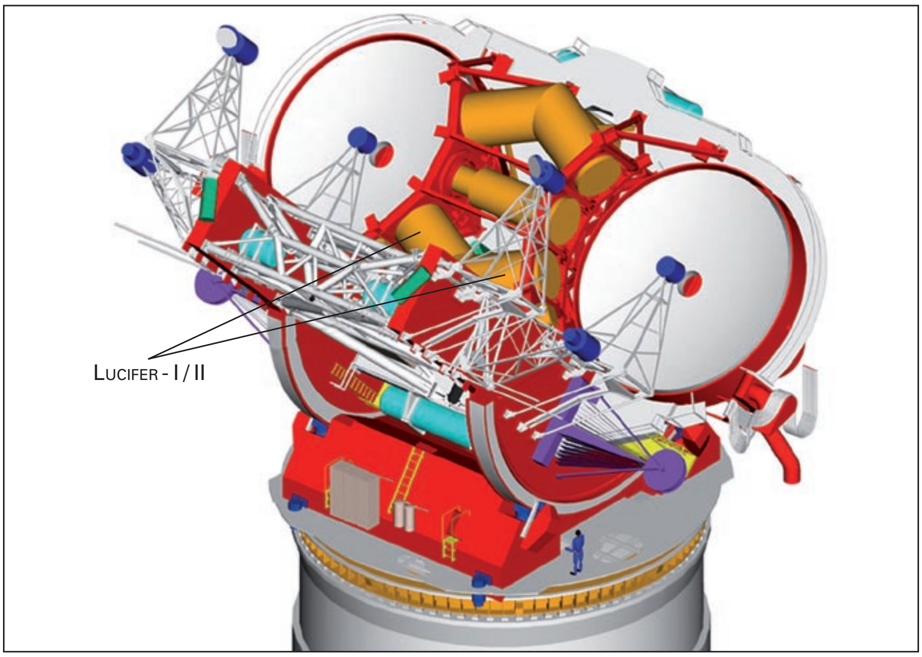
Instrument Concept

LUCIFER (LBT NIR Spectrograph Utility with Camera and Integral Field Unit for Extragalactic Research) is a spectrograph with camera designed for use at the LBT in the near infrared (wavelength range of 0.9 to 2.5 micrometers). A consortium of five Institutes (State Observatory Heidelberg, MPIA, MPI for Extraterrestrial Physics, Astronomical Institute of the Ruhr-Universität Bochum, and the University of Applied Sciences for Technology and Design Mannheim) built two identical versions of this instrument.

LUCIFER I/II will be the LBT's workhorse in the near infrared. It will be able to deliver infrared images and spectra both with seeing and diffraction limited angular resolution. An overview of the various observation modes is provided in Tables IV.1.1 and IV.1.2.

The instrument will work at temperatures of less than 70 K. Essentially, the following observation possibilities are available:

- seeing-limited imaging
- diffraction-limited imaging with a field of vision of 0.5×0.5 square arc minutes
- long-slit spectroscopy (seeing- and diffraction-limited)
- multi-object spectroscopy (MOS) with slit mask



mode	seeing limited		diffrection-limited
camera	N 3.75	N 1.8	N 30
FOV	4×4′	4×4′	0.′5 × 0.′5
f_{Coll}	1500 mm	1500 mm	1500 mm
f_{Cam}	375 mm	1800 mm	3000 mm
f_{eff}	30 940 mm	14 850 mm	247 540 mm
scale	120 mas/pxl	250 mas/pxl	15 mas/pxl
pupil diameter	102 mm	102 mm	102 mm
spaltlänge	≤ 4′	≤ 4′	≤ 0.′5
R_{lim}	10 000	500	
FSR (K)	0.22 μm	0.46 μm	

Table. IV.1.1: Instrumental parameters of the diffraction-limited and seeing-limited observing modes.

parameter	camera	spectroscopy
scale FOV resolution	0.″25 /pxl 4′×4′ acquisition mode only narrow band filter	0.′25 /pxl 3′×4′ 500 – 5000 acquisition mode total band zJHK longslit and MOS
scale FOV resolution	0.″12 /pxl 4′×4′ wide and narrow band filter	0.″12 /pxl 4′×3′ 1000 – 10 000 longslit and MOS
scale FOV resolution	0.″015 /pxl 0.′5×0.′5 FOV limited by isoplanatism	0.″015 /pxl 0.′5×0.′5 4000 – 40 000 longslit

Table. IV.1.2: The available observing modes.

The switch between direct imaging and spectroscopy takes place by swiveling the lattice unit (exchanging a flat mirror with a grating) and changing the focal mask (from field-limited mask to long-slit or multiple-slit mask). This swap of focal masks takes place via a complicated cryogenic robot system which was developed at the MPI for Extraterrestrial Physics.

A special observing mode – not shown in Table IV.1.2 – is still in the preparatory phase: To support the search for extrasolar planets, an optical system is being integrated in the filter discs delivering four parallel images with the *f*/30 camera that have slightly different narrow-band filters at and near the methane absorption wavelength of 1.6 μm. Thus differential images can be created which facilitate the search for planets in the immediate vicinity of bright stars, particularly where there are high levels of methane in the planetary atmospheres. The optical components required for this are currently being built at the Institute for Applied Optics and Fine Mechanics in Jena.

Technical Details

The Optical System

The optical concept is represented in Fig. IV.1.2: To permit cold field boundary masks, long slit and MOS masks to be swiveled in, the focal plane of the telescope is located in the cryogenic region (behind the entry window). The entry window itself is an AR coated quartz window which is inclined by 15 degrees against the optical axis. The reflected optical fraction of the incoming light is

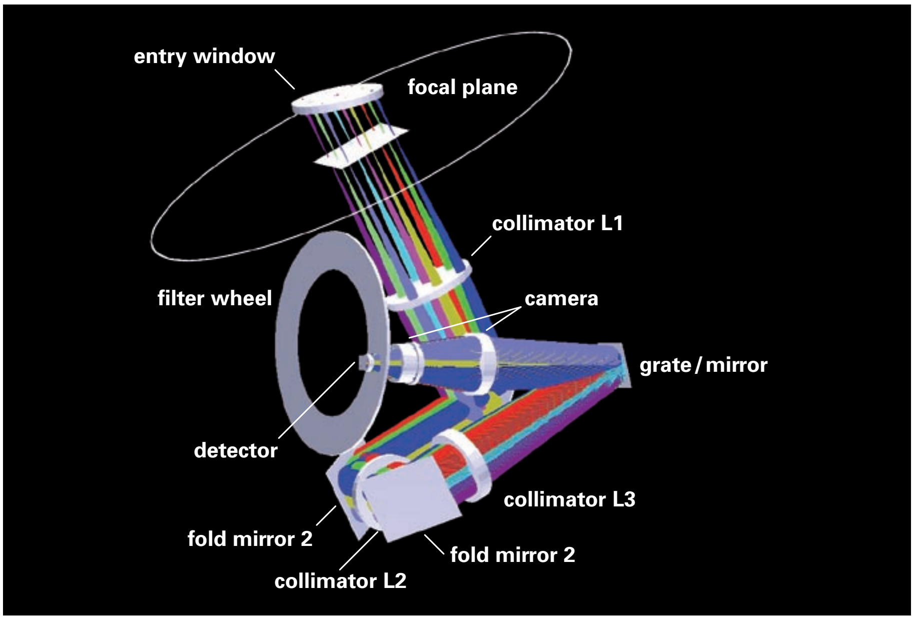


Fig. IV.1.2: The optical concept of the camera and of the spectrograph.

Fig. IV.1.3: LUCIFER in the MPIA's experimentation hall during the integration phase: The upper crystal portion is just being removed, the cold structure surrounded by super-insulation foil inside is becoming visible. The telescope simulator is in the background.

Fig. IV.1.4: The cable routing in the cryostat can be freely seen through the open flange for the cable bushings.

transmitted to the wave front sensor and serves as the control signal for the adaptive optics.

In order to limit the space required by the entire system, the triple lens collimator which follows in the beam path is pleated with the help of three flat mirrors. The pupil plane in the collimated beam path coincides with the plane of the grating (or of the folding mirror). The subsequent camera systems are housed on a wheel, thus making it possible to choose between three different image scales. While the $f/30$ camera is a cassegrain system with dual lens corrector, the two faster cameras are pure lens systems.

The detector is a Hawaii-II type with 2048×2048 18-μm pixels. The focus position can be corrected during operations. The 1.8, 3.75, and 30 aperture ratio provide 0.25, 0.12, and 0.015 arc seconds per pixel imaging scales, respectively.

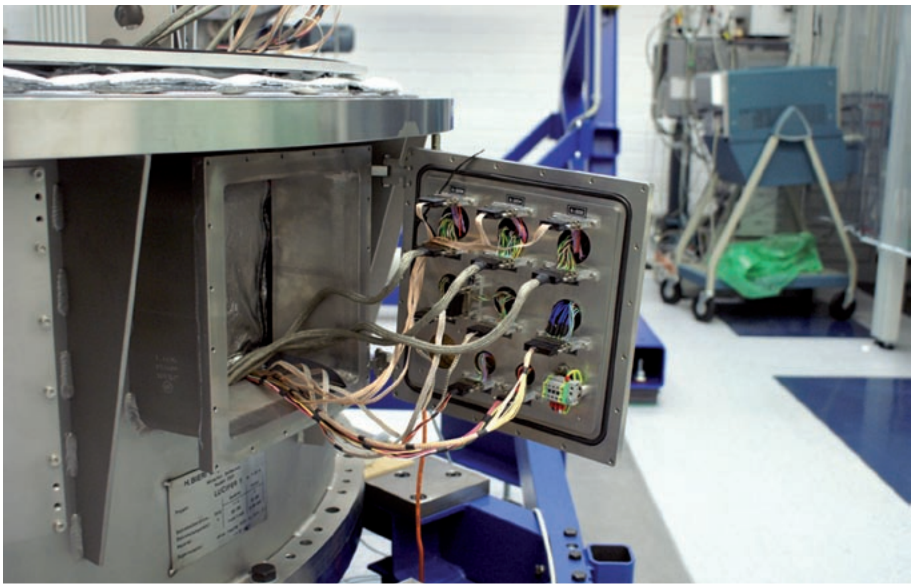
28 filters can be positioned on two filter wheels. The filter wheels are located on the convergent optical path in front of the detector (see Fig. IV.1.2). At present eight narrow band and ten wide band filters are designed for both LUCIFER instruments.

The Calibration Unit

For calibration purposes, a unit can be swung in front of the cryostat window which images the light from a calibration lamp emanating from an Ulbricht integrating sphere. Both a broadband lamp for the calibration of the camera and a gas discharge lamp for the calibration of wavelengths are available here.

The Cryostat

The entire optics, including the telescope's focal plane, are cooled in a cryostat to around 70 K. The cryostat's housing is a lightweight stainless steel construction (see Fig. IV.1.3). All supply openings such as plug flange, CCC cooler, vacuum connections, and in- and outflow of



liquid nitrogen are housed in the lower (or anterior) part of the cryostat. (see Fig.IV.1.4)

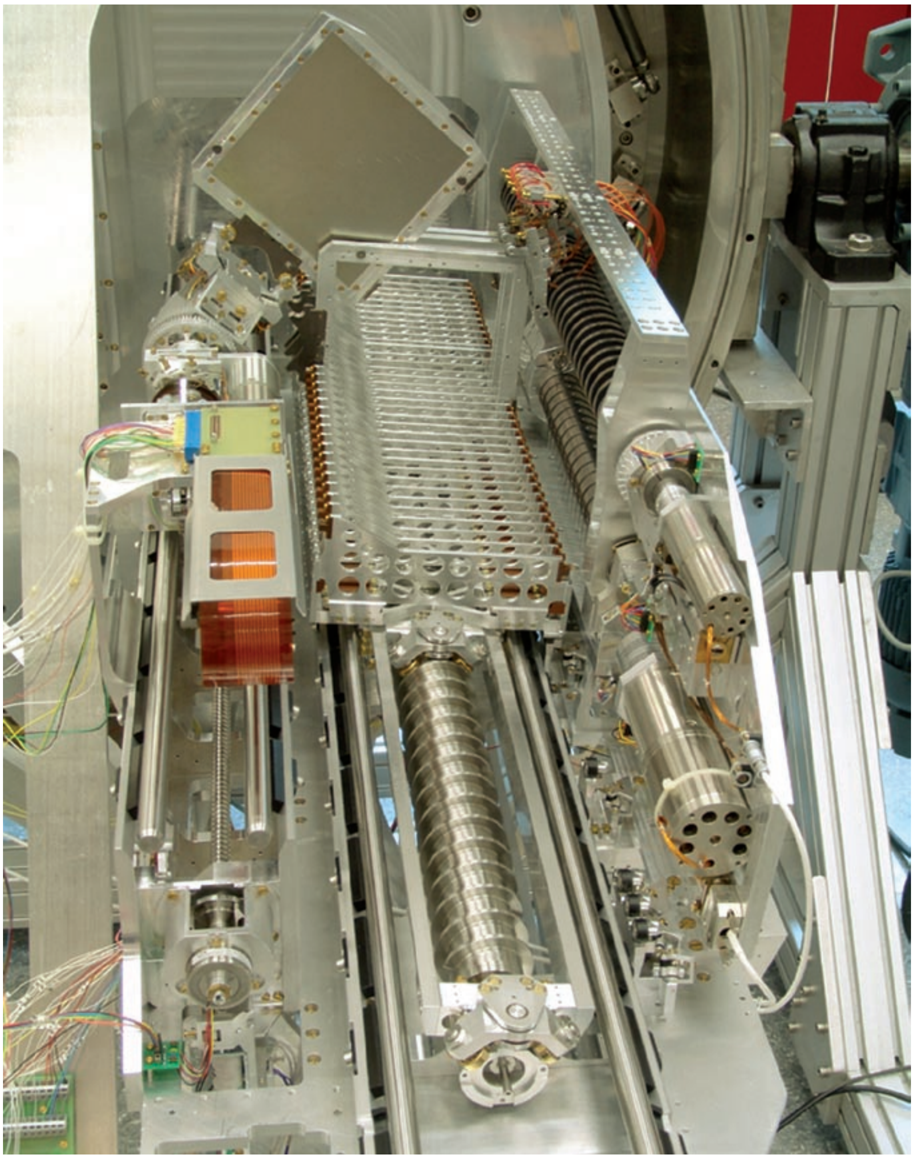
Two Gifford McMahon coolers (Sumitomo) keep LUCIFER at a temperature of roughly 70 K. To speed up the cooling process, liquid nitrogen can be introduced over a duct system with heat exchangers. The detector is connected to the same cooling system. A temperature regulator can stabilize it at its working temperature of between 72 K and 80 K to a precision of +0.01 K. Both CCC coolers are diametrically opposite each other. They are synchronized by using the helium pressure signal of the first cooler to synchronize the second one. This way, despite the cushioned brace, vibrations can be minimized which could otherwise possibly be transferred to the vacuum tank. This is of particular importance for the telescope's interferometric operation.

Fig. IV.1.5: View of the MOS unit with loader and robot in process of exchanging a mask.

The cylindrical vacuum tank has a diameter of around 1.6 m and a total length of about the same size. The completely integrated instrument weighs 2600 kg, of which around 400 kg are cooled to a working temperature of 60 K to 100 K. The flange for changing the loaders can be seen on the reverse side of the cryostat (facing the observer in Fig. IV.1.3). A large vacuum valve is added so that the mask loader can be pulled out after an auxiliary cryostat is flange mounted and pumped down.

Aside from the MOS unit, described in more detail below, eight motor units in LUCIFER are all actuated by cryogenic stepper motors:

- Two of the three folding mirrors can be inclined remotely in two directions in order to achieve a fine-adjustment in the cold. This mechanism can furthermore be used to compensate for any remaining deflection effects.



- Two gratings and a plane mirror are housed on the grating exchange unit. The drive serves on the one hand to change the grating or for the switch between the camera mode and spectroscopy and, on the other hand, to tune the central wavelength

- The two filter wheels provide room for 28 filters. Currently 18 positions are occupied with filters. In each wheel, an additional position is reserved for the differential camera.

- In front of the camera wheel an additional lens can be swiveled in to take an image of the pupil on the detector with an $f/1.8$ camera. In this manner the alignment of telescope and instrument can be controlled.

- The camera revolver houses the three $f/1.8$, $f/3.75$, and $f/30$ camera systems. All three can be used both as an imager and as a spectrograph. The $f/30$ camera can also be used as a differential methane band camera while the $f/1.8$ also serves with a fore-lens to take images of the pupil.

- By correcting the focusing by up to $+5$ mm, differences in the optic filter thickness can be offset.

The Mask Exchange Mechanism

Multi-object spectroscopy will likely be the most used mode on LUCIFER. Both LUCIFER devices are equipped with exchange loaders for the slit masks. Ten long-slit and field masks are available as standard equipment. In addition, 23 multi-slit masks (MOS masks) can be exchanged with the help of a cryogenic robot. The robot guides the current focal mask back to its spot in the loader, searches for the selected mask in the loader, and brings it to the focal plane. The loader with 23 MOS masks can be exchanged during the day as described above (Fig. IV.1.5). The complex device for loader exchange at low temperatures (Fig. IV.1.5) significantly improves LUCIFER's observational readiness: Although the process must take place during the day, this avoids a warm-up cycle that would render LUCIFER unusable for six days.

The first MOS unit has already been finished and has been tested successfully in a normal operating environment. The second unit is currently being assembled at the MPE for delivery to the MPIA in January 2008.

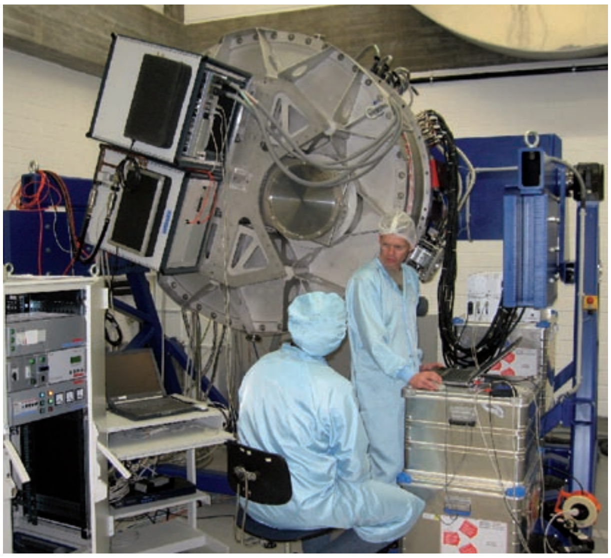
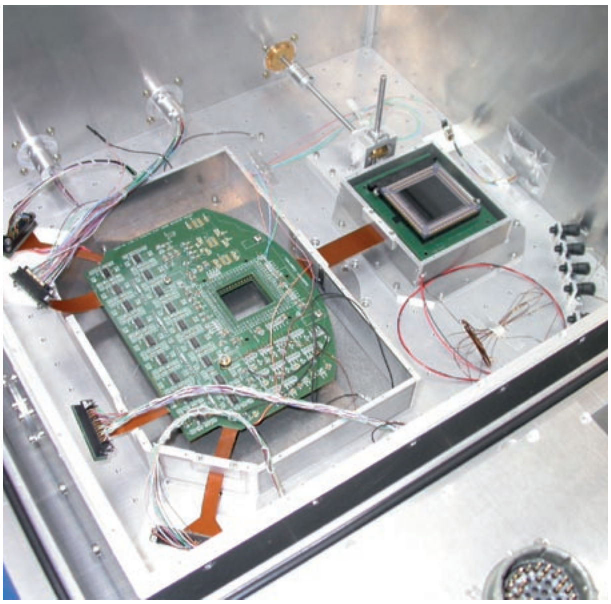


Fig. IV.1.7: LUCIFER on the telescope simulator. On the reverse side, the flange for exchanging the mask loaders can be seen. The cryostat was temporarily cabled and the detector is in operation.

Fig. IV.1.6: Fan-out board and detector array in the test cryostat during the first test of the detector.



Read-out and Control Technology

The instrument's control technology comprises the following components which are housed in a temperature-regulated rack: voltage supply, overvoltage protection and instrument fuse; temperature regulator for the rack and the detector; motor control electronics; and instrument communications unit. The rack with its control electronics will be fixed to the telescope and is connected with the instrument via the cable twister. Read operation and MOS control electronics are piggybacked to the reverse side of the cryostat. 32 channels are read out together with four additional reference channels. Tests of the read-out noise revealed around 1 ADU per read-out which corresponds to about one third of the detector read-out noise. In total, three read-out electronics systems are being built, one for each of the two LUCIFERs and one as an additional spare part.

The Software

The software for LUCIFER is being developed at the University of Bochum. The software package is based on the platform-independent object-oriented JAVA language. Software application has four surfaces and offers users particularly comfortable control possibilities on the top surface via a graphical user interface. The software was initially developed on a virtual LUCIFER instrument and in the meantime has begun operating on the actual instrument.

Installations at the LBT

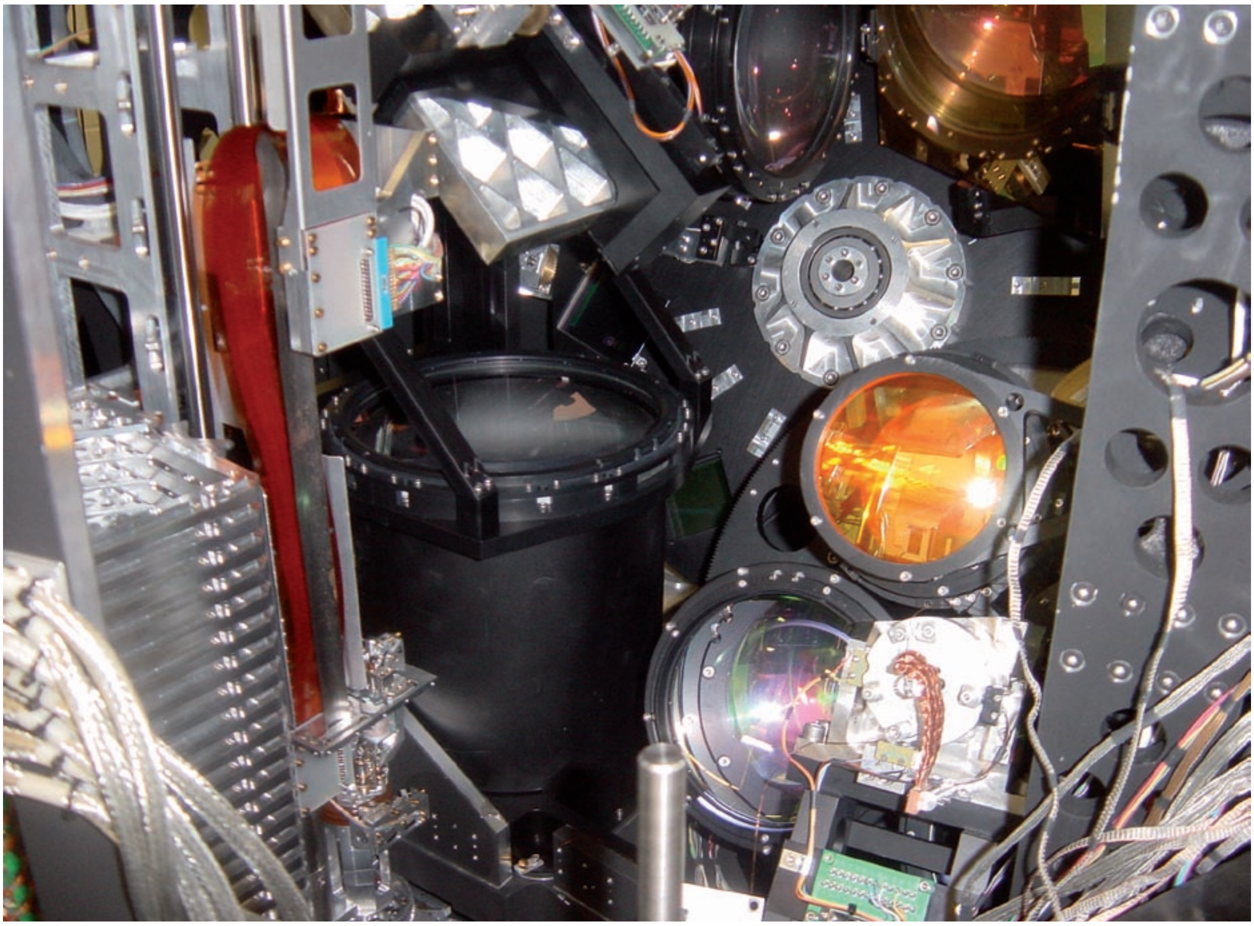
Various pre-installations were made on the LBT in preparation for the commissioning of LUCIFER 1: In particular, the fixed layering of the helium pressure ducts of the cooling system was prepared from the compressor to the cooling head on the cryostat. Cabinets were built for the four compressors; each cabinet holds one compressor. The emitted heat is dissipated by a glycol cooling system.

Status

Once the cooling system was installed and tested in 2006, LUCIFER I could be completely assembled in MPIA's experimentation hall and was successively tested during the reporting year. LUCIFER was initially tested for background radiation: Additional radiation protective plates and improvements in the focal mask brace were able to reduce the background to values below the detector's dark current. Following improvements to the mechanical assembly and the grating exchange equipment, turning warpage could be significantly reduced on the telescope simulator. Fine alignment of the collimator lenses resulted in satisfactory images for the three camera systems. In the fall of 2007, the MOS unit was also finally installed.

In parallel, the cryostat on LUCIFER II served at the MPE as a test cryostat for the first MOS unit. The complex system was trimmed for reliability and the MOS software was debugged. After delivery of the first

Fig. IV.1.8: A deep look into LUCIFER's tightly-packed innards: On the left, the loader for the focal masks with the robot that belongs to it; the black tubus carries the collimator's first lens, above which the first folding mirror can be seen. Below right one can see two cameras on the camera wheel above which is the axis of the first filter wheel. On top are the third collimator lens and its mirror image in the third folding mirror.



unit, the second MOS unit was prepared for LUCIFER II.

According to the time schedule currently in place, LUCIFER's acceptance will occur in April 2008 and will be followed by its ramp up in June. By then, the LBT will be equipped with a fixed secondary mirror which will replace the still unfinished adaptive secondary mirror. Initial tests on LUCIFER I will therefore be restricted to the seeing-limited mode.

The complete breadth of application, including adaptive optics, will likely be available at the end of 2008. LUCIFER II will then be completed within the following year.

For additional details see:
www.lsw.uni-heidelberg.de/projects/LUCIFER/

Rainer Lenzen, Bernd Grimm, Tom Herbst, Werner Laun, Michael Lehmitz, Ralf-Rainer Rohloff, Clemens Storz, Karl Wagner

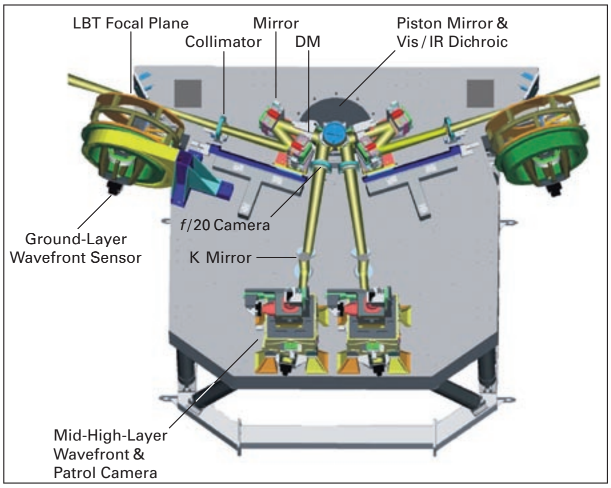


Fig. IV.1.9: Components of the warm optics for LINC-NIRVANA.

LINC-NIRVANA – the Interferometric Imager for the Large Binocular Telescope

LINC-NIRVANA (LN) is an innovative instrument, which seeks to combine the light from the two 8.4-meter primary mirrors of the Large Binocular Telescope (LBT) onto a single image plane, using the technique of Fizeau interferometry. This approach allows the instrument to achieve the sensitivity of a 12-meter telescope and the spatial resolution of a 23-meter telescope. LINC-NIRVANA is a collaborative effort between the German and Italian LBT partners, with major contributions coming from MPIA Heidelberg, INAF (Padova, Bologna, Arcetri, Roma), Köln, and the MPI for Radioastronomy in Bonn.

The LN team made significant progress in assembly, integration, and test of the instrument in 2007. Highlights include the delivery of the first of four wavefront sensors to the LBT Optics Lab in Heidelberg. MPIA and INAF scientists integrated the first Mid-High layer Wavefront Sensor (MHWS) with the warm fore-optics of the instrument in preparation for closed-loop adaptive optics tests early in 2008.

Work also continued on the cryogenic science channel, with receipt and integration of the cold test optics and the start of bench integration and test of the larger

Fig. IV.1.10: The first Mid-High layer Wavefront Sensor (tall structure to rear-left) integrated with the warm LN fore-optics in the MPIA lab.

Fig. IV.1.11: Installation of the upper half of the science channel cryostat for flexure tests on the large optical bench of LINC-NIRVANA.

components. A re-designed impeller for the cooling system promises reduced acoustic vibrations. The team is now at the stage where most components have been procured and the assembly and verification of sub-systems is well underway. A critical final aspect is flexure testing of these items on the large optical bench in the MPIA clean room.

The year 2007 also saw a major re-work of the science case for LINC-NIRVANA, producing the so-called "Design Reference Mission" or DRM. This is a series of individual science cases worked through with realistic simulated data and image reconstruction software. The goal of the DRM is threefold. First, the general science context has evolved since the beginning (and initial science case) of the project. Second, the DRM is specifically chosen to exercise a wide variety of instrument modes to ensure compliance of both software and hardware. Finally, the Design Reference Mission will form a coherent, high impact science program for early exploitation of the unique capabilities of the instrument.

Harald Baumeister, Jürgen Berwein, Peter Bizenberger, Armin Böhm, Luis Borelli, Florian Briegel, Mario Brix, Fulvio De Bonis, Sebastian Egner, Wolfgang Gässler, Tom Herbst (PI), Frank Kittmann, Martin Kürster (PM), Lucas Labadie, Werner Laun, Ulrich Mall, Daniel Meschke, Lars Mohr, Vianak Naranjo, Alexei Pavlov, Hans-Walter Rix, Ralf-Rainer Rohloff, Eva Schinnerer, Thorsten Schmidt, Jürgen Schreiber, Clemens Storz, Jan Trowitzsch, Karl Wagner,
in collaboration with:
INAF (Padua, Bologna, Arcetri,Rom,Genua), Universität Köln, MPIfR Bonn

LBT Characterization

Vibration Measurements

The vibration properties of the structures involved and possible measures to dampen them were studied in order to optimize performance of the telescope and its instruments. During a campaign in October/November 2007, both sides of the LBT were characterized under typical operating conditions. Numerous parameters determine the vibration characteristics at varying locations of the telescope structure. For this reason a measurement system with 16 parallel input channels was used in order to examine the right-left asymmetry of the acceleration appearing in similar structures (e.g. in the right and left primary mirrors). By knowing the amplitudes and frequencies of the strongest vibrations, active and passive compensation (through controlled actuators and/or through damping) processes can be developed.

Mario Brix, Vianak Naranjo

Telescope Control Software

The MPIA has accepted two working packets for the LBT's control software:

- The Instrument Interface Software (IIF) to control the communication between all instruments on the LBT and the telescope
- The software for the telescope's tracking system (Guide Control System, GCS) and for guiding the active optics of both main mirrors (Acquisition, Guiding and Wavefront sensing units, AGW), which will be used in those systems that use the units as tracking systems and for wavefront sensor technology

Both working packets comprise design, coding, implementation, and documentation of the software and their commissioning together with particular instruments. The IIF software is already being used together with both LBC primary focus cameras.

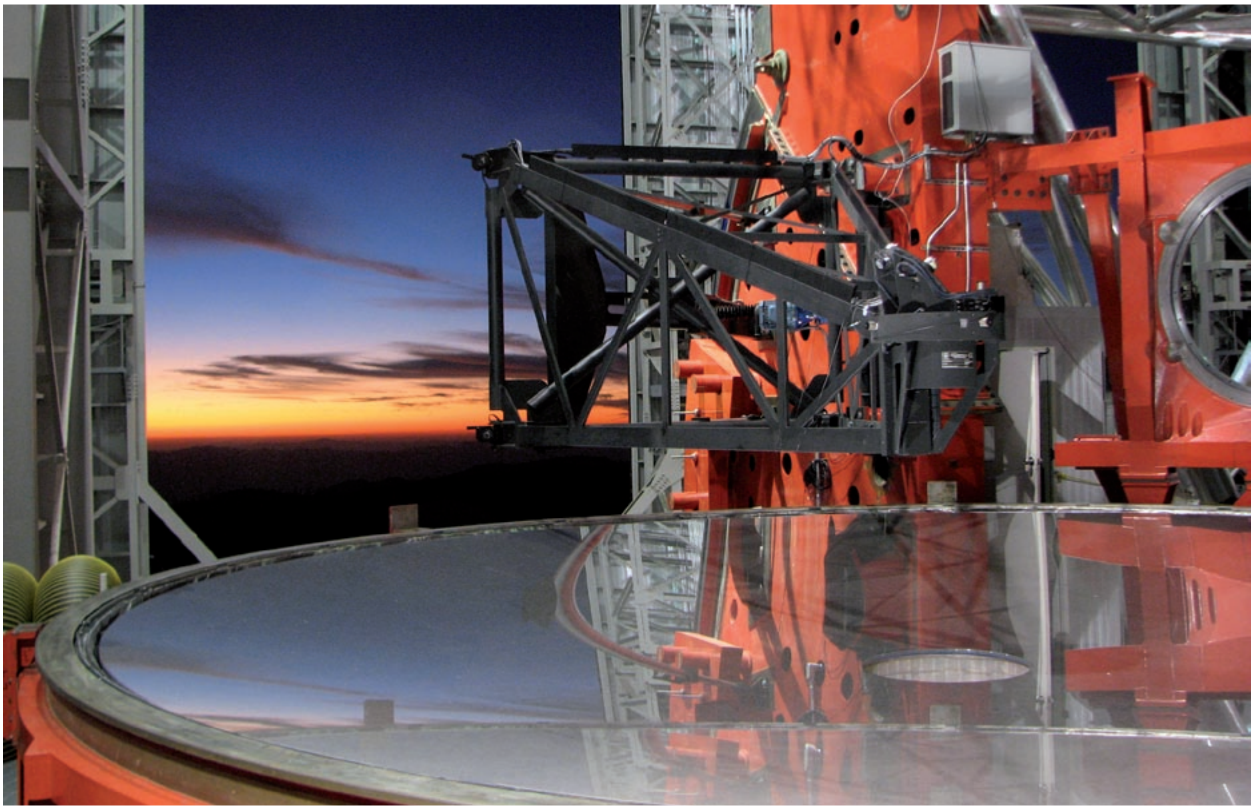
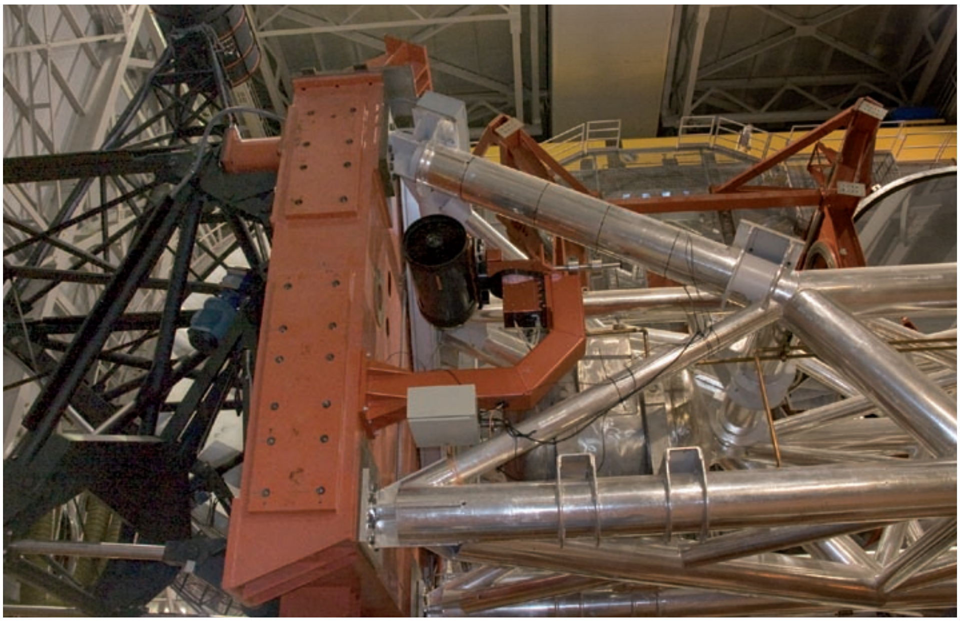


Fig. IV.1.12: Vibration measurements on the tertiary mirror carrier with LBT's protective structure open.

Two MPIA software developers for these tasks are fully integrated into the LBT software team in Tucson (Arizona). In the case of the IIF packet, a significant part of the work of the software engineer is dedicated to the coordination with various instrument builders in Columbus (Ohio), Bochum, and Potsdam; thus requiring extended stays in Tucson. The developer of the GCS packet has been dispatched by the MPIA for a longer period of time.

Martin Kürster, Luis Borelli, Torsten Leibold

Fig. IV.1.13: The MPIA DIMM (small telescope on J-shaped mount) located near the top end of the Large Binocular Telescope.



Differential Image Motion Monitor

Unambiguous knowledge of the current seeing conditions is essential to the success of large ground-based telescopes. Such knowledge permits reactive observing, in which the queuing of ongoing programs can be matched to current atmospheric conditions. Over the longer term, correlation of seeing measurements with other seasonal and meteorological indicators can help in predicting the image quality on any given night. This allows more effective planning and better use of scarce observational resources.

During 2007, a team of MPIA scientists constructed and delivered a Differential Image Motion Monitor (DIMM) to the Large Binocular Telescope (LBT). This device measures the seeing by recording the differential motion of two images of a single star, which pass through two slightly different paths in the Earth's atmosphere.

Although conventional in most ways, the MPIA DIMM faced a peculiar and difficult challenge arising from restrictions on construction at the LBT site. A typical DIMM installation includes a tall tower (ca 10 m) located sufficiently far from other structures to allow sampling of the free air turbulence. However, the LBT sits in a scientific natural refugium and new construction permits are essentially unavailable. As a result, the MPIA team developed a novel mounting and guiding system which allows the DIMM to point at and track a star while mounted to the LBT telescope, which is itself pointing at and tracking a different target.

Johannes Schmidt, Ralf-Rainer Rohloff, Armin Böhm

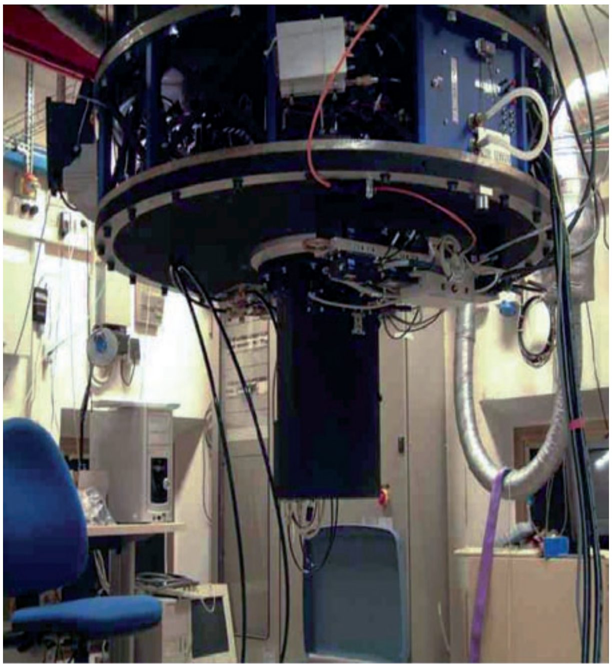
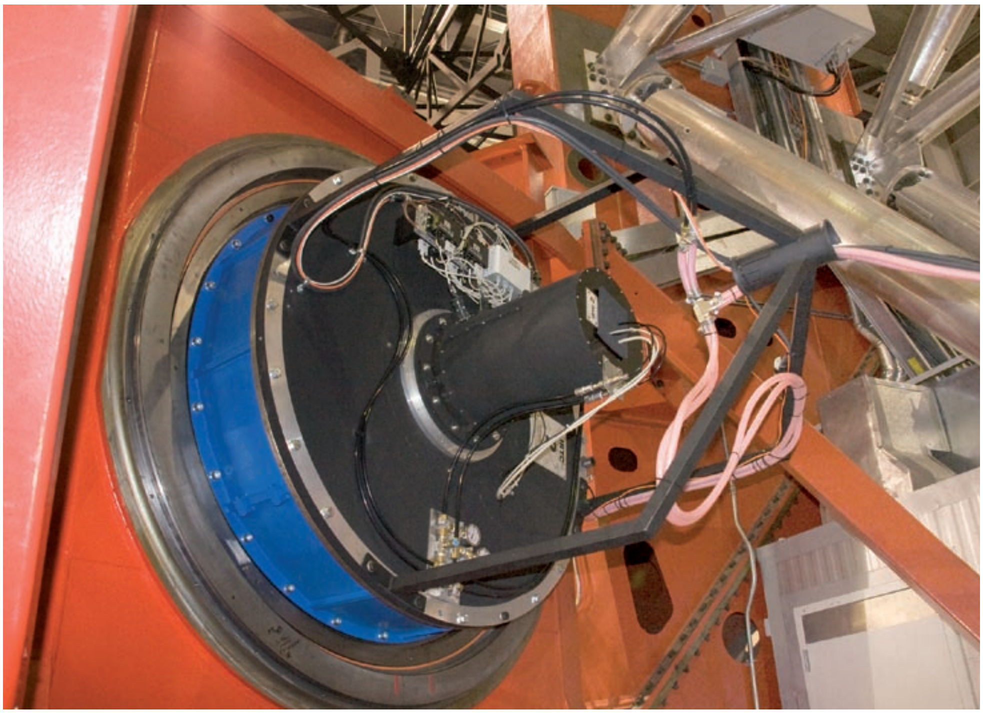


Fig. IV.1.14: Test camera #1 (above) mounted on the adaptive optics test tower in Florence. Test camera #2 (below) attached to the Gregorian focal port, which LUCIFER will occupy in Fall 2008.



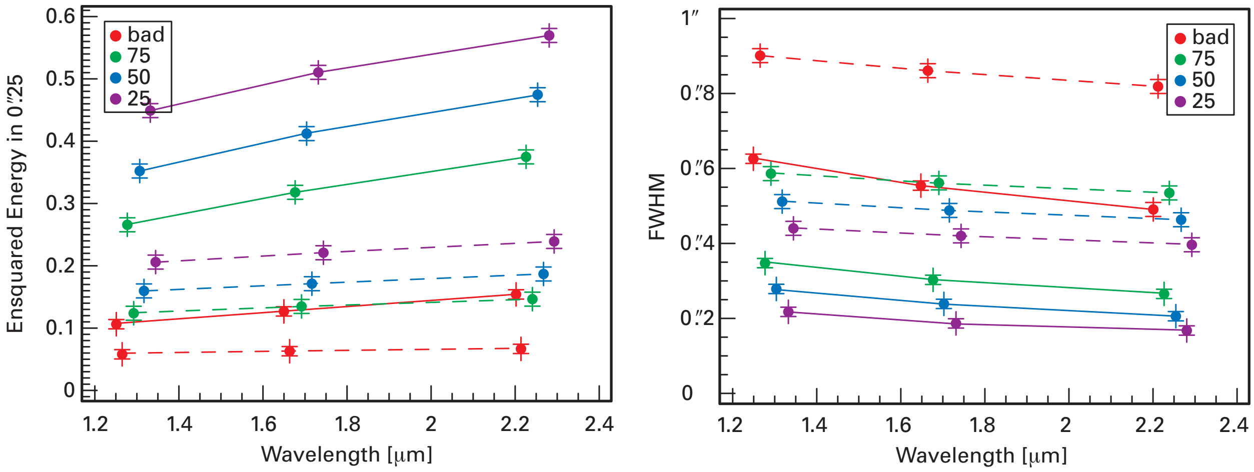


Fig. IV.1.15: Energy concentration simulation at 0.″25 (*left*) and FWHM (*right*) in dependence on wavelength for varying atmospheric turbulence profiles measured above Mt. Graham. The solid lines show the GLAO improved result while the dotted lines represent the uncorrected result. The worst profile has an image quality of 1.″18.

Infrared Test Cameras for the LBT

The Large Binocular Telescope is unique in having fully adaptive secondary mirrors as part of the facility infrastructure. These mirrors correct atmospheric turbulence by applying forces to a thin membrane of aluminized glass held by electromagnetic forces close to a thicker reference surface. The adaptive secondaries are extraordinarily complex systems and require proper test equipment for performance verification and commissioning. To simplify and accelerate this process, the LBT Observatory solicited proposals for a pair of infrared adaptive optics test cameras in late 2006.

The MPIA, in cooperation with its partners in Bologna, responded to the proposal and was given the green light in March 2007 to proceed with the design, fabrication, and implementation of the test cameras. These devices employ fast framing near infrared detectors That can capture the current delivered telescope image up to one hundred times per second (CHECK). Three different fields of view allow characterization of the core of the stellar point spread function (PSF), the fainter wings of the PSF, as well as the wider image plane of the telescope.

Daniel Meschke,
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Partners:
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Astronomical Observatory of Bologna

Phase-A Study of the Laser Guide Star

Laser guide stars are revolutionizing earth-bound near-infrared astronomy with adaptive optics and interferometry. This has already been demonstrated on different telescopes, e.g. the laser guide stars PARSEC of SINFONI and NACO on the VLT or the laser guide star of the Keck observatory on Hawaii. Adaptive optics which correct only the lowest layers of the atmosphere – also known as Ground Layer Adaptive Optics (GLAO) – can help over a wide viewing field to improve the image quality by at least a factor of 1.5 and the energy concentration by at least a factor of 2. This increases the efficiency of the telescope when there is high turbulence in the atmosphere.

The Phase A study for the LBT began in July 2007 and will end in March 2008. Its goal is to examine the advantages of such instruments and their earliest implementation. In addition, tests are being conducted as to how such an instrument can be used in the future even in a diffraction-limited mode for high image quality over a small field or for limited quality over a larger field for the individual or interferometric operation of both LBT channels.

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Michael Loyd-Hardt (UA),
Andreas Quirrenbach (LSW),
Jesper Storm (AIP)
und Richard Green (LBTO)

IV.2. Instruments for the VLT

Cat's Eye Optics for the PRIMA Differential Delay Lines

PRIMA, the instrument for Phase Referenced Imaging and Micro-arcsecond Astrometry, will implement the dual-feed capability at the Very Large Telescope Interferometer (VLTI). It will thus enable simultaneous interferometric observations of two objects that are separated by up to one arcminute.

PRIMA is designed to perform narrow-angle astrometry in *K*-band with two auxiliary telescopes as well as phase-referenced aperture synthesis imaging with instruments like AMBER and MIDI. The instrument is composed of four major sub-systems: Star Separators (STS), a laser metrology system (PRIMET), FRINGE Sensor Units (FSUs), and Differential Delay Lines (DDLs). The first three subsystems are currently being tested at ESO. In order to speed up the full implementation of the 10 µarcsec astrometric capability and to carry out a large astrometric exoplanet search program (ESPRI), the MPIA, in collaboration with the Observatoire de Genève (Switzerland) and Landessternwarte Heidelberg, is currently building the DDLs for PRIMA and develops the astrometric observation preparation and data reduction software.

The PRIMA facility is planned to become fully operational in 2009. In return for its effort, the consortium has been awarded guaranteed observing time with PRIMA and two ATs to carry out a systematic astrometric Exoplanet Search with PRIMA (ESPRI).

Measurement method

A two-telescope interferometer measures the delay between the wavefront sections from a star as they arrive at the telescopes. However, atmospheric piston perturbations usually prohibit accurate measurements of this delay in absolute terms. To circumvent this problem, a dual-star interferometer like PRIMA measures the differential delay between two stars. When their angular separation is smaller than the isoplanatic angle of the atmosphere (about 10″ in *K*-band), the piston perturbations of the two wavefronts are correlated and the differential perturbations (ΔOPD_{turb}) average to zero rapidly.

If one of the stars is bright enough to measure its fringe phase within the atmospheric coherence time, it can be used to stabilize the fringes on the other star (fringe-tracking), thus allowing for much longer integration times and hence increasing the number of observable objects.

To obtain fringes on the detector, the external delay difference, which is directly related to the angular separation $\Delta\alpha$ via the interferometer baseline (B), must be compensated with optical Delay Lines (DL) in the interferometer. The two star beams are first sent parallel through one main DL to minimize the effects of air turbulence in the tunnels.

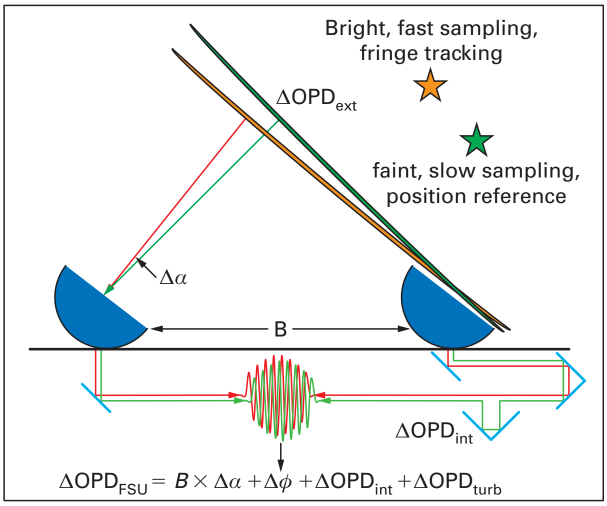


Fig. IV.2.1: Measurement principle: narrow-angle astrometry with differential delay interferometry. ΔOPD_{int} is introduced in the DDL.

Due to the non-zero angular separation between the two stars and the diurnal motion, there is however also a variable differential optical path difference (OPD) between the two stars that must be compensated with DDLs. The DDLs operate in vacuum and provide a much smaller stroke (≤ 60 mm). On a 100 meter baseline, 10 microarcseconds correspond to 5 nanometer OPD, which defines the total error budget for DDLs, fringe detection, and metrology. The beams from the two telescopes are then interferometrically combined in the PRIMA Fringe Sensor Units (FSU).

At zero fringe position external and internal delays are equal. The laser-monitored internal delay (ΔOPD_{int}) together with the residual differential fringe phase (ΔOPD_{FSU}) is then the primary observable of the interferometer (see Fig. IV.2.1).

With the auxiliary telescopes, the minimum *K*-band brightness of the primary stars, required for fringe-tracking, is $K = 14$ mag. The minimum *K*-band brightness of reference stars required to reach 10 microarcseconds is $K = 14$ mag. The maximum separation between target and reference star is about 15 arcseconds.

Hardware developments

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

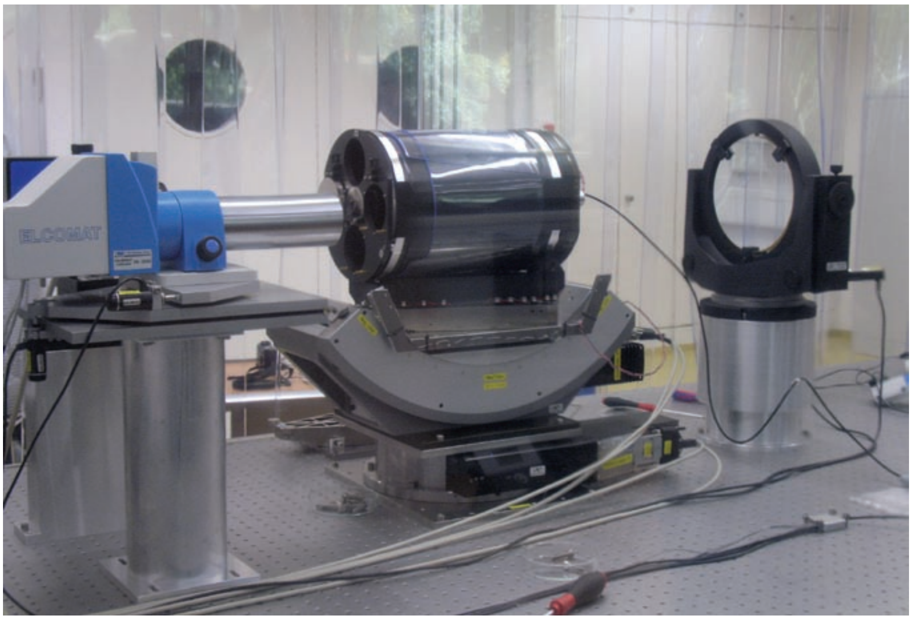


Fig. IV.2.2: DDL Cat's Eye in the optical laboratory at MPIA set-up for wavefront measurements.

(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 micrometers with an accuracy of 1 nm. Both actuators are driven by one control loop, such that the optical path can be smoothly adjusted within 120 mm (twice the stroke length) and with an accuracy of 2 nm. Together with an internal metrology system, the DDLs are mounted on a custom-made optical bench in non-cryogenic vacuum vessels.

Table IV.2.1: Specifications for PRIMA DDL system.

	Performance over full field of 10 arcmin
Positioning accurancy	< 100 nm rms
Mechanical guidance of optical axis	< 15 µm (PtP)
Pupil displacement over 70 mm stroke	< 50 µm (PTV)
Optical pupil abberations	< 25 µm rms
Maximum tilt error (in/out)	< 1.5 arcsec
Maximum differential tilt	< 0.75 arcsec
	OPD-Correction
Coarse stroke	70 mm (translation stage)
Fine stroke (Piezo)	10 µm (by moving M3)
OPD resolution	< 2.5 nm (goal: < 1.0 nm)
Bandwith	> 200 Hz

The main hardware contribution of MPIA consisted of developing and providing the four cat's eye telescopes. The ambitious anticipated astrometric accuracy on sky of 10 microarcsec (see Table IV.2.1) resulted in in very demanding technical specifications for the cat's eye optics (Table IV.2.2). For manufacturing the cat's eye telescopes, in 2006 the MPIA contracted the company Axsys from Detroit.

The first of the four optical systems was delivered to the MPIA in August 2007, where it was extensively tested over two months. A new, dedicated optical laboratory with special measurement equipment was installed at MPIA to verify the demanding technical specifications (see Table 2).

Fig. IV.2.2 shows the test setup in the MPIA lab to measure the wavefront abberations introduced by the cat's eye optics. All four cat's eyes were found to comply with the technical specifications: The first was then delivered to our project partner in Geneva, where it was

Table IV.2.2: Specifications for cat's eye optical system.

Beam diameter	18 mm
Field of view at pupil	10 arcmin
Separation of input/output beam	120 mm
Wavefront error	< 20 nm rms
Tilt of input/output beam	< 0.5 arcsec (on axis)
Differential tilt	< 0.2 arcsec
Wavelength range	0.6 – 28 µm
Overall transmission	> 95 % für $\lambda > 1.0$ µm
Maximum weight	12 kg (incl. plates)
Minimum eigenfrequency	> 200 Hz

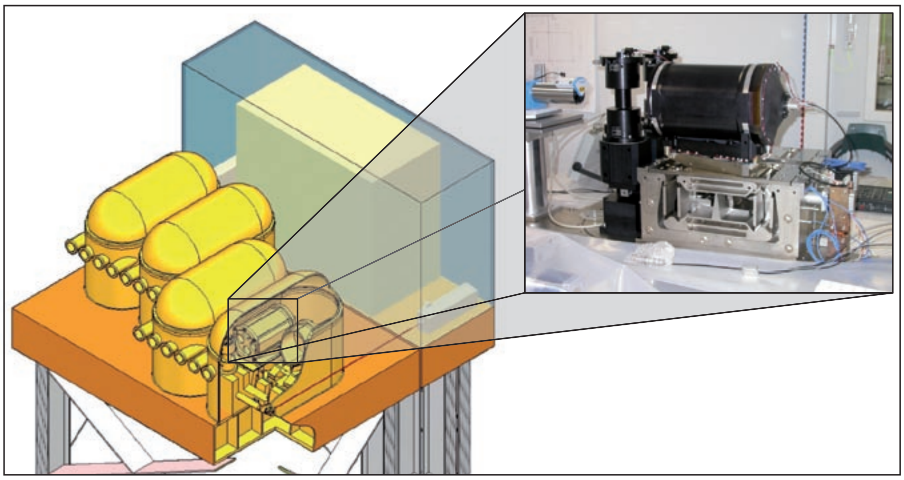


Fig. IV.2.3: Schematic view of the integrated Differential Delay Lines for PRIMA.

integrated with the other DDL components and prepared for system acceptance tests (Fig. IV.2.3 and Fig. IV.2.4).

The other three cat's eye optics were delivered by Axsys to the MPIA between November 2007 and January 2008. After testing them at MPIA they were also delivered to Geneva, where the full DDL system is being integrated and tested before shipping to Paranal (Fig. IV.2.5).

Fig. IV.2.4: (*From left*) – Ralf Launhardt, Johny Setiawan, and Thomas Henning in the DDL integration laboratory in Geneva with two of the four DDLs visible in the foreground.

High-quality optical windows for the vacuum vessels were manufactured by the company Halle (Berlin). They were also tested at the MPIA and were found to fulfill the accuracy requirements.

Software developments

Software developments by the ESPRI consortium include Observation Preparation Software for PRIMA astrometry (coordinated from Geneva) and the complete astrometric data reduction package (coordinated at LSW). Data reduction from raw instrumental data to calibrated delays will proceed fully automatically with two pipelines and a set of calibration parameters that is re-derived every few months from all available PRIMA astrometry data. The software packages will be delivered to ESO prior to the commissioning of the instrument and will be available to

Fig. IV.2.5: (*From left*) – the three project PIs, Didier Queloz (Geneva), Thomas Henning (MPIA), and Andreas Quirrenbach (LSW Heidelberg;) together with a chocolate model of the DDLs (now with vacuum vessels) at the "dedication" ceremony in Geneva.

all users. The conversion of calibrated delays into astrophysical quantities, e.g., planet orbits, is the responsibility of the science user.

Scientific preparations

Starting in 2009, a systematic astrometric Exoplanet Search with PRIMA (ESPRI) will address the following key questions:

(i) Precise determination of the planetary mass distribution
(ii) Detection of new Saturn- to Uranus-mass planets around nearby stars
(iii) Formation and evolution of multiple planet systems
(iv) Exploring planet formation as a function of stellar age and mass

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

1. Stars with known radial velocity planets
2. Nearby main-sequence stars within 15 parsec around the Sun
3. Young stars with ages between 5 and 300 Myr within 100 pc around the Sun

The team at the MPIA is currently carrying out an extensive preparatory observing program to identify suitable astrometric reference stars and to characterize the planet search target stars. With a final detection rate for reference stars of 10-15 percent, 100 to 150 stars will be monitored for astrometric signatures of extrasolar planets.

Towards commissioning

The integration of the first sub-systems for PRIMA (STS) on Paranal is scheduled for January 2008. As the last sub-system, the DDLs will be shipped to Paranal and integrated in July 2008. When assembly and integration is finished, the commissioning on sky is planned to start in late 2008. PRIMA will first be commissioned with two AT's. Commissioning with UTs will follow when the system is debugged and stable fringe-tracking is achieved. Although the commissioning is the responsibility of ESO, the consortium, including the MPIA, will support ESO in this task.

Harald Baumeister, Peter Bizenberger,
Uwe Graser, Thomas Henning,
Ralf Launhardt, Vianak Naranjo,
Johny Setiawan, Karl Wagner
Partners: Observatoire de Genève,
Landessternwarte Heidelberg, ESO

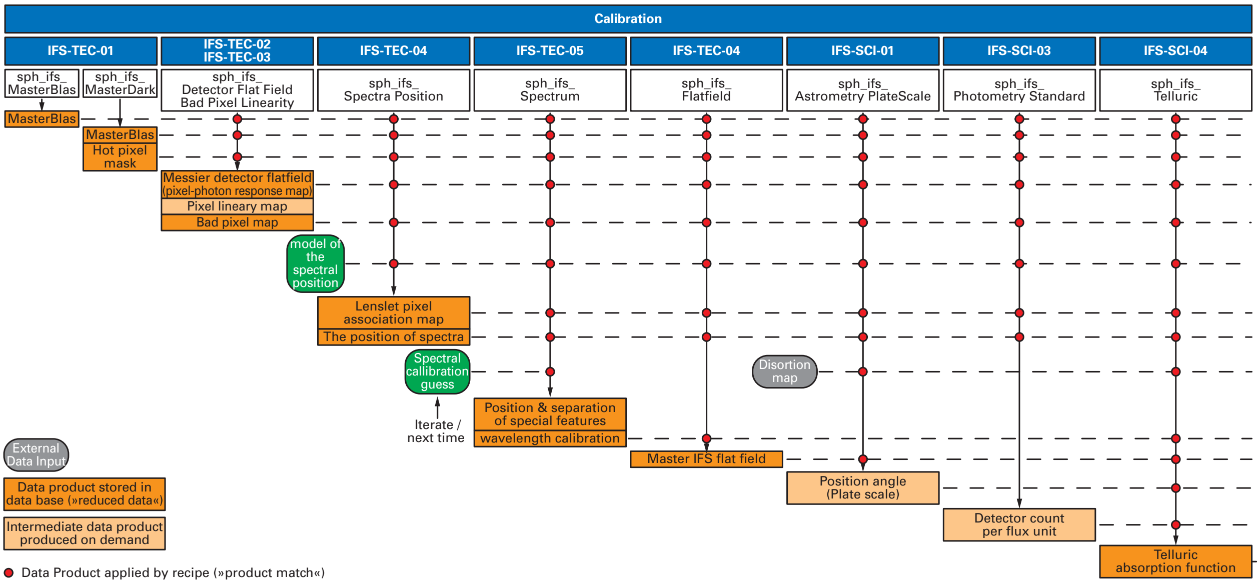
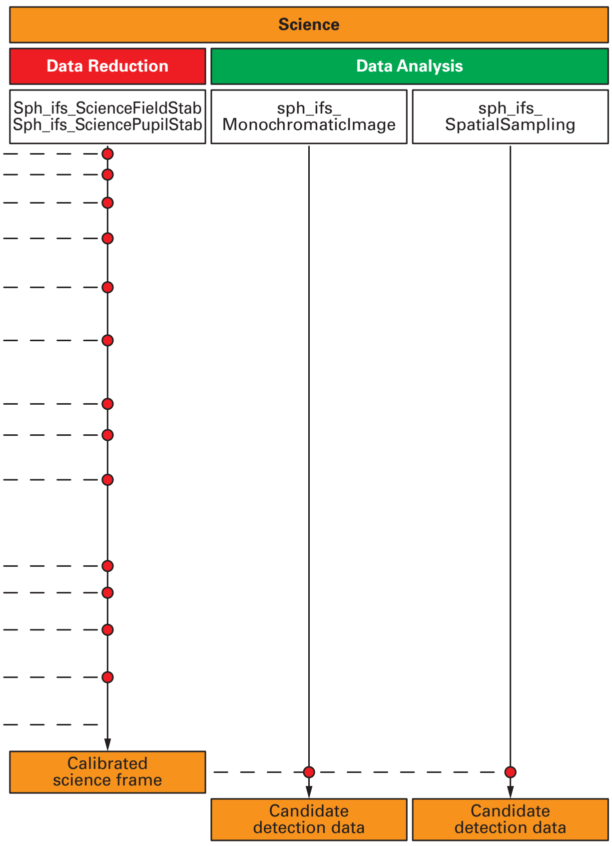


Fig. IV.2.6: The Product Association Map for the IFS sub-instrument.



SPHERE

SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) is a project aimed at the direct imaging of extrasolar planets using ESO's VLT. The MPIA is the Co-PI institute to the SPHERE Consortium, which consists of a total of 12 European institutes including the European Southern Observatory (ESO).

SPHERE is currently in the final design configuration phase (C) with the "Final Design Review" planned for December 2008. It successfully passed the "Preliminary Design Review" in 2007. SPHERE consists of a high-performance Adaptive Optics (AO) system and three focal instruments which all apply differential imaging technology in order to get a handle on residual scattered light from central stars: The IFS 3D-spectrometer, the IRDIS differential imaging camera, and the ZIMPOL differential polarimeter are the key elements for direct imaging of extrasolar planets.

With SPHERE, the MPIA is primarily involved in three areas: On the one hand, the MPIA is responsible for the development of data reduction, data analysis, and data flow control software. Given its 76 "recipes", SPHERE represents by far the most complex instrument (from the point of view of data reduction technology) that has been delivered to ESO to date. Fig. IV.2.6 shows the data product association map for the IFS sub-instrument. For the first time in ESO's history, automatic pipelines are provided to analyze the data.

On the hardware side, the MPIA is contributing through design and production of the correctors for atmospheric dispersion and by providing a detector shift unit (path = 0.2 mm × 0.2 mm, working temperature = –200 °C).

Together with Physik Instrumente (PI), a NEXLINE® piezo incremental step drive was specially designed and built at the MPIA for this unit's use at low temperatures

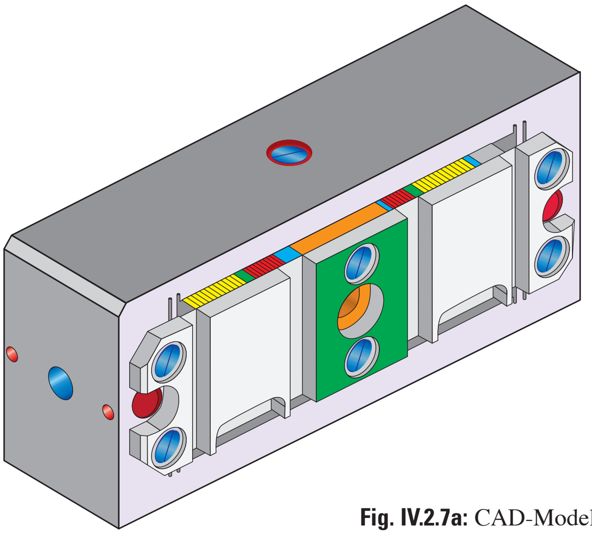


Fig. IV.2.7a: CAD-Model

Fig. IV.2.7b: Finished NEXLINE®-Actuator.

(Fig. IV.2.7). These actuators guarantee high resolution, long switch actuation paths, and self-retention while at rest. They have now for the first time been applied in the Cryo-area and in the future will be available in series for this area.

Markus Feldt
and the SPHERE-Consortium

VLT-Instruments of the Second Generation

MATISSE

The "Multi Aperture Mid-Infrared SpectroScopic Experiment" is one of three VLTI second generation Instruments which was selected by ESO in 2006 for a phase-A study.

After delivery of the phase-A study in June 2007, the responsible committees of ESO (the STC and the Council) gave the green light for the development of this mid-infrared spectro-interferometer. Thus MATISSE is in a sense the successor of MIDI, the Mid-Infrared Interferometric Instrument, which was built at the MPIA and which is working on Paranal since 2003.

MATISSE will combine the beams of up to four of the 8 m UTs (Unit Telescopes) or up to four of the 1.8 m ATs (Auxiliary Telescopes) of the Very Large Telescope Interferometer (VLTI) on Paranal. Since MATISSE will be able to measure in "closure phase mode" it offers an efficient capability for image reconstruction with a spatial resolution of up to 10 milliarcsec. It will work at three wavelength bands: L, M, and N, where the L and M band (3 µm – 5.4 µm) open new wavelength windows for the VLTI. Furthermore, L band observations can be performed simultaneously to the N band (7 µm – 13 µm) observations.

Three different spectroscopic resolutions in the range of $R = 30 - 1500$ will allow for interferometric spectroscopy. Thus it provides the basis for a fundamental analysis of the composition of gases and dust grains in various astrophysical environments.

Key science programs for the ATs cover for example the formation and evolution of planetary systems, the birth of massive stars, as well as the observation of the high-contrast environment of hot and evolved stars; with the UTs, selected astrophysical programs such as the study of Active Galactic Nuclei and Extrasolar Planets will also be possible.

MATISSE is developed and built by a collaboration of the Observatoire de la Cote d'Azure, the MPIA, the MPI for Radio Astronomy in Bonn and two institutions (ASTRON / Dwingeloo and Leiden University) from the Netherlands.

The MPIA is making major contributions to MATISSE: With the Project Scientist (Sebastian Wolf, Co-PI) the MPIA is leading and coordinating the scientific efforts for MATISSE. Furthermore, the MPIA is responsible for the cryogenics system (including the large cryostat), the entire control electronics, and the instrument control software. In addition several smaller work packages, such as e.g. image de-convolution software, integration and testing, will be performed at the MPIA in Heidelberg.

The basic concept of MATISSE was developed in the course of the phase-A study. Several difficulties had to be overcome: For a long time it was not sure if the new *N*-band detector would be available. Raytheon had stopped the development of the new 1 K × 1 K mid-infrared detector ("Aquarius"), asking for additional money from ESO. In September, funding could be found and the emergency back-up solution of using the DRS Technologies MegaMir, 1 K × 1 K detector (smaller pixel size) could be dropped.

Another still open problem is the future location of MATISSE in the Interferometric Laboratory. Since its size will be nearly twice that of MIDI it cannot just replace the MIDI instrument. This issue is under discussion with ESO.

Another topic during the second half of 2007 was the development of an appropriate cryogenic concept for the huge cold optical bench and the various temperature levels to be used in MATISSE. With the cold optics at 40 K, the detectors at 35 K (L-band) and 8 K (N-band) and their pre-amplifiers at > 80 K, it is very difficult to include all these in a cryostat, which from its size (more than twice that of MIDI) is already at the limit and which is confined by the small space available in the Interferometric Laboratory.

Sebastian Wolf, Uwe Graser,
Thomas Henning, Werner Laun,
Karl Wagner, Udo Neumann

GRAVITY

GRAVITY is an adaptive optics assisted 2nd generation instrument for ESO's Very Large Telescope Interferometer. GRAVITY will combine the light from all four of the 8 m Unit Telescopes of the VLT to do interferometric phase referenced imaging with a resolution of 4 milli-arcseconds, and narrow-angle astrometry with an accuracy of 10 micro-arcsec for objects as faint as $K = 20$ mag.

In 2007, GRAVITY successfully passed its Phase A review at ESO. Contract negotiations with ESO for the Preliminary and Final Design Phases are currently underway. First light of GRAVITY at the VLTI is foreseen for 2012.

GRAVITY is a consortium with the 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 the MPIA.

GRAVITY will take advantage of the unique 1.7 arcsecond 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. The MPIA is developing the optical switchyard and infrared wavefront sensors as major instrumental components for GRAVITY. Located in the VLTI laboratory, the GRAVITY infrared wavefront sensors will not only sense the atmospheric turbulence, but also wavefront errors introduced in the VLTI beam relay optics. This, combined with the interferometric instrument based on integrated optics, and the use of all four 8-m Unit Telescopes gives GRAVITY an unrivalled combination of sensitivity and astrometric accuracy.

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-arcsec, 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. The 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, as well as to survey very-low mass stars in the solar neighbourhood for planetary mass companions.

Wolfgang Brandner, Stefan Hippler,
Ralf-Rainer Rohloff, Rainer Lenzen

IV.3 Instruments for Calar Alto

PANIC

A wide field imager for the near infrared was named by the astronomical communities both at the MPIA and the IAA as the most desirable new instrument for Calar Alto. Such an instrument, albeit not the first of its kind, would have many applications, ranging from solar system studies to cosmology. Since the overbooking is normally much higher for the 3.5 m telescope than for the 2.2 m telescope, it was decided to build PANIC, a Panoramic Near Infrared Camera, for the 2.2 m telescope.

The currently available detectors have sizes of 2048 × 2048 pixel. It was decided to use an array of four detectors to increase the available field of view. To cover a field of view of 0.5 degrees × 0.5 degrees results in an image scale of 0.45 arcsec/pixel. Since these detectors are buttable with a gap of only about 167 pixels, PANIC will have a very convenient foot-print.

The instrument will have pure lens optics with ten lenses in eight groups. The image quality is defined as usual, 80 percent encircled energy within two pixels over the whole field of view and for all wavelengths. The spectral range extends from 0.8 to 2.5 microns and thus includes the optical *z*-band.

The layout is shown in Fig. IV.3.2. The instrument first has to meet limits of length and weight, which requires the optical path to be folded by three mirrors. Second, the cryostat is extremely lightweight in order to meet the limits set by the telescope. Cooling is achieved with liquid nitrogen, the holding time is estimated to be 34 hours with a 30 liter filling. A sec-ond small liquid nitrogen vessel is exclusively used to cool the detector. The conical steel element attaches the whole instrument to the telescope; its weight is only 15 kg, and its flexure is only 10 microns

All optical elements are mounted to an optical bench in order to minimize flexure. This is very important since the optics requires small mechanical tolerances, typically on the order of 50 microns. Finite element analysis has shown that the flexure of the optical bench exceeds this value by factors of a few, but only in the most extreme cases.

Four filter wheels, with six positions each, are foreseen to accomodate 20 filters. The optical design also allows the use of narrow band 1 percent filters.

These detectors allow also on-chip guiding in a small sub-window. This will be necessary since the standard guiding unit of the telescope would vignette a part of the field of view and therefore cannot be used in combination with PANIC.

The read-out electronics will be the latest development of the standard MPIA read-out electronics. The four detectors will be read out simultaneously in 128 channels. A fast read-out mode will also be included.

To aid observers, an observation tool will allow easy input of all information to set-up the instrument and perform the observation. A quick-look system with online data reduction will allow the observer to judge the quality of the data obtained, and the data will be archived automatically.

Although optimal for surveys, the image scale is inadequate for studies requiring a high spatial resolution. An enhancemant was investigated to supply a second pixel scale of 0.25 arcsec/pixel by exchanging parts of the optics, accomplished by mounting the corresponding lenses on a motorized wheel; however, with the required additional optics and mechanics the instrument would have exceeded the weight limit at the 2.2 m telescope. Fortunately, optical calculations have shown that PANIC can also be used at the 3.5 m telescope, with a pixel scale of 0.22 arcsec/pixel. The instrument can thus be used for observations which need the large field of view at the 2.2 m telescope and for observations which require higher spatial resolution at the 3.5 m telescope.

Josef Fried in collaboration with IAA, Granada

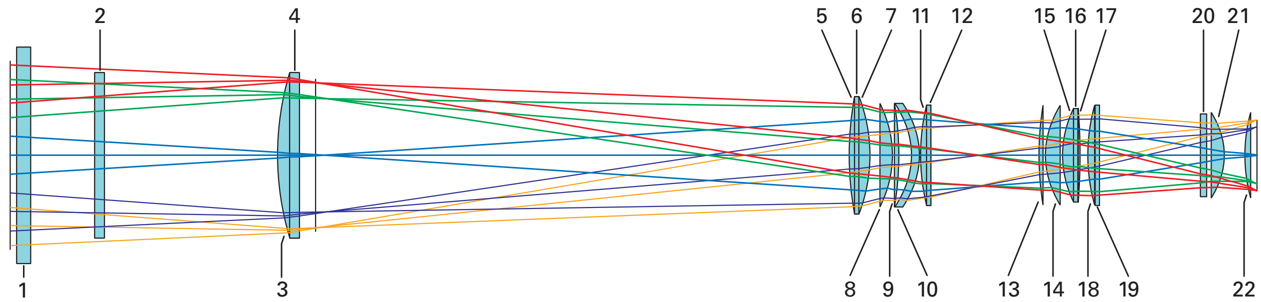


Fig. IV.3.1: The optical system of PANIC. The total length is about 180 cm and requires a folded design.

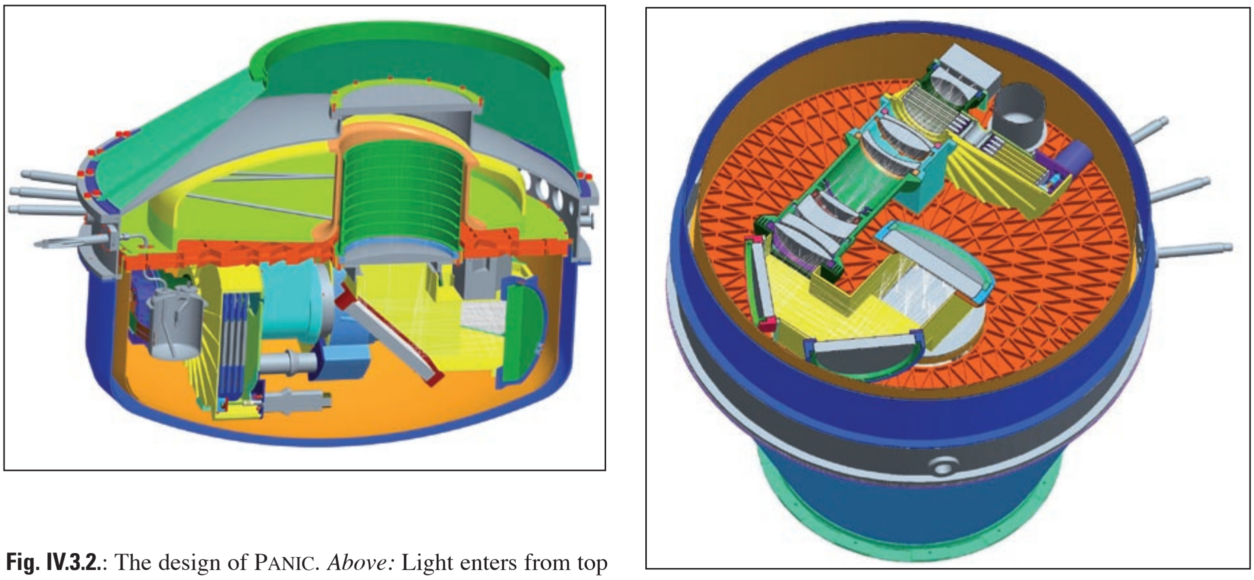


Fig. IV.3.2.: The design of PANIC. *Above:* Light enters from top into the cryostat, three mirrors fold the light path to a compact design. The diameter of the cryostat is about 100 cm. All optical elements are mounted to an optical bench (*red*) to minimize flexure. *Below*: view on the optical bench showing the folding mirrors, the lens optics and the filter wheels (*yellow*).

The New Control System for the 3.5 m Telescope

The 3.5 m telescope had a control system that dated from the 1970s and its contemporary hardware had reached the limits of its useful life; repairs to the outdated technology had become extremely difficult as replacement parts were no longer available – not even equivalent types. In order to prevent breakdowns of purely technical nature, the system was completely replaced.

The new system controls the telescope's drives in hour and variation, the rotation of the Cassegrain flange, and the focus drive. The telescope computer system no longer consists, as before, of only one computer where the bus extended across the entire telescope building in order to communicate with the individual drives to be controlled, but of a total of five VME computers which are assigned to the drives. They are networked with the central computer across a standalone Ethernet. Commercially available digital, highly integrated, intelligent modular components control and regulate the individual drives. The old, mostly analog hardware was thus replaced with modern, highly integrated, and intelligent digital electronics.

Because there are very high precision demands on such a control system, the required control loops are complex. Thus, for example, the most complicated and important drive, the hour drive, consists of three control loops which are interconnected with each other. These structures, which were established by ZEISS in experiments, were retained in simplified form in the design in order to save on development time.

After two years of operation, it is clear that the new control is excellent. The computer system has been running for months without a hitch and the installed modular components have had no breakdowns so far.

In addition to reliability, an important criterion for controlling a telescope is obviously the precision achieved. Here too there has been improvement: With the original control from the desired position, the rms-deviation was 0.15 arcseconds; with the new control it is now only 0.1 arcseconds.

Josef Fried, Karl Zimmermann, Rainer Wolf,
in cooperation with Calar Alto's engineers

IV.4. LAIWO – the Large Area Imager for the Wise Observatory

The MPIA, the University of Tel Aviv and the Institute for Astrophysics in Göttingen, initiated a transit search program, the Giant Transiting Planets Observations (GITPO), funded by the three institutes and the German-Israeli Foundation. The aim of the research project is to detect transiting extra-solar Jupiter-size planets around stars with magnitudes *I* = 14 – 15 mag.

The transit or eclipse method consists of the temporary drop in the brightness of the central star when its planet passes in front of it. The observing strategy will consist in the continuous monitoring of three fields at any given time, until 3000 images are acquired. We anticipate to have 15 days 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, operated by the University of Göttingen. The network of these two telescopes will increase the number of measurements, enhancing the estimated number of planets detected. Dozens of transiting extra-solar planets are expected to be found over the three years observation campaign.

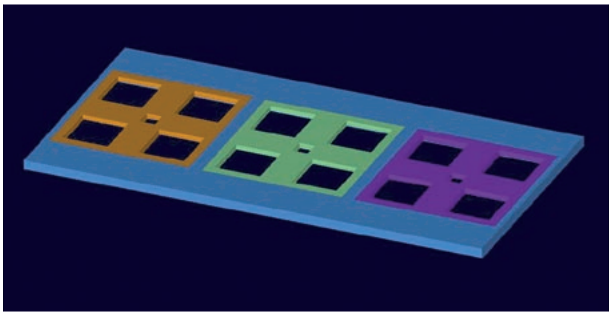
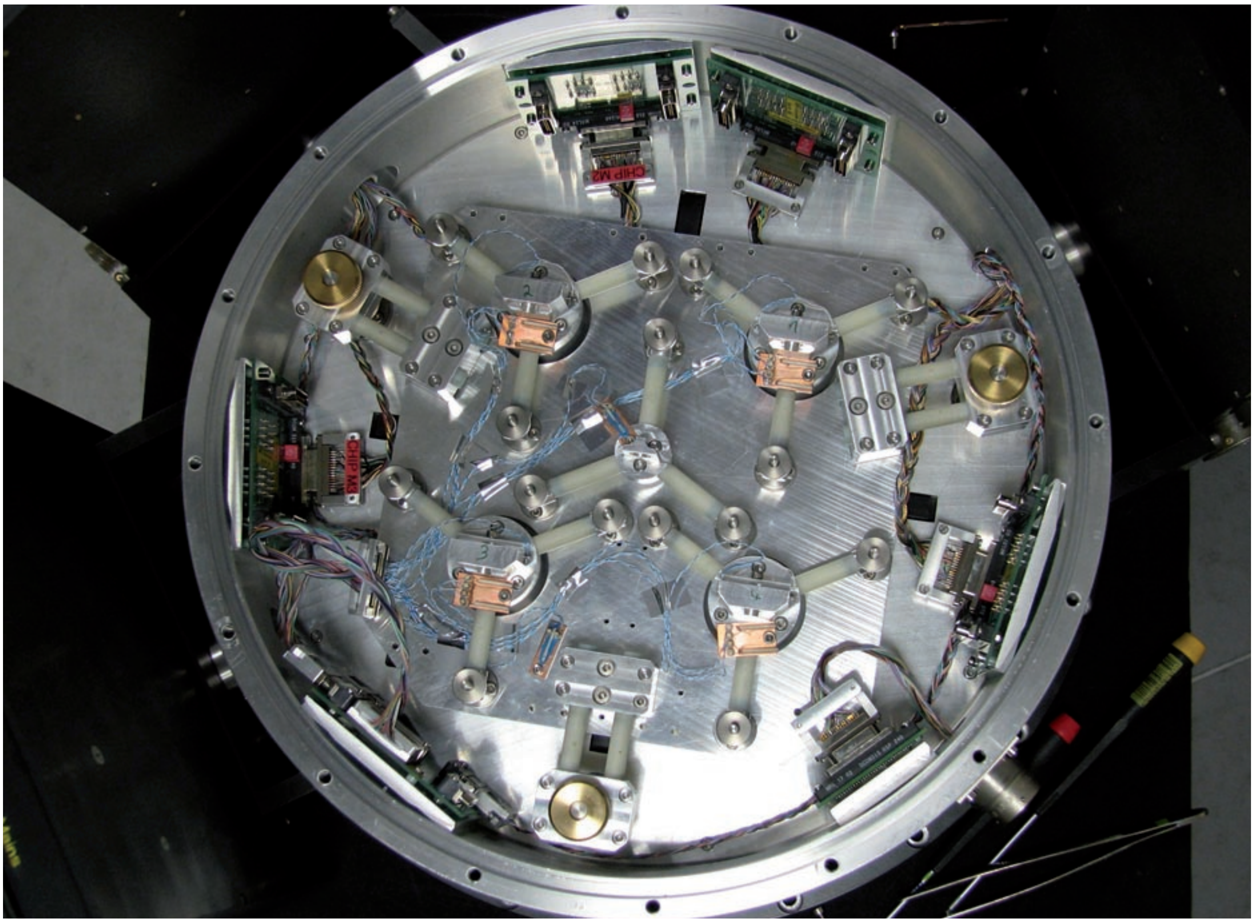


Fig. IV.4.2: The filter Ruler.

In this context a Large Area Imager for the Wise Observatory – LAIWO (see Fig. IV.4.1) with a field of view of one square degree was built at the MPIA. The camera is composed of four front-side illuminated Lockheed CCD486 devices, each with 4000 × 4000 pixels, the pixel size being 15 microns. The camera is divided in two seg-

Fig. IV.4.1: View of the LAIWO dewar.



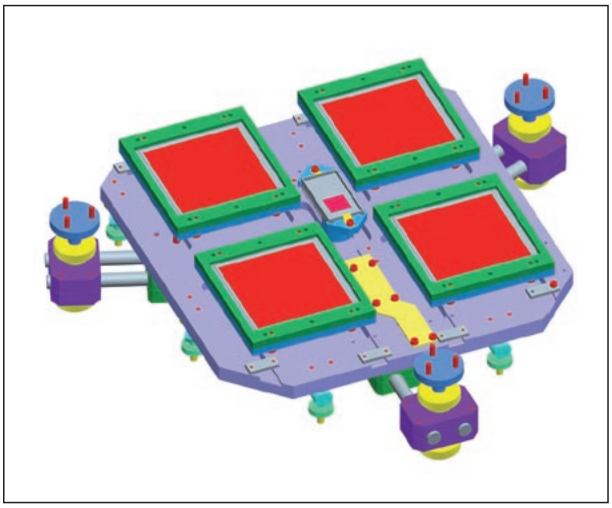


Fig. IV.4.3: The CCD mosaic of the LAIWO detector.

Fig. IV.4.4: The Wise-Teleskop.

ments: 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 is the filter drawer with a ruler inside, where three separate plates of sets of filters (Johnson B,V, R, Cousins I and the Sloan z′) can be mounted at the same time (see Fig. IV.4.2). Each plate may contain five filters, four for the science CCDs and one for the guider CCD. The guider CCD, an e2V CCD47-20 frame transfer device, with 1000 × 1000 pixels, each with a size of 13 microns, is located at the center of the mosaic surrounded by the four science CCDs (see Fig. IV.4.3).

The camera was completed in September 2007 and shipped to Israel. In October, a MPIA team of scientific as well as technical staff went to the Negev desert to install the camera on the 1-m telescope in the Wise Observatory (see Fig. IV.4.4). The installation went smoothly and commissioning started slowly since we were hindered by frequent bad weather. After our return, observations were pursued by the Israeli colleagues, T. Mazeh, Avi Shporer and technical staff from the Wise Observatory, when the first serious problems started to appear, described below.

The CCDs are read out in a 16 channels mode, i.e. each CCD is divided in four quadrants. Observations are performed on a 15 days per month basis, which implies that the camera has to be regularly dismounted to free space for other instruments of the Wise Observatory. After a first dismount and mount process of the LAIWO camera, a CCD quadrant appeared to be dead, and a second died shortly after, as well as two more during the next observing run. It was then decided that all operations had to be discontinued, to investigate further the problem and return to the Wise Observatory in Israel to perform additional tests on-site. In the meantime, after approaching the CCD manufacturer to inquire for possible reasons that could explain the unexpected events, it was discovered that a special powering-up and powering-down sequence had to be followed, and had not been communicated to MPIA at the time of purchase. The manufacturer added the crucial information, unfortunately too late, that the violation of this sequence could damage the CCDs in an irreversible manner.

During the second visit to Israel by a small MPIA team (C. Afonso and R. Klein) for further tests and to establish the health of the remaining CCDs, that exhibited functional features in the last observing run, it was established that now all the CCDs were unresponsive. It was then decided to ship back the LAIWO camera to Heidelberg, and to acquire new CCDs. Hopefully, LAIWO will be soon in good shape (mid 2009), since we are all very eager to start hunting extrasolar planets and discover new Jupiters!

Cristina Afonso (SciM), F. Briegel,
Thomas Henning (PI), R. Klein,
Karl-Heinz Marien (PM),
in collaboration with
the Univerities of Göttingen
and Tel Aviv

IV.5. Instruments for Space Observatories

PACS – Far Infrared Camera and Spectrometer for HERSCHEL

Within a consortium of 15 European institutes, MPIA is participating in the development of the PACS instrument, a camera and spectrometer for wavelengths of 60 to 210 µm for the HERSCHEL space observatory, which is scheduled for launch at the end of 2008.

As largest Co-I institute in the European PACS consortium, MPIA is providing the focal plane chopper, characterizing the large Ge:Ga spectrometer cameras and their -270 °C cold readout electronics, investigating radiation damages to these components, and contributing to the calibration of the instrument before and during flight.

With the delivery of the refurbished chopper qualification model and its implementation into the PACS flight spare unit, the hardware provision from Heidelberg finally ended in 2007. Laboratory measurement of the Ge:Ga detectors have continued in order to optimize the detector operation in flight. These measurements comprise the characterization of transient behaviour after flux changes and responsivity behaviour under ionizing radiation.

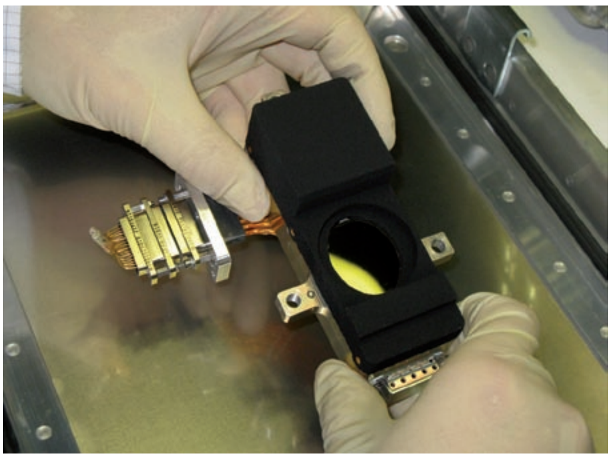
Focus of the MPIA team has now become the characterisation and calibration of the PACS flight instrument on-ground, and building up the Instrument Control Center (ICC). The main subjects worked on by the MPIA ICC team are the optimisation of the chopper performance as well as the performance assessment of the instrument internal calibration sources and the spectrometer's stressed Ge:Ga detectors and cold read-out electronics.

Fig. IV.5.2: Members of the MPIA ICC team in front of the commanding console in the PACS operational room at MPE while executing a PACS flight instrument test script.

MPIA has also significantly contributed to the setup of the overall ground calibration plan. The MPIA team also contributes to the general interactive and pipeline analysis development and documentation and sets up special calibration analysis scripts for the ground tests. Results have been documented in about 50 test reports for information to the whole ICC team, the PACS consortium and ESA as well as for reference for later corresponding in-flight tests. Follwing the delivery to ESA, the PACS flight model was integrated into the HERSCHEL flight cryostat at Astrium-Friedrichshafen in the summer. In autumn, MPIA started to coordinate the build-up of the PACS performance verification plan, which covers the first important in-flight phase, and established the first in-flight calibration of the instrument.

Two MPIA-led Guaranteed Time (GT) key projects on the dusty young universe and the earliest stages of star formation have successfully passed review by the HERSCHEL observing time allocation committee. In addition, Heidelberg is participating in three other GT key projects and is involved in a number of Open Time key programs covering a broad range of astrophysical topics. The decision on time award for these programs is expected for January 2008.

Fig. IV.5.1: Integration of the refurbished chopper qualification model into the PACS flight spare instrument in the clean room at Kayser-Threde, Munich.



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

Cryogenic Wheel Mechanisms for the MIRI and NIRSPEC Instruments aboard JWST

The MPIA is the only European institute which is engaged in the development of two of the four scientific instruments for the James Webb Space Telescope (JWST). In close collaboration with ZEISS (Oberkochen), the Institute is developing filter and grating wheel mechanisms for MIRI and NIRSPEC – the cryomechanical hearts that enable the full operational functionality of these complex instruments. In addition to the hardware contributions, MPIA is responsible for the electrical system engineering of the MIRI instrument. Members of the Institute are deeply involved in the ground-testing of MIRI and also involved in the science teams of both MIRI and NIRSPEC.

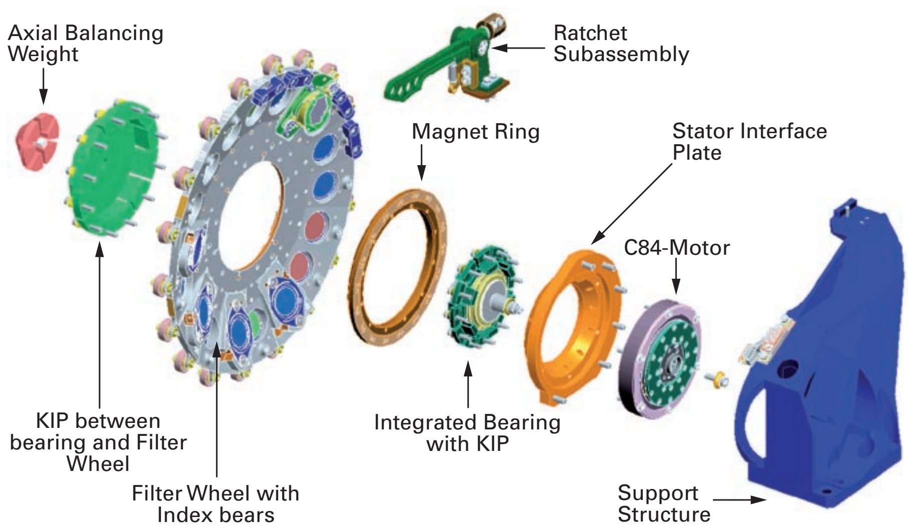
The infrared space observatory JWST is jointly developed by the US, European and Canadian Space Agencies. Its 6.5 m mirror will allow acquisition of images that will be as sharp as those taken by the smaller Hubble mirror in the optical range. To avoid blinding of the sensitive cameras by its own thermal radiation, the primary mirror is cooled radiatively to – 230 °C. This "passive cooling" is possible at the Lagrangian Point L_2 at 1.5 million km anti-solar distance from Earth. NASA will have overall responsibility for the JWST mission to be launched aboard an European ARIANE-5 rocket in the year 2013.

JWST is equipped with four scientific instruments, two of which are built mainly in Europe: MIRI, a camera with coronograph 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 range (1 to 5 μm) multi-object spectrograph capable of observing more than 100 objects simultaneously, is developed by ESA and an industrial consortium led by EADS-Astrium, Germany.

Common to all focal-plane instruments is that they have to be operated in a cryo-vacuum at temperature between – 267 °C (MIRI) and – 240 °C (NIRSPEC) so that their own thermal emission will not outshine the cosmic infrared radiation. Another common property of the instruments is that all of them have large optical exchange wheels with numerous gratings, filters beam splitters, mirror, prisms and coronagraphic masks mounted on them. Although every space technician is anxious to avoid mechanisms like these wheels (...may fail...), powerful scientific instruments without moving parts are not feasible. Because of previous successful developments of such mechanisms for the European space telescopes ISOand HERSCHEL, our Institute was well prepared for these high-risk challenges and became involved in the development of wheel mechanisms for MIRI and NIRSPEC, which have even more demanding requirements than those of previous missions.

The JWST wheel mechanisms are based on a ratchet principle (see Fig. IV.5.3): At the periphery of the wheel small ball bearings are mounted. Their number corresponds to the quantity of optical elements. A wedge-shaped element on a moving lever latches between two ball bearings, thus locating the position of the wheel with a repeatability of about one second of arc. The central motor is a torque motor without transmission. The exact position is carried out mechanically without electric power by the spring torsion of the ratchet system. This drive

Fig. IV.5.3: Filter wheel mechanism for the Mid-Infrared Instrument (MIRI). The wheel carrying filters, coronographic masks and a douple prism is moved by a central torque motor. Positioning is performed using a detent latching into the index bearings outer race. The mechanism has a diameter of 28 cm and a total mass of 3 kg.



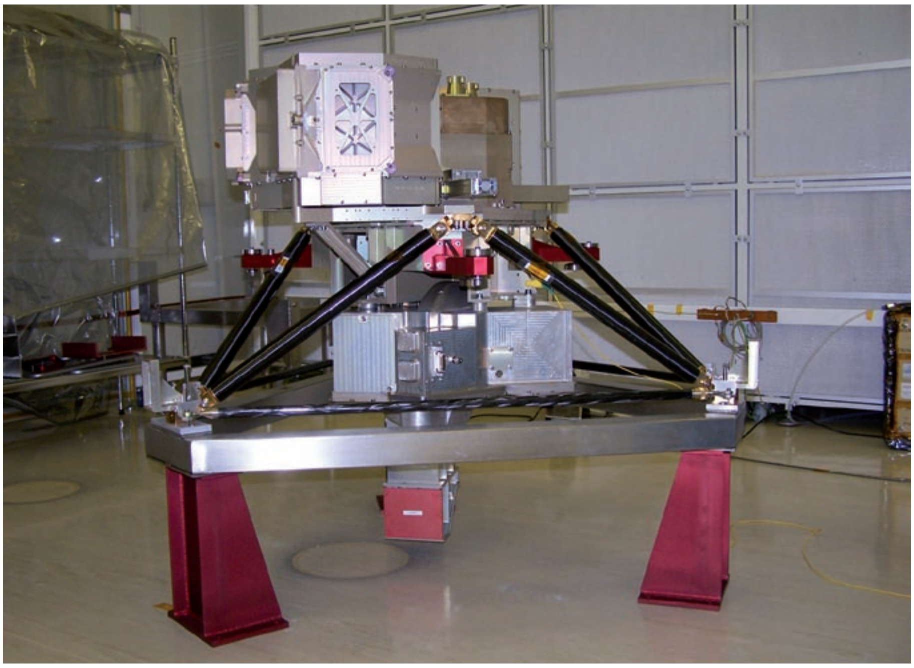


Fig. IV.5.4: Verification Model of the MIRI instrument after integration at Rutherford Appleton Labs. This is the first fully functional model of a JWST science instrument. The instrument is suspended and thermally insulated by a carbon-fibre hexapod structure. The spectrometer unit is located at the top of the image shown; beneath the imager section and the entrance optical chain can be seen.

concept avoids feedback from an electrical position sensor and electrical power dissipation since positioning is always carried out mechanically with great reliability.

After a successful Critical Design Review (CDR) of the MIRI optical system, MPIA and C. ZEISS are currently working on the qualification models of the MIRI wheel mechanisms. NIRSPEC is shortly behind in schedule. Preparation of all necessary documentation according to space standards for the NIRSPEC wheel mechanisms CDR started in 2007. While MPIA contributes to the development of the NIRSPEC grating and filter wheels as a contractor to C. ZEISS and is responsible for the development of the electric components (motors, position sensors, cryo-harnesses) the roles are reversed for MIRI: Here C. ZEISS builds the flight hardware as industrial contractor of MPIA.

To mitigate technological risks in the mechanism development programme and to decrease cost, prototype models have been built and tested at MPIA prior to the qualification models. These prototype have been integrated into the MIRI verification model which is the first scientifically representative model of a JWST instrument (Fig. IV.5.4), allowing a first assessment to be made of the performance. The first extensive cryogenic test campaign in 2007 was very successful: All subsystems worked without any major flaws, providing further confidence that the development of the flight model is on a successful way.

Oliver Krause, Ralph Hofferbert, Friedrich Müller, Thomas Henning, Dietrich Lemke, Ulrich Grözinger, Armin Huber, Armin Böhm, Monica Ebert, Karl Wagner, Stefan Meister, José Ricardo Ramos, Ralf-Rainer Rohloff, Silvia Scheithauer, Thomas Blümchen, Tobias Junginger, Stephan Birkmann, Matthias Alter

V People and Events

V.1 Conferences, Public Lectures, Tours, and More

The MPIA not only had a series of shining moments in 2007; there were also numerous functions with varying scope: In addition to a series of scientific conferences, the institution's daily routine now includes public lectures, tours, and events for high school and university students.

Astronomers no longer research or live in an ivory tower. Both the personal exchange among specialists and the presentation of scientific results to the public have gained importance: Vividly prepared presentations of research results provide for wide awareness among the people and for animated interest among both male and female students.

Conferences and Summer Schools

Together with the astronomy center of the University of Heidelberg (ZAH), the MPIA organized an international conference under the banner "Galaxy Growth in a Dark Universe". The conference ran from July 16 to 20 at the Heidelberger Kongresshaus and was attended by around 200 renowned astrophysicists from around the world. The astronomers presented around 70 lectures and discussed the newest results and theories on the creation and development of galaxies. Since the discovery of dark matter and the insight that almost all galaxy centers accommodate super massive black holes with masses that correlate indeed to the mass of their host galaxy, excitement has again widely spread through this research field of astronomy. Thus it seems that galaxies in the young universe were closely linked with the formation of central black holes. How this happened though remains widely unknown and was the focus of intense debate between observers and theoreticians.

The close link between observation and theory is also clear from another conference that MPIA held at the Hiedelberger Kongresszentrum from September 10 to 14: "Massive Star Formation: Observations confront Theory". These days various concepts relating to the formation of high-mass stars are being discussed and simultaneously being reviewed through observations. In this light, completely new possibilities are opening up with the Large Binocular Telescope (LBT), when both mirrors will be working from Spring 2008, as well as with the future Alma and Herschel observatories.

This large advance with the LBT led to initial scientific work that partially appears in this annual report and where the first authors are MPIA astronomers (see Chapter II.5). The institute's dedication to the LBT additionally showed itself in the "LBT Board Meeting" event in mid-May that was held at the MPIA.

It's not automatically the end of light for the former large telescopes with 2 to 4 meter mirror diameters when 10 m class telescopes begin their operation. The former telescopes continue to hold their place in part in their own application areas such as the large and time consuming surveys of the universe. This is also true for the Calar-Alto observatory, the scientific results from which were mirrored in the presentations of numerous participants at the "Calar-Alto Colloquium" held at the MPIA from the 2nd to the 3rd of May.

MPIA additionally organized two conferences in the MPG's Ringberg Castle on Lake Tegern. From May 20 to 26, the relationship between Galaxy activities and their formation was the focus of a conference with the title "The Impact of AGN Feedback on Galaxy Formation". Half a year later another topic was the primary focus: "Astronomy with Laser Guide Star Adaptive Optics". More and more telescopes can be driven close to the limits of diffraction through adaptive optics supported by artificial laser stars. Observations that were impossible until recent times and which open new windows for astronomy are possible because of the concomitant increase in sensitivity and resolution.

The MPG founded the International Max Planck Research Schools (IMPRS) in order to provide students with the best education possible. Since 2005, MPIA has been leading the "IMPRS for Astronomy and Cosmic Physics at the University of Heidelberg" (see annual report 2005, Chap. V.4). During this reporting year, the MPIA in Heidelberg completed the IMPRS Summerschool 2007: "The Milky Way Galaxy". In addition, in Dorio, Italy, the "4th MPIA Student Workshop" took place – an additional large event especially for students.

Public Relations

Whenever possible, the MPIA seeks to link its scientific events with public relations. Thus, parallel to the Galaxy Growth Meeting, a total of ten press releases were issued this year and one press conference was called.

Tours through the MPIA also continue to generate great enthusiasm. Aside from tours for the IMPRS, students, school classes, and other groups, there were also some special tours for prominent guests. Thus for example in November a group accompanying Heidelberg's mayor, Dr. Gerner, visited the institute. In the middle of the year, we started guiding visitors through a newly designed hallway. Here, large backpanel lit astronomy diagrams are the attraction, all of which have a direct relation to institute projects. Guests can also obtain much information from the newly designed institute brochure which was gratefully supported by several of our partners from the business world. The brochures supplement our already existing "handouts" such as the annual report and our very detailed leaflet.

One of the peak moments among the public events was the institute's participation in the "Night in Science". We will discuss this event – which was attended by several thousand people – in the next segment. An additional highlight was again, however, our lecture series "Astronomy on Sunday Morning" which we set into motion last year. Each of the eight lectures was attended by a full house adding up to nearly thousand visitors in total. We also found good resonance again with the popular science lectures that some of our members held in schools, planetariums, or at other outside events. During the reporting year, a new lecture series was also started. It was titled "Astronomy in Heidelberg" and will be taking place during the winter months at the Mannheim Planetarium. Researchers from all of Heidelberg's five astronomy institutes lecture there and our institute is involved in its organization.

The MPIA's journal Sterne und Weltraum and the project "Science in Schools!" generously supported by the Klaus Tschira Foundation (see Annual Report 2005, Chapter V.10) also continue to move forward. Since 2006, it has included middle school level students as well as high school students. Together with classroom tours, the biennial student practicum to guide high school students in their career choice, and our participation in Girls' Day, MPIA's presence continues to make its mark among our youth. To keep it this way, the MPIA invited guests from the Council of German Observatories in May to the first Working Meeting for the Year of Astronomy, 2009.

2007 was a successful year for the MPIA. This was the case both for scientific advances as well as for pubic events and other activities. The success was also possible because employees provided renewed dedication to the institute. The latter deserves special mention because in October 2007 the Advisory Council was our guest and performed a comparative evaluation of the MPIA. This very important event for the institute also ended in great success.

Klaus Jäger

V.2 The "Night of Science"

For the first time in the Rhein-Neckar Region, the *Night of Science* was held on November 10, 2007. Similar to the *Night of Museums* that was established years ago, more than one hundred institutes and companies in Heidelberg, Mannheim, and Ludwigshafen opened their doors to the public. The MPIA and the state observatory were special attractions as usual: Just around 4000 of the total estimated 23 000 participants headed up the Königsstuhl.

Astronomy is and remains a science that deeply fascinates much of the population. Proof of this is the third large event in a short period of time after the MPIA took part in the 2005 *open house* and the institute participated in the *Long Night of Museums* in 2006.

On November 10, 2007, the MPIA and the state observatory presented a varied program to the public between 6 pm and 2 am. The large onslaught of visitors was remarkable because many guests had to decline the opportunity to addend other sessions due to the long travel times here and back. Even the bad weather and the sometimes pouring rain quite obviously did not stop people from visiting the institute of astronomy.

The visitors were able to obtain an overview of modern astronomy research at a total of 28 stations that were spread between both institutes. Lectures, explanations of exhibits, and demonstrations of experiments helped us to report on scientific causes and technical challenges. Instruments for current and future earth- and space-based large telescopes were also explained onsite. Films were shown and at times commented on live. Even the youngest visitors were provided for: A specific childrens' program at the state observatory allowed them to experience the fascinating universe.

One of the main attractions was the lecture series in MPIA's large auditorium. Black holes, distant galaxies, extrasolar planets, and the search for life in the universe were the subject of 10 lectures. Even the last lecture held at one in the morning still saw the auditorium nearly fully occupied. Great excitement was generated by the several stations which dealt with the Large Binocular Telescope. Practical demonstrations, for example on infrared observations, adaptive optics, data analysis, and space-bound observations, also were attended with great interest.

An additional magnet for the public was the MPI station for nuclear physics which dealt with high energy astrophysics. Due to routine construction, the MPIK could not open the entire building to the public. Unceremoniously, they decided to appear as guests on MPIA's premises.

Sufficient informational material to take home was also provided and each visitor had the opportunity to purchase T-shirts, cups, or posters. Naturally, the physical well being of our guests was also provided for.

As with similar events, the *Night of Science* was only a success because of the dedication of numerous employees – not a requirement for a Saturday night. Even

Fig. V.2.1: Full house at the MPIA during the *Night of Science* fed the typically high demand for informational material.

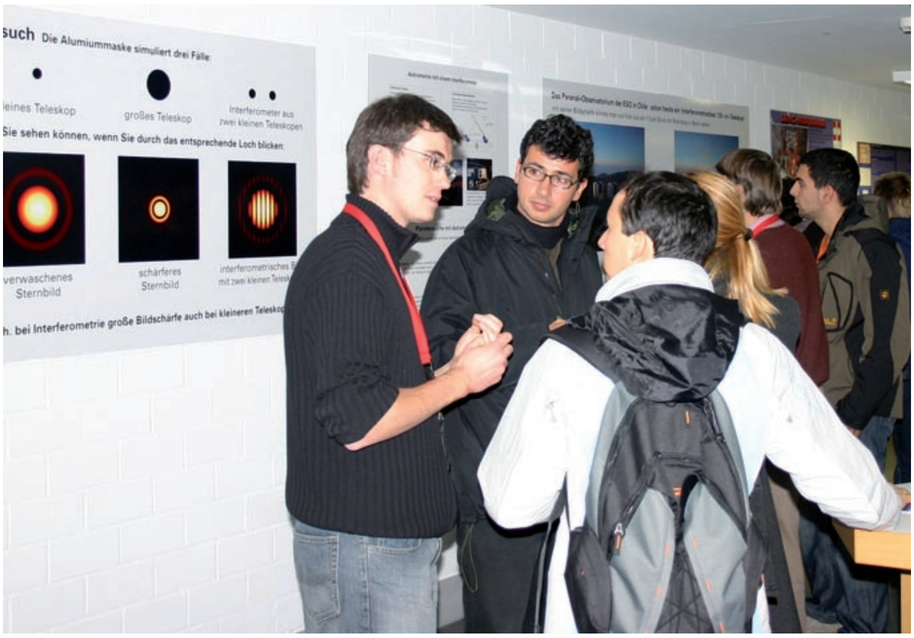


Fig. V.2.2: The visitors, curious to obtain new knowledge, were happy to receive explanations on complex technologies such as the inferometer.

the support of the local organizations by the regional promoters functioned very well. Thus, the bus transfer from and to Heidelberg went without a glitch. And even though the onslaught of citizens left all participants little time to catch their breath, the atmosphere after a strenuous eight hours was quite positive. So yet again, the effort paid off and those participating really enjoyed the event.

Klaus Jäger

Fig. V.2.3: Even the last lecture held at one o'clock in the morning still saw the auditorium nearly fully occupied.

V.3 THISBE's Last Journey

In the 1970s the THISBE balloon telescope from Heidelberg flew a total of 17 times into the stratosphere to observe the sky in the infrared. At that time, the research in Heidelberg opened a new window into space. In June 2007, the device took its last journey. It was transported from the MPIA on the Königstuhl to the State Museum for Technology and Labor in Mannheim where it will be kept for prosperity as an "original from the early age of space astronomy".

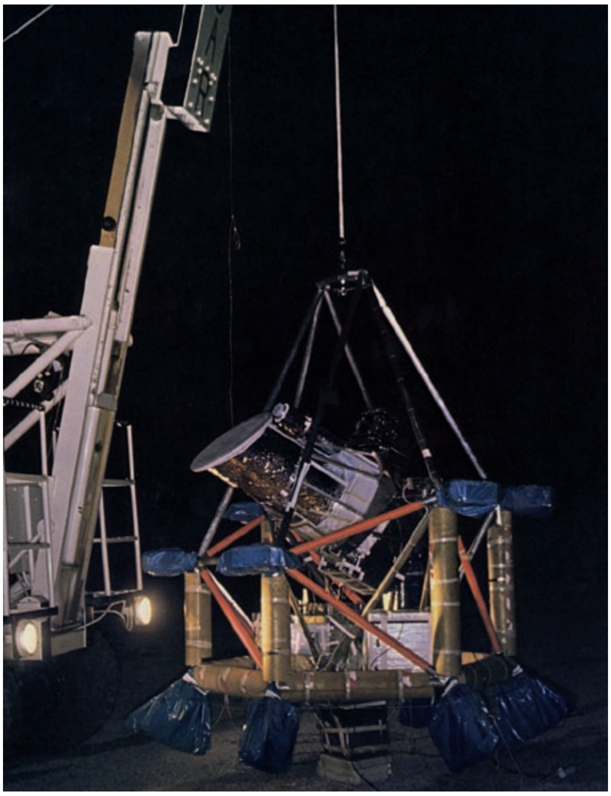


Fig. V.3.1: The THISBE balloon gondola and the infrared telescope cooled with dry ice for the observation of 2.4 and 3.5 μm wavelengths shortly before take-off on August 12, 1974 at the launch site for scientific balloon flight in Palestine, Texas.

Since its foundation, the MPIA has been dedicated to extraterrestrial research. Especially its early entry into the related infrared spectrometry effort was of great significance to the institute's later development. Next to the two photometers for the Helios 1 and 2 sun probes (lift-off in 1974 and 1976), the THISBE (Telescope of Heidelberg for Infrared Studies by Balloon-borne Experiments) was developed and built together with Dornier and the institute's shop under the leadership of Dietrich Lemke. In those days, observations with the balloon-borne telescope offered the only possibility to observe space objects in the infrared and ultraviolet spectral ranges.

With such a research balloon, it's possible to carry telescopes and equipment weighing up to 400 kilograms into altitudes as high as 40 kilometers. There, 99.7 percent of the earth's atmosphere lies below the balloon and thus observations in the ultraviolet and infrared become possible. Four telescopes with openings of 6 to 20 centimeters were built in the MPIA's workshop and were used on the THISBE.

THISBE climbed into the stratosphere from Meppen im Emsland for the first time in September 1969 – in those days still just for test journeys. With a 50 000 cubic meter large hydrogen-filled plastic balloon, the instrument was able to reach a height of 25 kilometers, then parachuted after a two and a half hour flight into the Lüneburger Heide.

The entire flight program that lasted up to ten hours, was stored on punched tape and ran automatically guided by a quartz clock. At the earth station, the measurement data were sketched with a recording stylus in real time and stored for final analysis on magnetic band tape.

Most flights took place in the 1970s with helium-filled balloons in Texas – the first two during the autumn of 1971. After up to ten hours of observation in the stratosphere, the balloon telescope would parachute to earth and would be recovered. The landing was moved to very thinly populated areas several hundred kilometers from the starting point. Many of these recoveries in the snake-infested swamp regions of the American Southeast turned out to be true adventures for the Heidelberg scientists. The last flight in October 1980 took off from Oberpfaffenhofen.

Of special scientific significance were the first observations of the Milky Way's central region at a wavelength of 2.4 μm, observations of the zodiacal light, and measurements of airglow – an emission of the OH-radical in the atmosphere. The intensive infrared radiation of billions of stars, mostly cooler than our sun, was charted in the central region of the Milky Way which is darkened by interstellar dust. From ultraviolet and infrared measurements of the zodiacal light which occurs through the dispersion of sunlight in interplanetary particles, information on the size distribution of the dust particles was derived. Cosmic night-sky brightness, an important dimension in theoretical development models of galaxies from the time of their creation, was measured in a gap of the OH airglow emission spectrum.

The experience with THISBE tipped the scale for the MPIA and in the 1980s it participated in building infrared instruments for satellites. THISBE was excellent preparation for the ISOPHOT camera which up to 1998

operated very successfully in the European Iso infrared satellite. With Isophot, the far infrared at up to 240 µm wavelength was explored for the first time. This long-wavelength radiation is emitted from very cold cosmic sources that are at around – 240 degrees Celsius. Thereafter, significant contributions were made to the Pacs instrument on the European Herschel space telescope which will be launched in the coming year. MPIA will assume a leading role in the development of two infrared instruments for the successor to Hubble, the future James-Webb Space Telescope.

Fig. V.3.2: The loading of the balloon telescope into the vehicle of the State Museum for Technology and Labor in June 2007 at the MPIA on the Königsstuhl in Heidelberg. *Left to Right:* Klaus Barth, museum conservator, Dietrich Lemke, then the project leader for Thisbe, Wilfried Hofmann, who obtained his PhD 30 years ago based on Thisbe measurements, and Thomas Kosche, head of collections for the museum. (Photo: S. Kresin, Rhein-Neckar-Zeitung.

Dietrich Lemke

V.4 Honors, Prizes, and an Appointment

Eric Bell receives the Heinz Maier Leibnitz Prize

At a banquet event on 5 June 2007, the German Research Foundation awarded, for the 30th time, the Heinz Maier Leibnitz prize for up-and-coming scientists, worth 16,000 Euro. One of only six recipients of this award, Eric Bell of the MPIA was honored for his "experiments seeking to clarify how galaxies formed in the initial fluctuations after the big bang." The laudation acknowledged to "achieve an international role through a skilful combination of thorough modeling preparatory work, the inclusion of a multiplicity of data from different wavelength ranges, and new cosmological observations."

Eric Bell studied physics and astronomy at the University of Glasgow and received his doctorate at the University of Durham (UK). Thereafter, he worked as scientific assistant at the University of Arizona. In 2002, he joined the MPIA where he initiated the European Union Research Training Network for "Spectroscopic and Imaging Surveys for Cosmology". In 2006, Eric Bell founded, within the frame of the DFG's Emmy-Noether program, a group of up-and-coming scientists who were focused on how large galaxies develop.

The development of galaxies over a cosmologically long period of time can be followed, for example, on the basis of its total mass and luminosity. However, measured brightness is only an insufficient indicator for the total stellar mass. The reason for this is that, compared to old stars, young stars radiate much more light per stellar mass unit. The result, for instance, can be that two galaxies' stellar masses can differ from each other by a factor of ten in terms of luminosity.

Bell developed a method through which stellar masses in the middle of galaxies can be established with a 30 percent uncertainty. For this, it is necessary to record the galaxies in varying spectral ranges. This method and the resultant processes have very quickly become standards in astronomy.

Through this process, modern inquires can be re-examined. Thus, it was assumed that mass-rich galaxies steadily grew through mergers with other galaxies. It was unclear, however, whether this process continued until today or whether mass-rich galaxies completed their formation long ago and steadily aged up until now. Bell and his colleagues were able to prove that mass-rich galaxies had not created new stars during the past eight billion years (the current age of the universe being estimated at 13.7 billion years). On the other hand, the research showed that the number of mass-rich galaxies today is significantly greater than it was ten billion years ago.

The growing number of mass-rich galaxies in the "second half" of the "universe's evolution" is significant. According to current theories, growth through merger is important especially for mass-rich galaxies and it is an immediate consequence of the gravitational effect of dark matter. Bell defends the thesis that this increase in the number of mass-rich galaxies is likely caused by merging galaxies.

Two decisive questions still remain open and are the main priority for further research. First, Bell would like to attempt to obtain a more exact understanding of the rate at which galaxies are merging. This would provide a reference point for the distribution of dark matter.

Second, current theory predicts that galaxies can also grow through the cooling of gasses. Observations do not support this. Why is that the case? Bell and colleagues want to compare the characteristics of mass-rich galaxy populations with models of galaxy formation and evolution. In this way they hope to obtain insight into the conditions under which a cooling of gasses is suppressed.

Henrik Beuther receives the Astronomical Society's

Fig. V.4.1: Eric Bell at the DFG's Heinz-Maier-Leibnitz Prize award ceremony on June 5 in the Bundeskunsthalle in Bonn. He is being congratulated by DFG President Matthias Kleiner (*right*) and Federal Minister of Research, Annette Schavan. (Photo: DFG)

Ludwig-Biermann Prize

Since 1989, the Astronomy Foundation has been awarding the Ludwig Bierman sponsorship prize worth 2500 Euro. The award was named after the founder and first director of the Institute for Astrophysics in Garching and was conceived as a travel sponsorship for outstanding young astronomers. In 2007 the prize was awarded to Henrik Beuther for "his important observations and original contributions to understanding the creation of massive stars". Beuther was the first astronomer from Heidelberg to receive this prestigious prize.

Fig. V.4.2: Ludwig-Biermann Prize recipient Henrik-Beuther.

Henrik Beuther studied physics at the University of Cologne and received his PhD at the Max-Planck Institute for radio astronomy in Bonn for his studies on the early stages of the formation of massive stars. Thereafter, he did his postdoctoral work there and as a DFG Emmy-Noether fellow at the Harvard-Smithsonian Center for Astrophysics in the US. Since September 2005, he has been heading the MPIA's Emmy-Noether group which primarily studies the early phases of massive star formation. Many questions still remain unanswered in this research area. For example, it remains unclear whether the most massive stars are formed through similar accretion mechanisms as low mass stars or whether other processes, such as the merging of proto-stars, become important.

Henrik Beuther is approaching these questions from different directions and is directing his focus on the following points: What are the characteristics of massive accretion disks, what is the influence of the high-mass star formation regions' initial fragmentation, what type of dust and gas chemistry is involved in star formation regions, and what role does gas outflow and infall play in a star and/or in its circumstellar disk? In 2006, Beuther generated attention particularly through his observations of accretion disks of mass-rich, young stars (see Annual Report 2006, p. 32).

Gerhard Hensler read the statement of praise at the award ceremony. It read in part: "Henrik is well respected internationally and has an impressive list of publications where he is predominantly the first author... The Astronomy Foundation hopes to provide a small contribution to Henrik's future by awarding him the Ludwig-Biermann sponsorship prize. But, most importantly, the award emphasizes the excellence of his research."

Anders Johansen, Boris Häussler, and Konrad Tristram receive the Ernst Patzer Prize

The Ernst Patzer prize to sponsor up-and-coming scientists is financed from by the scientific Ernst Patzer Foundation which was established by the widow of the philosopher and art lover, Ernst Patzer. This foundation has set itself the goal to financially encourage and support science and research, primarily in the field of astronomy. It awards its sponsorship prizes to young male and female MPIA scientists. The best peer-reviewed publications of an up-and-coming male or female scientist during the PhD or post-doc phase are honored. The examination of the submitted suggestions is done by a selection board which consists of two MPIA scientists and one third party scientist. The three laureates for 2007 each received 2000 Euro.

Anders Johansen received the award for his work titled "Rapid planetesimal formation in turbulent circumstellar disks" (Johansen et al., Nature 2007, 448, 1022) (see Chap. II.3). There, Johansen describes a new scenario in our understanding of the formation of planetesimals and small planets out of small stone lumps. Johansen showed that the gravitational accretion of stone lumps in turbulent eddies can take place at a high level of acceleration.

Only the application of new software allows for the calculation of the movement of such lumps in turbulent accretion disks. Johansen played a crucial role in the further development of the pencil code which solves on a numeric grid the magneto-hydro-dynamic equations for a gas which can interact with smaller particles. It was only thanks to the development of a parallel solver that the gravitational accretion of dust lumps could be captured quantitatively. This work opened new possibilities in the understanding of how planetesimals and small planets form.

Boris Häussler obtained the Patzer Prize for his work titled "GEMS: Galaxy fitting catalogues and testing parametric galaxy fitting codes: GALFIT, GIM2D" (Häussler et al., Astrophysical Journal). For his research he took up an extremely important technical problem in the study of the cosmological development of galaxies: The systematic examination of different algorithms for the analysis of galaxy images on CCD images of the HUBBLE space telescope. Without this examination, one would not be able to understand whether the observed development in the galaxy populations was real or whether it resulted from selection and analysis effects. Through his systematic examination, Häussler created the technical foundation on which scientific studies on the development of galaxies stand within the frame of the GEMS (Galaxy Evolution from Morphologies and Spectral Energy Distributions) project.

His publication is the result of a systematic approach and very time-consuming work. In it he also provides practical suggestions for data analysis which will be very helpful for other scientists working in this field.

Konrad Tristram was recognized for his work "Resolving the complex structure of the dust torus in the active nucleus of the Circinus galaxy" (Tristram et al., Astronomy and Astrophysics, in press). In his work, he presents the first direct measurement of the long postulated hot gas torus which surrounds an active galactic nucleus of the near Seyfert-2 galaxy, Circinus. A new method of inferometric observation in the mid-infrared was used to obtain this important information on the structure of dust distribution. This method's breakthrough lies especially in the successful observation with multiple base lines of the Very Large Telescope Interferometers in combination with the MIDI instrument. MIDI was developed and built under the direction of the MPIA.

Fig. V.3.3 a-c: The winners of the Ernst-Patzer Prize: Anders Johansen, Boris Häussler and Konrad Tristram (*L to R*).

To interpret these excellent data, a new modeling method was developed. This made it possible to take full advantage of the data set's complete information content. Thus the spatial distribution of two dust components could be ascertained. Furthermore, Tristram found indications that the torus itself did not have a homogenous structure but that it rather consisted of individual clumps. The result was of great significance for understanding active galactic nuclei.

Fabio Fontanot receives the Tacchini Prize of the Italian Astronomical Society

The Italian Astronomical Society annually awards the prize to the writers of the five best Italian PhD theses in physics. The prize is named after Pietro Tacchini (1838 – 1905) who was the founder of the Italian Society of Spectroscopists (Societa degli Spettroscopisti Italiani). In 2007, Fabio Fontanot was recognized for this PhD thesis "Multiwavelength approach to the joint formation and evolution of galaxies and AGN".

Fabio Fontanot studied physics as the University of Triest where he also received his PhD. Since May 2006, he has been working at the MPIA as a post doctoral candidate on distant quasars and the development of AGN and massive galaxies.

In his PhD thesis, he examined the mutual development of active galactic nuclei (AGN) and galaxies whereby he incorporated both observations as well as models. The experimental part of his work relies on the Goods survey of the universe which was conducted with the Spitzer, Hubble, Chandra and XMM-Newton space telescopes. This data set aided in the search for high redshifted quasars and for the evaluation of their numerical density. Fontanot could show, for example, that at redshiftings between $z = 5.2$ and $z = 3.5$, the quasars alone could not be responsible for the complete ionization of the intergalactic medium.

Fig. V.3.4: Fabio Fontanot, Tacchini Prize recipient.

In the second part of his thesis, Fontanot presented a new model named Galrise with which he was able to simulate the mutual development of galaxies and AGN. Of significant importance here was the inclusion of feedback mechanisms such as the accretion of material on a super-massive black hole and the creation of a super wind driven by the black hole's radiation and by stellar radiation. These formation scenarios can explain the relationship between the masses of the black holes in the centers of active galaxies and the star bulges surrounding them.

Benjamin Moster receives the University of Heidelberg Otto Haxel Prize

For several years now, the Department of Physics and Astronomy at the University of Heidelberg awards the Otto Haxel Prize. Each semester, the prize honors an outstanding thesis in theoretical and experimental physics. In 2007, MPIA's Benjamin Moster received the 500 Euro award for his research of galaxy halos and the clustering of galaxies at high redshiftings.

The goal of the work was the examination of a relationship between the stellar mass of galaxies and the masses of dark matter halos in which these are located. Moster approached the problem through N-body simulations. He then compared the results for the relationships of the star to halo masses with semi-analytical calculations. The results were able to simulatet the SDSS observational data well. Thereafter the star halo mass relation was used in order to derive predictions regarding for other more distant galaxies. One of the results is that the relationship of the masses in the stars of one galaxy to the masses of the surrounding halo should decrease toward larger redshifts. Put another way: The dark matter halos dominated the total mass of the galaxies more than they do today.

Fig. V.3.5: Benjamin Moster, Otto-Haxel Prize recipient.

Sebastian Wolf accepts an appointment at the University in Kiel

During the reporting year, Sebastian Wolf was appointed to a W2 professorship at the University in Kiel. Wolf wants to dedicate himself there to the study of star and planetary formation. The focus of his research will be on numerical simulations and the observation of circumstellar disks.

Since 1997, Sebastian Wolf has been working at the state observatory in Thuringia. There he developed a method with which radiation transportation can be particularly easily and quickly treated numerically in any three-dimensional dust configuration. At the same time at the Eso on La Silla he observed circumstellar disks around binary stars. Within the framework of his doctorate, he then applied the theoretical models, inter alia, to these dust disks and made predictions on the polarization of the dispersed light. During this time he thus gathered experience both in theoretical and observational astronomy which was of great advantage for his current appointment.

After research visits at the MPIA, the Jet Propulsion Laboratory where he participated on the Spitzer space telescope's legacy program, and the California Institute of Technology, he joined the MPIA as the head of an Emmy-Noether group. The DFG sponsored his working group, which included a PhD and a post doctoral candidate, for four years. After deepening his studies on protoplanetary disks by applying high spatial high resolution observation methods, he was able to join the Matisse interferometry project as a project scientist (see Chap. IV.2).

Fig. V.3.6: Sebastian Wolf, in front of the MPIA building.

Within the scope of the Emmy-Noether program, the purpose of the grant is also to reach the "qualification of a university teacher" – as it's known to be said at the DFG. Sebastian Wolf took advantage of this opportunity: Since January 2008 he is a Professor at the University in Kiel.

Markus Pössel receives the Hanno and Ruth Roelin Prize for Scientific Journalism

At the annual meeting of the Astronomy Society in 2007 in Würzburg, Markus Pössel from the Max Planck Institute for Gravitational Research (Albert Einstein Institute) in Golm received the Roelin Prize for scientific journalism. The prize is in the amount of 3000 Euro and is awarded by the Max Planck Institute for Astronomy. A jury of scientists and science journalists makes the selection.

The Hanno and Ruth Roelin Prize recognizes a science journalist who has been particularly successful in conveying new insights in astronomy and space research to a wide audience (see Annual Report 2005, Chap. V.11). Markus Pössel who was honored in 2007 (born 1972) received his PhD from the Max-Planck Institute for Gravitational Research in 2003. His thesis discussed "Hidden Symmetries in Five-dimensional Super-Gravitation". At the time of the award, he was working at the institute as a scientist focusing on the basics and the conveyance of the general theory of relativity. Currently he is Senior Science Advisor to the World Science Festival which will take place in New York at the end of May 2008.

Just in time for the Einstein Year 2005, Pössel had the idea of creating a generally accessible online portal for the theory of relativity. Since then, »Einstein Online« has developed to a wide platform in which 17 renowned universities and research institutes are participating. The portal comprises around 500 text pages in German and English and more than 200 images and animations which bring visitors closer to the fundamentals and applications of the theory of relativity. It was released in January 2005 and had 800 000 hits worldwide by the Fall of 2007.

At the same time, Markus Pössel published in renowned magazines and newspapers numerous generally accessible texts on the theme of relativity theory including in the book "The Einstein Window: a Journey through Space-Time".

Fig. V.3.7: Markus Pössel

And finally, Markus Pössel published texts and conceived interactive experiments for various exhibitions during the Einstein Year. Worth a special mention is his collaboration in the large exhibition "Albert Einstein – Engineer of the Universe" which attracted 130 000 visitors in 2005 in Berlin. He was significantly involved in the conception, planning, and implementation of the "Einstein World Today" part of this exhibition in which current developments in relativity theory were presented and for which he also wrote exhibition and catalogue texts.

His scientific competence and the breadth of the multimedia approach provided the jury with the impetus to aware the 2007 Hanno and Ruth Roelin Prize for scientific journalism to Markus Pössel.

Jakob Staude

V.5 A Researcher's Enthusiasm Infects his Students

A conversation with Willy Benz, the new external scientific member

Willy Benz, professor at the University of Bern, was appointed in 2007 as an external scientific member of the MPIA, making official a partnership that has existed for a long time between him and astronomers from Heidelberg. In the coming years his research will focus on planetary formation. In this conversation, Benz explains his research, his attitude toward the unity of research and lecturing, and his future plans for collaboration with the MPIA.

Question: What are you working on right now with your colleagues?

WB: At the Institute of Physics at the University of Bern, we concentrate on the formation and development of planetary systems, especially our own. Among us is a group which builds measurement instruments for space probes: An instrument packet from the University of Bern is currently flying in the ROSETTA comet probe. In contrast, my own group's work is theoretical. For example, we have conducted much research on the formation of extrasolar gas planets and also of the moon. In doing so, we have simulated the collision of the young earth with a body the size of Mars.

You have been recently pursued the question whether Mercury was the target of such a direct hit during its formative period. What motivated you to do this?

WB: Mercury has a special position in the solar system because it is 70 percent iron. Some scientists explain this by saying that part of its rocky mantle vaporized. The alternative we are examining assumes that Mercury was hit in its early stages by a body and that it lost a part of its mantle in the process. It is interesting that both models make varying predictions about the chemical composition of the mantle. For this reason we are also very interested in the results of the MESSENGER and BEPICOLOMBO Mercury probes. It is naturally a shame that, for cost reasons ESA cancelled the initial plan of including a landing probe on BEPICOLOMBO.

Although you are a theoretician, you recently appeared as curator to a much admired publication by Michel Mayors' group, who discovered a star with three Neptune-sized exoplanets. How did this come about?

WB: Michel Mayor was my PhD advisor. As Mayor was thinking about the HARPS instrument, I helped him with the grant application. Since then, Bern has belonged to the HARPS working group.

HARPS is a high-resolution spectograph assisting in the search for exoplanets on ESO's 3.6 m telescope on La Silla.

WB: That's correct. At the end of the 1990s, no one in Switzerland had built an instrument for ESO. There simply was no access to financing. HARPS then provided the ability to find a completely new line of financing for astronomical instruments in Switzerland. This was only possible due to the success of ELODIE, with which Mayor and Queloz discovered the planet orbiting 51 Pegasi. Parts of HARPS were built in my institute's workshop in Bern. I myself never performed an observation with HARPS but one of my PhD candidates was in Chile several times for this reason.

This is how you are involved in the exploration both of extrasolar planets and of our own system.

WB: For me, the exploration of planets must inclu de both aspects. Our solar system can to some extent be viewed under a magnifying glass. We conduct detailed studies of the planets, send probes there, and even bring some samples back to Earth. We will never be able to do this with exoplanets. Here we can only study one unique system. There is a lack of diversity. We don't know what is possible. That is what the study of other planetary systems will lead us to.

What methods do you use for this approach?

WB: Simulations, for which we use observation data as input quantities. This includes for example the mass distribution and life of circumstellar disks, the metallicity of stars, and many other things. With these we limit the parameter space for our Monte-Carlo simulations. We then allow for one million simulations of disk formation and are able to obtain as a result an equal number of possible planetary populations. We compare these with the observational data of known exoplanets. As a result we have reached the point today that we can make statistical comparisons to the observations. For example, we can derive a list of stars from the result of these analyses, where the search for exoplanets should prove particularly rewarding or where particularly informative results could be obtained.

Fig. V.5.1: Willy Benz

Common Interests

Now we would like to discuss your new status as external scientific member to the MPIA. What do you hope to gain from this relationship?

WB: I have been following the MPIA's work for several years now because some of the groups here work in the same area that my group in Bern does. I therefore hope that we will be able to scientifically complement each other. This will be possible in many, highly topical areas, of course, especially regarding the formation and development of planets.

What is your concrete image of this future cooperation?

WB: Well, for one thing Bern and Heidelberg are not very far apart from each other. There are no visa or immigration formalities which complicate exchanges. This simplifies many things. Among other things, I imagined that we will be exchanging PhD candidates and post doctoral students for limited periods. I have already discussed this with several of my people and they are very excited about the opportunity. On the other hand, fellows from the MPIA could naturally come to Bern. This could prove advantageous for the education of younger members, to expose them to other work approaches, methods, and research conditions for a few months. This should be possible without any great formal effort.

Would you yourself like to come to the MPIA for a longer period?

WB: I have not thought this through yet. But one possibility that is coming my way is a sabbatical. In that case, I would come to Heidelberg for a few months and work together with colleagues here on some projects. Of course, I have to discuss this with my family too; I have three children of which two are in school. But given the short distances, I could at least come here for a few days at a time.

In your opinion, how would you compare your institute with the MPIA?

WB: My institute is part of a university with fewer means at its disposal than the Max-Planck Institute. Nevertheless we are still quite capable of devising theories or of building instruments for a space probe like Rosetta. While the material aspects are always important, in the end it depends on the right people; on this level our university is competitive. Here in Switzerland the state-financed Confederate Technical Universities (ETH) are comparable to the Max-Planck Institutes. The ETH basically have more means at their disposal than universities.

What I really value at the MPIA is the breadth of its research. Here, I can attend lectures on cosmology which I consider to be extremely fascinating. After all, I taught astrophysics for 14 years in the US and I also dabbled a little in supernovae. I would'nt necessarily want to reenter astrophysical or cosmological research, but my interest has continued uninterrupted. I miss this in Bern.

Unity of Research and Instruction

Research and instruction are very closely linked to each other in universities. Would you consider it more advantageous if there were a clear separation here so that, for example, scientists would have more time for research?

WB: Under no circumstances! I believe if one really wants to train students well, then one needs professors who know their material not only from books but who are also able to draw on actual research.

In other words, the old Humboldt unity of research and instruction principle…?

WB: Exactly. Even when someone is really able to present the material from a book, the enthusiasm is still completely different if he is conducting research himself. And this enthusiasm infects the students. That is extremely important. For this reason it is also important that Max-Planck researchers hold lectures and seminars at universities. In this way, one can generally interest students in research and in the Max-Planck Institutes in particular.

In Heidelberg, cooperation between universities and Max-Planck Institutes was encouraged through the foundation of the Center for Astronomy. Now, three university institutes and two Max-Planck Institutes work much more closely together than before.

WB: This is very good, because using the hook of astronomy, many students can be led to study physics. Of course, not all astrophysics graduates stay in research, but physicists are always needed. Here, students can see that astronomy is a modern, dynamic field in which much is going on. After all, that's what interests young people.

Here in Bern at the moment a completely different trend prevails: Many are studying geography. Initially that sounds rather surprising. The reason for this is rather simple. Climatology is included in geography and, today, that's what's modern. But, do we really need so many geographers?

In closing, an assessment on the MPIA's future direction. You probably know that we are trying to bring a third director to the institute. What would your recommendations be in this regard?

WB: First and foremost: both current directors are truly top class. They have brilliant ideas, harmonize well with each other, and have brought the MPIA to a wonderful position. If one decides to include a third director, then one should pay heed to growth that is well-balanced. Growth just for its own sake is not meaningful. I would find it regrettable if building a third department came at a cost to the other two.

A third department would therefore have to be a supplement to the two existing departments and not detract from either of them. What would you say to having a third leg to stand on by adding the field of astrobiology?

WB: Naturally that would be a very topical research field even though it is very interdisciplinary. Primarily, it seems to me that it is more oriented toward biology/chemistry than toward astronomy. Here one would really have to question whether this would be the right place for such a group. In addition, one would have to ask from when on they would be able to count on spectra from exoplanets that could actually be analyzed. In this context, I would have to remind the readers that ESA has deferred Project DARWIN for the examination and spectroscopic characterization of exoplanets. It is no longer included in the current Cosmic Vision Program which means that something like this won't happen before 2020.

I believe that the decision about a third director position should include a vision for future research at the MPIA. One should take the time to think it through.

The interview was led by
Jakob Staude and Thomas Bührke

Willy Benz was born on July 6, 1955 in Neuchâtel, where he studied physics. In 1984 he obtained his PhD in astrophysics at the University of Geneva under the tutelage of Michel Mayor who in 1995, together with Didier Queloz, was the first to discover an extrasolar planet around the star 51 Pegasi. Benz then completed his post doctoral work at the Los Alamos National Laboratory (USA) and at Harvard University (USA) where he later was appointed Assistant Professor. In the years following, he taught at the University of Arizona (USA) and at the University of Geneva. Since 1997, Willy Benz has been Professor at the University of Bern's Institute of Physics which he has been leading since 2002 as the managing director.

His dedication to teaching and research was recognized in 1988 with the Milton Fund Award and one year later with the Thomas Temple Hoopes Prize for Excellence in Undergraduate Teaching. Since 2004 he has been a member of the Swiss Science and Technology Board and since 2005 a corresponding member to the International Academy of Astronautics. In addition he is currently a member of the Swiss Delegation to the European Space Agency's (ESA's) Science Program Committee.

His research area focuses on the creation and development of planetary systems whereby he has distinguished himself in particular through his simulations of large body collisions in the early phase of the solar system.

You may find out more about Willy Benz and his research at:
www.space.unibe.ch/taps

V.6 »A clear plea for basic research«

A conversation with MPIA trustee Ranga Yogeshwar

Ranga Yogeshwar is known as the editor and moderator of the television science program "Quarks & Co." Yet the heart of this trained physicist who has received numerous prizes still beats for research – especially in astronomy. Since the Summer of 2007, the 30cm telescope in his garden has even become an official observatory for the Minor Planet Center, a division of the International Astronomical Union. Since 2003, he has been a member of the MPIA board of trustees. In this interview he talks about his background and his plans.

Journalist, Politician, or Consultant?

Question: *In your thesis you focused on astrophysical processes; for example, with the question of how stars form new elements. This is an exciting field. Why did you nonetheless leave research?*

RY: Research always fascinated me, but the researcher's days are marked by routine. They are often occupied with very ordinary things such as defective amplifiers, faulty indicators, crashing computers, and so on. And one is really forced to specialize.

So, this was a proactive decision against a career in research – not something that was discontinued against your wishes. What then led you to journalism?

RY: Journalism was not the only possible option I had. Rather, I placed two demands on my work: First, my learning curve always had to point upward. Second, my work had to have social relevance; I wanted to – and still want to – change something.

A sense of mission of sorts?

RY: Yes, one could possibly put it that way. I saw three ways to achieve this goal. After journalism, I recognized a second possibilityin politics. While I had never been part of an organized party, during my university studies I became deeply involved against increasing militarization. During the 1980s, Reagan's SDI space defense system and the NATO double-track decision were up for debate. Medium-range missiles stood opposite each other at dangerously close distances. It was time to finally break out of the "Logic" of mutual destruction. My first edited book "Responsibility for Peace" grew out of these activities. War can no longer be an option in our century!

But in the end you didn't enter into politics after all.

RY: No. This option was dropped again because politics primarily focuses on preserving itself. Parties are too often guided by the voter rather than by offering the voter guidance. Power is a decisive drive and votes count more than a long-term and considered view. For this reason, I like physicists more than others: Most of them are not obsessed with power but are interested in discussions based on facts.

And the third option?

RY: Consultant.

Really?

RY: Yes. In their work, consultants experience varied fields, must think themselves into new enterprises, and are able to change much – a positive learning curve. However, I soon realized that money was the primary criterion that stood ahead of all else. Pure profit thinking is insufficient for me and, for example, the consultant detour is often used to effectuate drastic job cuts. In the end, journalism seemed to me to be the most attractive path.

In your program "Quarks & Co", you focus on all areas of science. In the meantime, you have become known for your sometimes excessive experiments on yourself. Are there any chances that there will be changes?

RY: Media mark many peoples' lives. On average, citizens view two hours of television per day. For me, the media are a chance to inform people well and to make them more responsible. Yet, unfortunately, there is an increasing superficiality. I try to actively counteract this with the varying program formats. Through "Quarks & Co.", after all, we reach more than one million viewers. Many programs are used in classroom instruction. Even in the entertainment area with the "Show der Naturwunder", which airs on Thursday nights with Frank Elstner, I reach many people who otherwise would never turn on a natural sciences program. Given six to seven million people, one can certainly "infect" a few with science!

Stars @ School

Aside from your professional activities in television, do you also try to bring science to the people in other ways?

Fig. V.6.1: Ranga Yogeshwar standing in front of his telescope.

RY: Yes. I continuously try to use my influential cultural, industrial, and political contacts in order to transmit knowledge. In our country, we need more active promoters of education. In the meanwhile, many have understood this but we still have much more to do. The "years of science" was an attempt. It was revolutionary because science was actively introduced to the citizens, and it was well received. I made great efforts to have 2000 become the year of physics and it's why I am going to push the Federal Government to make 2009 the year of astronomy. But those in power want to promote it as the year of the Federal Republic, it will be an election year in Germany. In any case, I would prefer a year of astronomy. Another idea is a project that I call "Stars@School".

What does that look like?

RY: I imagine that, at large observatories worldwide, smaller telescopes with a protective hood could be installed and taken care of by the observatory's employees. The devices would be operated by classrooms via the internet.

How many locations would be required and how large would the telescopes have to be?

RY: At the beginning there should be at least five or six. The mirrors would presumably have an opening of roughly 60 centimeters. There is an optimal point here in terms of costs and maintenance.

Concretely, how would the telescopes be used?

RY: A school classroom could register via the internet to use a specific telescope. For example, one could develop the teaching unit to, say, observe variable stars or to measure a Mars cycle of whatever else. The results of these data or courses on specific topics could then be posted on the internet where they can be accessed by everyone. Dedicated teachers will be able to engage many more students. This way, even students at schools that are not as well equipped will be able to have challenging physics and/or astronomy instruction.

You consider instruction in astronomy to be important?

RY: Astronomy is especially suited for teaching the natural sciences, because there are wonderful references to astronomy from mathematics and physics on through to information technology and the humanities. In addition, depending on the students' age, interesting modules can be developed: Young students for example determine the earth's orbital speed or the brightness of the stars, while older ones measure small planets or calculate the distance to particular galaxies. Through astronomy, natural sciences can be very vividly presented. Add to that that it's international: The heavens are the same for all of us. In certain inquiries there are even opportunities for international exchange of ideas and experience – especially for young people, a chance to work internationally while still in school. With Stars@School, the global distribution of the telescopes would have the additional advantage of permitting observations during school periods or at least during the day. German schools would then use a telescope at Eso in Chile and Chilean students in turn could use one at Calar Alto in Southern Spain or on Tenerife.

That sounds very alluring, but where will the money come from?

RY: I don't view this as such a difficult problem. Compared to the use potential, the investment sum is comparatively small and would be of direct benefit to many schools. Naturally one could receive donations from large enterprises for this: I know many very dedicated foundations and enterprises who would definitely contribute. The more difficult question is how to organize it effectively. After all, there already are excellent initiatives. These should all be tied together. While unfortunately I don't have the time at the moment, I am confident that a long-term structure for this can be formed. And in many cases, politics has to be engaged to make the project a part of the school's teaching plans. The opportunities abound; this would be a positive impulse toward strengthening the natural sciences.

A fascinating idea, the implementation of which makes me take a deep breath. Maybe one could – if it ever takes off – link it with the SuW project: "Science and Schools".

RY: Yes, of course, that would be wonderful. This way you could win even more physics instructors over to astronomy. There are, after all, still many physics instructors who hardly have an idea about astronomy. I think that's a great shame. Astronomy is not only a fascinating science, it excites young and old and, to a certain extent, is the thing that gets you hooked on physics and engineering.

And now a little bit about your own personal addiction: astronomy. The Minor Planet Center officially recognized your observatory and gave it a number: B 43. What did you have to do for this?

RY: You get an MPC station code after you're able to more precisely measure the orbits of small planets. It is not a huge effort and was rather a motivation for me. Astronomy allows me – with a very limited budget of time – to practice all aspects of scientific work: measurement, evaluation, parts of machinery, software and – most importantly – to share the joy of the heavens with others!

Public Advocates are needed for Basic Research

How did you become an MPIA trustee?

RY: I already was a trustee at the Max Planck Institutes for gravitational physics in Golm and for the history of science in Berlin. Then Peter Gruss, the president of the MPG, asked me whether I would also like to become a member of the trustee's at Heidelberg's MPIA. I agreed to it because I greatly admire the institute but I won't be assuming anymore posts of this type for some time to come.

What do you view your role on the board of trustees to be?

RY: The board of trustees has above all the task of encouraging connections with the public and, for example, discussing the institute's development and its public perception with the directors. Naturally, this is what we do as trustees at the institute's meetings. And to the extent that I can, I am happy to support the institute on special occasions. But for this, special meetings are not required – at least not for me. If the institute is stuck somewhere and I have the ability to help them, they can always call me. By the way, I don't profit directly from the membership because I already have good contacts with all types of institutes.

Do you take the MPIA into special consideration when you research a program involving astronomy?

RY: Not really. Principally, I am a free thinker. I first think about the topic and only afterward about a particular institute. But generally, every type of basic research needs its public promoters in the media. Otherwise, we are very quickly written off by politics. And I stand for basic research because I know where I come from and what fascinates me. For example, this is what I focused on in my commentary on the topic of the day when Peter Grünberg was awarded the Nobel Prize. At that time I made a very strong and clear plea for basic research.

The interview was led by
Jakob Staude and Thomas Bührke
(also photography)

Ranga Yogeshwar was born in Luxembourg in 1959. He attended school there and in India, where his father is from. In Luxembourg he obtained his Abitur and obtained piano lessons at the city conservatory. He subsequently studied physics at the Technische Hochschule in Aachen and graduated as a qualified physicist specializing in "Experimental Elementary Particle Physics and Astrophysics". This was followed by research at the Swiss Institute for Nuclear Research (SIN) in Villingen and at CERN in Geneva as well as at the Jülich research center.

In 1983 he began his work in journalism by publishing in newspapers and journals and later working in radio and television. After a one-year stay in India, he was appointed as scientific editor to the Westdeutsche Rundfunk in Cologne in 1987. Since then he has moderated numerous broadcasts, including Quarks & Co, W Wie Wissen, Die große Show der Naturwunder and, since March of this year, Wissen vor 8.

Ranga Yogeshwar had edited and written several books, including "What is AIDS?" and "The Synthetics Report". He has received several honors incluing the Georg von Holtzbrinck prize for journalism (1998), the medal of the Deutsche Physikalische Gesellschaft for natural sciences journalism (2002) and the Order of Merit of the Federal Republic of Germany for his dedication to the area of education (2006).

As one of the most prominent promoters of science, he is a sought-after consultant to scientific and cultural establishments and organizations, he is a trustee to the Max Planck Institute for gravitational physics in Golm and for astronomy in Heidelberg.

You can obtain more information at:
www.yogeshwar.de.

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Technical Services: Zergiebel (Head); F. Witzel (Substitute), Behnke, Drescher (since 1.2.), Herz (until 31.1.), Jung, Lang, Nauss, B. Witzel, E. Zimmermann (since 1.2.)

Freelance Science Writer: Thomas Bührke

Guests: Stijn Wuyts, Holland, Jan 9 – 12; Joseph Carson, JPL, Jan 14-17; Michiel Min, Univ. Amsterdam, Jan 22 – Feb 14; Alexander Richard, Jan 24 – 26; Johannes Koppenhöffer, MPI f. Extraterr. Physik, Jan 23 – 26; Pawel Pietrukowicz, Copernicus Astron. Center, Jan 29 – 31; Robert Lupton, Princeton University, Jan 28 – Feb 4; Pawel Pietrukowicz, Copernicus Astron. Center, Jan 29 – 31; Nikoletta Sipos, Konkoly Observatory, Jan 29 – Feb 17; Joao Alves, CAHA, Jan 2 – Feb 2; Thorsten Naab, Univ. München, Jan 30 – 31; Michaela Hirschmann, Univ. München, Jan 30 – 31; Kim Nilsson, DCC Copenhagen, Jan 30 – Feb 1; Federico Gasparo, INAF, Jan 30 – Feb 3; Riccardo Smareglia, INAF, Jan 30 – Feb 3; Matthias Heininger, MPIfR Bonn, Jan 31 – Feb 1; Andreea Petric, Columbia Univ., Feb 1 – 4; Emmanuel Di Folco, Obs. de Genève, Feb 5 – 7; Thorsten Ratzka, AIP Potsdam, Feb 7 – 9; Hsiang-Hsu Wang, ASIAA, Taiwan, Feb 9 – 10; Andras Zsom, Konkoly Observatory, Feb 9; Akemi Tamanai, FSU Jena, Feb 5 – Mar 5; Hsiang-Hsu Wang, Chiba Univ., Feb 9 – 10; Joanna Arka, Univ. Athens, Feb 11 – 13; Jennifer Connelly, Wesleyan Univ., Feb 11 – 15; Denija Crnojevic, Univ. Trieste, Feb 11 – 15; Warrick Lawson, Univ. New South-Wales, Feb 12 – 15; Owen Matthews, Paul Scherrer Inst. Zürich, Feb 12 – 13; Stefano Zibetti, MPE, Feb 12; Ulfert Wiesendahl, Univ. Hamburg, Feb 14; Olga Zacharopoulou, Univ. Athens, Feb 13 – 15; Triaud Amaury, Univ. St. Andrews, Feb 14 – 16; Nicola Da Rio, Univ. Trieste, Feb 13 – 16; Silvia Leurini, ESO, Feb 13 – 16; Hauke Engel, Oxford University Feb 15 – 16; Peter Abraham, Konkoly Observatory Feb 18 – 20; Andrea Isella, INAF, Feb 19 – 23; Marco Miranda, Univ. Zürich, Feb 20 – 23; Olof van den Berg, Univ. Utrecht, Feb 21 – 22; Martin Henze, Feb 25 – 27; Edward Taylor, Leiden Univ., Feb 26 – Mar 9; Wu Szu-Ying, Inst. Astron., Taiwan, Feb 28 – Mar 6; Daniel Sevilla Sanchez, Univ. Mainz, Mar 6; Giovanni Natale, Univ. Napoli Mar 6 – 10; Michihiro Takami, SUBARU Telescope, Mar 8 – 13; Yutaka Hayano, SUBARU Telescope, Mar 8 – 13; Masa Hayashi, SUBARU Telescope, Mar 8 – 13; Shoken Miyama, SUBARU Telescope, Mar 8 – 10; Andras Zsom, Konkoly Observatory, Mar 9; Daniel Angerhausen, Cologne Univ., Mar 9; Andre Lipand, Univ. Tartu, Mar 5 – 18; Elmar Körding, Univ. Southampton, Mar 12 – 16; Jose Rodriguez, IAC, Mar 12; Valery Dikarev, MPI f. Sonnenforschung, Mar 14 – 15; Jürgen Fliri, LMU München, Mar 15; Thorsten Ratzka, AIP, Mar 15 – 16; Michael Weiler, TU München, Mar 16; Klaus Pontoppidan, Caltech, Mar 11 – 25; Erica Ellingson, Subaru Telescope, Mar 13 – 23; S. Josephine Chang, UK, Mar 22 – 23; René Geißler, Univ. HD, Mar 19 – Apr 13; Martin Altmann, Univ. Chile, Apr 3; Tyler Bourke, Harvard CfA, Apr 9 – 12; Mark Sargent, ETH Zürich, Apr 12; Maximiliano Moyano, Apr 12 – 18; Jorge Pinedas, AlfA, Bonn, Apr 13; Nikolai Voshchinnikov, St. Petersburg Univ., Apr 22 – May 20; Andras Zsom, Konkoly Observatory, Apr 16 – May 21; John Peacock, Inst. f. Astr., Edinburgh, Apr 23 – 25; Mordecai-Mark Mac Low, Am. Museum Nat. Hist., Apr 12 – Sep 15; Davide Elia, Univ. Lecce, Italy, 24 – 26 Apr; Tsevi Mazeh, Wise Observatory; 25 – 29 Apr; Scott Trager, Univ. Groningen, Apr 30 – May 2; Mark Swain, JPL, April 30 – May 10; Eric Hoveland, JPL, Apr 30 – May 4; Christian Wolf, Oxford University, May 2 – 4; Eric Thiebaut, Obs. de Lyon, May 1 – 5; Pawel Zielinski, CA Torun, May 2 – 5; Tomek Laczkowski, CA Torun, May 2 – 5; Stefan Kraus, MPI Radioastronomie, May 2 – 5; Siegfried Falter, Dublin City Univ., May 2 – 3, Vanessa Menke, Indian Inst. Techn., May 4 – Aug 30; Vamsi P. Pingali, May 4 – Jul 25; David Golimowski, Johns Hopkins Univ., May 6 – 8; Holland Ford, Johns Hopkins Univ., May 6 – 8; Marcos Ubierna Gorricho, IAA, May 3 – 15; Erica Ellingson, Univ. Colorado, May 9 – 13; Til Birnstiel, Univ. Würzburg, May 14 – 15; Lengger, MPG Revision, May 7 – 11; Scott Michael, Indiana University, May 1 – 25; Richard Durisen, Indiana Univ., May 16 – Jul 3; Götz, MPG/Revision, May 14 – 25; David Hernandez, Univ. Arizona, Tucson, May 16 – Aug 15;

Chien Peng, STScI, May 16 – Jun 17; Jeffrey S. Oishi, Am. Mus. Nat. Hist., May 18 – 23; Alan McConnachie, Univ. Victoria May 21 – 29; Christy Tremonti, Univ. Arizona, May 27 – 30; Zaunseder, MPG / Revision, May 21 – Jun 1; Ari Maller, City Univ. NY, June 2 – 7; Matt Covington, Univ. California June 3 – 6; Romeel Dave, Steward Obs. Jun 10 – Jul 21; Götz, MPG Revision, Jun 11 – 15; Giovanni Pinzon, Univ. Bogotà, Jun 12 – 15; Harinder Singh, Univ. Delhi, Jun 15 – 22; Jason Rowe, Univ. Brit. Columbia, Jun 25 – 29; Kerstin Meyer-Ross, MPI f. Comp. Science Jun 21 – 24; Min Fang, Purple Mount. Obs. Jun 1 – Aug 31; Taysun Kimm, Yonsei Univ. Jun 2 – Aug 31; David Hogg, NY Univ., Jun 11 – Aug 5; Veronica Castellanos, Univ. Mexico, Jun 11 – Sep 14; Giovanni Pizon, Univ. Bogotà, Jun 12 – 14; Veronica Castellanos, Univ. Mexico, Jun 11 – Sep 14; Manuel Guedel, ETH Zürich, Jun 11 – Aug 31, Benjamin Saliwanchik, Univ. Chicago, Jun 20 – Aug 20; Akemi Tamanai, FSU Jena, Jun 6 – 27; Jason Rowe, Univ. Brit. Columbia, Jun 25-29; Kathryn Johnston, Columbia Univ., Jun 25 – 30; Lukasz Wyrzykowski, Cambridge Univ., Jun 25 – 26; Michael Smith, Jun 25 – 29; Markus Hartung, ESO Santiago, 25 Jun – 12 Jul; Feng Xu, China, Jun 27 – 29; Tom Megenth, Ritter Obs., Jun 27 – 29; Steve Beckwith, STScI, Jul 2 – 9; Nikoletta Sipos, Konkoly Univ., Jul 2 – 9; Peter Abraham, Konkoly Observatory., Jul 2 – 9; Agnes Kospal, Konkoly Obs., Jul 2 – 9; Jakob Walcher, Jul 2 – 8; Joe Shields, Ohio Univ., Jul 1 – 14, Christian Wolf, Univ. Oxford, 2 – 14 Jul; Peter Schuller, Univ. Paris, 4 – 11 Jul; Chao-Chin Yang, Am. Museum Nat. Hist., 7 Jul – 15 Sep; Torsten Boeker, ESA/ESTEC, Jul 9 – 13; Ronin Wu, NY Univ., Jul 9 – 13; Adi Zolotov, NY Univ., Jul 9 – 13; Owen Matthews, Paul Scherrer Inst. Zürich, Jul 10-11; Barry Rothberg, STScI, Jul 11 – 13; Ben Oppenheimer, Steward Obs., Jul 6 – 21; Kristian Finlator, Steward Obs. Jul 8 – 21; Ignacio Ferreras, Kings College, London, Jul 8 – 28; Warrick Lawson, Univ. New South Wales, Jul 17 – 21; Gwendolyn Meeus, AIP, Jul 17 – 21; Vincent Coudé du Foresto, Obs. Paris, Jul 19 – 20; Ronin Wu, NY Univ., Jul 22 – 26; Zsolt Sandor, Eotvos Univ., Jul 23 – 24; Martin Ilgner, Jena Optik, Jul 13; Lukasz Wyrzykowski, Cambridge Univ., Jul 15 – 16; Carlos Eiroa, Univ. Madrid, Jun 26 – Aug 10; Csaba Kiss, Konkoly Observatory,18 Jul; Hou-jun Mo, Univ. of Mass., Jul 15 – Aug 24; Julianne Dalcanton, Univ. Washington, 24 Jul – 24 Aug; David Martinez Delgado, IAC, Aug 1 – 31; Jim Pizagno, State Univ. NY, Aug 10 – Sep 5; Elena Puga, Katholike Univ. Leuven, Aug 14 – Sep 28; Jochen Eislöffel, LSW Tautenburg, Aug 20 – 21; Daniel Harbeck, Univ. Wisconsin, Aug 23; ALMA Ruiz Velasco, Dark Cosmology Center, Kopenhagen, Aug 8 – 10; Stefano Zibetti, MPE, Aug 27 – 28; Robert Williams, STScI Baltimore, Sep 2 – 6; Felicitas Mokler, TU Braunschweig, Sep 10 – 12; Johannes Koppenhöfer, MPE, Sep 3 – 14; Andrey Sobolev, Ural State Univ., Sep 7 – Oct 27; Annie Robin, Observatoire de BesanÁon, Sep 9 – 11; Céline Reylé, Observatoire de BesanÁon, Sep 9 – 11; Henry Lee, Gemini South, Chile, Sep 6 – 9; Brad Warren, McMaster Univ. Canada, Sep 29 – Oct 3; Peter Barthel, Kapteyn Inst., Groningen, Sep 30 – Oct 2; Mislav Balokovic, Univ. Zagreb, Sep 15 – Oct 14; Tesse van der Laan, Kapteyn Inst. Groningen, Sep 30 – Oct 6; Davide Elia, Univ. Lecce, Oct 1 – 26; Gaspar Bakos, CfA, Harvard Univ. Oct 10 – 12; Brian Yanny, Fermi Nat. Acc.Lab, Oct 15 – 21; Stephane Courteau, Queens Univ., Oct 14 – 27; Hans-Rainer Klöckner, Oxford Univ., Oct 22 – 26; Andrew Youdin, Univ. Toronto, Oct 22 – Nov 3; Boris Häussler, Univ. Nottingham, Nov 1 – 2; Daniel McIntosh, Univ. Massachusetts, Nov 8 – 9; Ruud Visser, Sterrewacht Leiden, Nov 9 – 17; Rob Wittenmyer, Univ. Texas, Nov 11 – 14; Nikoletta Sipos, Konkoly Observatory, Nov 12 – Dec 20; Dimitri Vibe, Russ. Acad. Sci, Moscow, AIP, Nov 19 – Dec 19; Gwendolyn Meeus, Nov 19 – 23; Christian Thalmann, ETH Zürich, Nov 22 – 23; Katherine Inskip, Univ. Sheffield, Nov 19 – 20; Wladimir Lyra, Uppsala Astron. Obs., Nov 18 – Dec 1; Henry Lee, Gemini South, Chile, Nov 23 – Dec 8; Doug Lin, UC Santa Cruz, Nov 25 – 28; Warrick Lawson, Univ. New South Wales, Nov 27 – Dec 2; Warrick Lawson, Dec 6 – 8; Henrik Nissen, Univ. Aarhus, Dec 3 – 5; Santabrata Das, Sejong Univ., Dec 9 – 15; Matthew Hayes, Univ. Geneva, Dec 13 – 15; Paola Re Fiorentin, Univ. Lubjuliana, Dec 7 – 21; Boris Häussler, Univ. Nottingham, Dec 14 – 21; Marijn Franx, Leiden Observatory, Dec 18 – 20; R. Wolf, Dec 18 – 20; Thorsten Ratzka, AIP Potsdam, Dec 19 – 20.

Calar Alto Observatory Almeria, Spanien

Since June 2005, the Observatory is a consortium, operated by the Consejo Superior de Investigaciones Cientificas and the Max Planck Society.
Astronomy Coordination: Thiele
Telescope Technology and Data Processing: Henschke (until 31.1.), Müller, W.
Technical Services: Klee

Departments

Department Planet and Star Formation
Director: Thomas Henning

Infrared Space Astronomy: Oliver Krause (Head); Stephan Birkmann, Thomas Blümchen, Jeroen Bouwman, Helmut Dannerbauer, Ulrich Grözinger, Martin Hennemann, Ralph Hofferbert, Armin Huber, Ulrich Klaas, Ernest Krmpotic, Friedrich Müller, Markus Nielbock, Silvia Scheithauer, Jürgen Schreiber, Christian Schwab, Jutta Stegmaier

Star Formation: Thomas Henning (Head); Aurora Aguilar Sicilia, Andrés Carmona, Joseph Carson, Xuepeng Chen, Min Fang, Markus Feldt, Miwa Goto, Attila Juhasz, Ralf Launhardt, Rainer Lenzen, Hendrik Linz, Laszlo Mosoni, Yaroslav Pavlyuchenkov, Diethard Peter, Sascha Quanz, Veronica Roccatagliata, Markus Schmalzl, Dmitri Semenov, Robert Tubbs, Roy van Boekel, Antonin Vasyunin, Tatiana Vasyunina

Brown Dwarfs / Exoplanets: Reinhard Mundt (Head); Cristina Afonso, Alessandro Berton, Wolfgang Brandner, Matilde Fernandez, Kerstin Geißler, Bertrand Goldmann, Felix Hormuth, Markus Janson, Viki Joergens, Boyke Rochau, Florian Rodler, Victoria Rodriguez Ledesma, Johny Setiawan, Patrick Weise, David Weldrake, Matthias Zechmeister

Theory (SP): Hubertus Klahr (Head); Andrej Bicanski, Frithjof Brauer, Frank Dettenrieder, Natalia Dziourkevitch, Artur Gawryszczak, Patrick Glaschke, Anders Johansen, Rolf Kuiper

Laboratory Astrophysics: Friedrich Huisken (Head), Marco Arold, Olivier Debieu, Cornelia Jäger, Torsten Schmidt, Angela Staicu

Frontiers of Interferometry in Germany (FRINGE): Uwe Graser (Head); Ralf Launhardt, Thorsten Ratzka, Jürgen Steinacker

AO Laboratory: Wolfgang Brandner (Head); Alessandro Berton, Nicola Da Rio, Fulvio De Bonis, Markus Feldt, Dimitrios Gouliermis, Stefan Hippler, Felix Hormuth, Micaela Stumpf

Emmy Noether Group I, "The Evolution of circumstellar disks to Planetary Disks": Sebastian Wolf (Head), Kacper Kornet, Jürgen Sauter, Alexander Schegerer

Emmy Noether Group II (»Properties and Formation of Substellar Mass Objects«): Coryn Bailer-Jones (Head), Steve Boudreault, Paola Re Fiorentin

Emmy Noether Group III, "The Formation of Massive Stars": Hendrik Beuther (Head), Cassandra Fallscheer, Javier Rodon

MPG Junior Research Group: Cornelis Dullemond (Head); Tilmann Birnstiel, Riccardo Coratella, Zsolt Sandor, Andras Zsom

MPG Minerva Group: Cristina Afonso (Head), Maximiliano Moyano, Nikolai Nikolov

Department: Galaxies and Cosmology

Director: Hans-Walter Rix

Structure and Dynamics of Galaxies: Hans-Walter Rix Head), Matthew Coleman, Jelte De Jong, Kelly Foyle, Josef Fried, Rainer Klement, Sergey Koposov, Nicolas Martin, Nadine Neumayer, Anna Pasquali, Domenico Tamburro, Xiangxiang Xue, Stefano Zibetti; Coryn Bailer-Jones (Head GAIA Project Group), Christian Elting, Kester Smith, Carola Tiede

Stellar Populations and Star Formation: Fabian Walter (Head), Ioannis Bagetakos, Frank Bigiel, Sebastian Jester, Kirsten Kraiberg Knudsen, Adam Leroy, Dominik Riechers, Hélène Roussel; Coryn Bailer-Jones (Head Emmy Noether Group), Steve Boudreault, Paola Re Fiorentin, Paraskevi Tsalmantza; Thomas Herbst (Head), Fulvio de Bonis, Wolfgang Gäßler, Maiken Gustafsson, Stefan Hanke, Frank Kittmann, Lucas Labadie

Evolution of Galaxies and Cosmology: Eric Bell (Head Emmy Noether Group); Isabel Franco, Anna Gallazzi, Boris Häußler, Aday Robaina, Christine Ruhland, Rosalind Skelton, Xianzhong Zheng; Klaus Meisenheimer (Head), Kris Blindert, Leonard Burtscher, Isabel Franco, Hans Hippelein, Hélène Nicol, Kim Nilsson, Hermann-Josef Röser, Irini Sakelliou, Konrad Tristram, Michael Zatloukal

Active Galactic Nuclei: Klaus Meisenheimer (Head), Christian Fendt, Sebastian Jester, Marc Schartmann, Konrad Tristram; Eva Schinnerer (Head Special Program for the Promotion of Excellent Female Scientists), Knud Jahnke, Alejo Martinez Sansigre, Sebastian Haan, Vernesa Smolcic; Knud Jahnke (Head Emmy Noether Group, build-up phase)

Theory: Formation of Galaxies and Large Scale Structure: Rachel Somerville (Head), Fabio Fontanot, Akimi Fujita, Andrea Maccio, Christian Maulbetsch, Ben Moster, Hsiang-Hsu Wang; Frank van den Bosch (Head Independent Junior Group), Marcello Cacciato, Jianling Gan, Xi Kang, Surhud More, Ramin Skibba

Instrumental Developments: Thomas Herbst (Head), Sebastian Egner, Josef Fried, Wolfgang Gäßler, Stefan Hanke, Lucas Labadie, Eva Meyer, Hermann-Josef Röser

Teaching Activities

Winter Term 2006 / 2007

H. Beuther, Ch. Fendt: Outflows and Jets: theory and observations (Lecture, IMPRS)

Ch. Fendt, K. Meisenheimer, H.-W. Rix: Current Research topics in Astrophysics (IMPRS Research Seminar, with J. Wambsganss, ZAH)

J. Fried: Galaxies (Lecture with Exercises, with B. Fuchs, ZAH)

Th. Henning: Substellar Objects – Extrasolar Planets and Brown Dwarfs (Lecture, with B. Goldmann, ZAH)

Th. Henning: Physik der Sternentstehung (Oberseminar)

K. Meisenheimer: Sources of High Energy Radiation (Seminar, with M. Camenzind and S. Wagner, ZAH, and with J. G. Kirk, MPIK)

H.-J. Röser: Introduction to Astronomy and Astrophysics, III (Seminar, with J. Heidt, LSW and J. Wambsganß, ZAH)

Sommer Term 2007

C. Bailer-Jones: Machine Learning, Pattern Recognition and Statistical Data Mining (Lecture)

H. Beuther, Sebastian Wolf: Stern- und Planetenentstehung (Vorlesung)

C. Fendt, S. Wolf: Current Research Topics in Astrophysics (IMPRS Research Seminar, with A. Just and R. Spurzem, ZAH)

C. Dullemond: Numerical hydrodynamics (Lecture)

C. Dullemond: The Primordial Matter out of which Stars and Planets are Formed (Research Seminar, with H. Krüger and E. Grün (MPIK), and with M. Trieloff, Min. Institut)

Th. Henning: Physics of Star Formation (Seminar)

K. Meisenheimer: Active Galactic Nuclei – Theory and Observations (Lecture)

R. Mundt, H.-J. Röser: Introduction to Astronomy and Astrophysics III (Seminar, with J. Wambsganß, ZAH)

Lecture Series "The Hydrodynamics of Young Circumstellar Disks", MPIA, June 11 – 12 (R. H. Durisen, Indiana University)

Winter Term 2007 / 2008

E. Bell: Observing the Big Bang (Lecture)

Ch. Fendt, K. Meisenheimer: Current research Topics in Astrophysics (IMPRS Forschungsseminar, with J. Wambsganß, ZAH)

Th. Henning: Physik der Sternentstehung (Oberseminar)

K. Meisenheimer: Quellen hochenergetischer Strahlung (Seminar, with S. Wagner, ZAH und J. G. Kirk, MPIK)

H.-J. Röser: Einführung in die Astronomie und Astrophysik III (Seminar, with E. Grebel, ZAH und J. Heidt, LSW)

S. Wolf: Einführung in die Astronomie und Astrophysik I (Lecture and Exercises, with Max Camenzind, ZAH)

Service in Committees

C. Bailer-Jones: Member of the GAIA Science Team; Member of the GAIA Data Processing and and Analysis Consortium Executive; Manager of the subconsortium "Astrophysical Parameters" in the GAIA Data Processing and Analysis Consortium; Member of the Scientific Organizing Committee of Commission 45 (Stellar Classification) of the International Astronomical Union; Panel member of the Observing Programme Committee (OPC) of the European Southern Observatory (ESO)

E. Bell: Member of the SDSS collaboration council and of the PanSTARRS1 science council

Ch. Fendt: IMPRS board; Ad-hoc Ausschuss Promotionsstudium, University Heidelberg

R. Gredel: ESO OPC and chair of OPC panel C3; PS1 visiting committee (chair); ARENA NA2 (chair); ESO, member of ELT-ESE; member of STAC at MPIA; CAHA 2013+ (chair)

M. Hennemann: Students representative

Th. Henning: ESO Council (Vice President); SOFIA Science Council (Member); German Interferometry Centre FRINGE (President); Science Council of the European Interferometry Initiative (President); PanSTARRS1 Board (Member); Member of the Advisory Councils of the Kiepenheuer Institute for Solar Physics, Freiburg and of the Thüringer Landessternwarte, Tautenburg; Co-I of the infrared instruments FIFI-LS (SOFIA), PACS (HERSCHEL), MIRI (JWST), SPHERE (VLT), PRIMA-DDL (VLTI); MATISSE (VLTI); Member of the Astronomische Gesellschaft and of the Deutsche Physikalische Gesell-schaft; Member of the Deutsche Akademie der Naturfor-scher Leopoldina (Chairman for Astrophysics); Member of the Berufungskommission Professur für Astrophysik, ETH, Zürich

T. Herbst: Member of the MPIA PhD Thesis Advisory Committee

F. Huisken: Member of the International Advisory Committee of the "International Symposia on Rarefied Gas Dynamics" (RGD); Member of the International Advisory Board of the Romanian Conference Series "ROMOPTO"

K. Jäger:PR-Responsile of the LBT-Board and member of the LBT PR-Committee

H. Klahr: Member of the MPIA PhD Thesis Advisory Committee

U. Klaas: Member of the HERSCHEL Calibration Steering Group as representative of the PACS Instrument Control Centre Calibration Working Group, Chairman of the Library Committee

K. K. Knudsen: Member of the Scientific Committee of the Instrument Center for Danish Astrophysics

M. Kürster: Member of the Organizing Committee for the Creation of IAU Commission 53, "Extrasolar Planets"

R. Launhardt: Member of the Council of the Ernst Patzer Stiftung

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

R. Lenzen: Member of the MPG Time Allocation Committee for the 2.2 m telescope at La Silla

A. Pasquali: Member of the ESO panels

H.-W. Rix: Chairman of the Advisory Council of the Astrophysikalisches Institut Potsdam (AIP); Member of the Large Binocular Telescope Corporation (LBTC) Board and of the Large Binocular Telescope Beteiligungsgesellschaft (LBTB) Board; Member of the JWST / NIRSPEC Science Team; Member of the BMBF Reviewing Committee "Astrophysics and Astroparticle Physics"; Member of the DFG Fachkollegien; Member "at large" of the ASTRONET Infrastructure Roadmap Working Group

H.-J. Röser: Member of the MPG Time Allocation Committee for the 2.2 m telescope at La Silla; Member of the MPIA PhD Thesis Advisory Committe

E. Schinnerer: Proposal Referee for the SPITZER Space Telescope (cycle 4); Member of the Erich Patzer Prize Committee, MPIA

J. Staude: Member of the Jury at the national contest "Jugend forscht"

F. Van den Bosch: Member of the Science Policy Oversight Committee for PanSTARRS1

S. Wolf: Member of the Selection Committee at the Centro di Astrofisica de la Universidade de Porto (CAUP) for advanced Postdocs and high-level Researchers; Member of the Strategic Time Allocation Committee (STAC) at the MPIA; Organizer of the Research Program for Undergraduate Students (Miniforschung)

F. Walter: IRAM Program Committee (chair); NRAO User's Committee (member); MPIA Strategic Time Allocation Committee (member)

Further Activities

In the Advanced Practical Course in Physics at the University of Heidelberg, Stefan Birkmann, Martin Hennemann and Jutta Stegmaier were responsible for the experiment "FP30 – CCD photometry", Stefan Hippler, Felix Hormuth, Anders Johansen, and Daniel Meschke were responsible for FP36 – wavefront analysis with a Shack-Hartmann sensor".

The Undergraduate Research Projects (Miniforschungsprojekte) at the MPIA were organized by Sebastian Wolf, with the help of numerous colleagues.

Girls' Day (April 26) at MPIA was organized by Stephan Birkmann, Eva Meyer, Eva Schinnerer, and Jutta Stegmaier.

Two practical courses for schoolboys and -girls (BOGy) were organized by Klaus Meisenheimer, with the help of Nadine Neumayer, Jutta Stegmaier, and many others.

The public lecture series "Astronomy on Sunday Morning" at MPIA (June 10 – July 29) was organized by Klaus Jäger, Jakob Staude and Jutta Stegmaier, with the help of many others.

The "Night in Science" (November 10) at the MPIA organiziert by Klaus Jäger, Coryn Bailer-Jones, Stephan Birkmann, Jeroun Bouwman, Helmut Dannerbauer, Ulrich Grözinger, Martin Hennemann, Tobias Junginger, Oliver Krause, Markus Nielbock, Silvia Scheithauer, Jutta Stegmaier and many others, as well as by B. Feuerstein (MPIK) and Holger Mandel (LSW)

In the course of the year, 650 visitors in 26 groups were given a guided tour through the MPIA (Axel Quetz, Stephan Birkmann, Cassandra Fallscheer, Patrick Weise, and others). Klaus Jäger organized several special guided tours, e.g. for "Baden-Württemberg International, Society for International Economic and Scientific Cooperation", ‚January 29; Stift Neuburg, February 13; Guests from SUBARU Telescope, March 9.; International Max Planck Research School, August 30; Förderkreis Planetarium Göttingen, October 28; Advisory Board and Executives of the Max Planck Society, October 9 (with M Kürster, T. Herbst, O. Krause, R. Lenzen, and others); Heidelberg major Bürgermeister Gerner with guests of the Swiss Rotary Club, November 17.

Ten press releases were published, numerous radio and TV interviews were given, including to RadioEins/MDR, ZDF-Heute Journal, Deutsche Welle-TV, and a new flyer for public outreach was prepared (Klaus Jäger, Axel M. Quetz, Jakob Staude)

Roland Gredel was Visiting Professor at the Université Louis Pasteur in Strasbourg (July).

Klaus Jäger contributed to the organization of the public lecture series "Astronomie in Heidelberg" at the Planetarium Mannheim.

Martin Kürster served as referee for Astronomy & Astrophysics.

Rainer Lenzen was security officer (scientists) and representative of the disabled persons at MPIA.

Markus Nielbock participated to the "Initiativkreis für Horizontastronomie im Ruhrgebiet" for the promotion of astronomical culture (25. – 29.06.); he also helped in performing a practical Astronomy course at the Pädagogische Hochschule Zentralschweiz Luzern, and at the Observatory "Hoher List".

Jakob Staude, assisted by Axel M. Quetz, edited the 46. annual volume of the monthly astronomy magazine "Sterne und Weltraum".

Sebastian Wolf organized the program "Miniforschung" for students at MPIA.

Prizes

Eric Bell received the Heinz Maier Leibnitz Prize of the German Research Foundation

Henrik Beuther received the Ludwig Biermann Prize of the Astronomical Society

Fabio Fontanot received the Tacchini Award of the Italian Astronomical Society for PhD Thesis work.

Anders Johansen, Boris Häußler, and Konrad Tristram received the Ernst Patzer Prize

Nicolas Martin received the Thesis prize from the "Société des amis des Universités de l'académie de Strasbourg" for one of the best theses defended in one of the universities of Strasbourg in 2006 (awarded in 2007)

Benjamin Moster received the Otto Haxel Prize of the University of Heidelberg

Dominik A. Riechers: PhD Summa cum laude, Awarded a Hubble Postdoctoral Fellowship at Caltech for the research project: "From the Epoch of Reionization to the Peak of Galaxy Formation: Properties of Intensely Star-Forming Galaxies in the Early Universe" (2007-2010)

Compatibility of Science, Work, and Family

In the course of the last year, more measures were implemented at the MPIA to improve the compatibility of work and family. In addition to the existing "baby office" for young scientists and researchers, the creation of opportunities for family-related telework, work-at-home, and the improvement of information exchange on the issue of compatibility of work and family, the MPIA's own daycare room was set up. The MPIA now also shares entitlement to a total of 20 crib and kindergarten places with the other Max-Planck Institutes in Heidelberg. The 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 MPIA 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 MPIA are permanently upgraded in order to further improve the boundary conditions for research here.

Cooperation with Industrial Companies

4D electronic GmbH, Bretten
AB multimedia GmbH, Oberding
ABB (ehem. Hartmann+Braun), Alzenau
ADR, Paris
Advanced Office, Bochum
Abacus Deltron GmbH, Unterhaching
Agilent Technologie, Böblingen
Allice Messtechnik GmbH, Frankfurt
allSMT GmbH&Co.KG, Roetgen
Almet-AMB, Mannheim
Alternate, Linden
America II Europe GmbH, Mönchengladbach
Amphenol AIR LB GmbH, Saarlouis
AmpPower GmbH, Bad Homburg v.d.H
Angst+Pfister, Mörfelden
APE Elektronik, Kuppenheim

Arlt Computer, Magstadt
Arrow Central Europe GmbH, Dreieich
Arthur Henninger, Karlsruhe
ASKnet, Karlsruhe
ASYS Prozess- und Reinraumtechnik, Dornstadt
Auer Paul GmbH, Mannheim
Axsys technologies, Rochester Hills
bacuplast GmbH
Baier Digitaldruck, Heidelberg
Barth, Leimen
Bechtle, Neckarsulm
Bectronic GmbH, Derschen
BECK GmbH & CO, Nürnberg
BEHA, Glottertal
Best Power Technology, Erlangen
Beta Layout, Arbergen
Binder Elektronik GmbH, Sinsheim
Binder Magnete, Villingen-Schwenningen
biw Isolierstoffe GmbH, Enneptal
Blaessinger, Stuttgart
Böllhoff GmbH, Winnenden
Börsig GmbH, Neckarsulm
Bohnenstiel, Heidelberg
Bubenzer Bremsen, Kirchen-Wehrbach
Buerma Werner Machauer KG, Stuttgart
BueroMix, Mannheim
Bürklin OHG, München
C&D Technologies (Datel) GmbH, München
C&K Components, Neuried b. München
Cancom Frankfurt, Bad Homburg
Cargopack, Mannheim
CAB, Karlsruhe
CAMCenter GmbH
CAP CNC+Coating Technik, Zell. a. H.
C. Bruno Bayha GmbH, Tuttlingen
Cadillac-Plastic, Viernheim
Carl Roth, Karlsruhe
Carl Zeiss 3D Automation GmbH
Carl Zeiss, Optronics GmbH
Caspar Gleidlager GmbH
CEF, Heidelberg
Cherry Mikroschalter, Auerbach
Christiani, Konstanz
Clear Screen (CLS), Mannheim
Coating-Plast, Schriesheim
Com Pro, Stuttgart
Compumess Electronik, Unterschleissheim
ComputaCenter, Kerpen-Sindorf
Comtronic GmbH, Heiligkreuzsteinach
Conrad Electronic GmbH, Hirschau
Contag GmbH, Berlin
Creasco GmbH, Gilching
Cryophysics, Darmstadt
Dannewitz, Linsengericht
db electronic Daniel Böck GmbH, Ehringshausen
DDC Elektronik GmbH, München
DELL-Computer GmbH, Frankfurt
Delta-V, Wuppertal
Deltron Components GmbH, Neuried b. München
Deti, Meckesheim
Digi-Key, Enschede
Dicronite U.T.E Pohl GmbH
DMG-Service, Pfronten
DPV Elektronik Service GmbH, Eppingen
druckerDruck, Bietigheim
Dürkes & Obermayer GmbH, Edingen-Neckarhausen
Dyna Systems NCH, Mörfelden-Walldorf
e2v, Gröbenzell
EBARA Pumpen, Dietzenbach
EBJ, Ladenburg
EBV-Elektronik, Leonberg
EC Motion, Mönchengladbach
Edsyn Europa, Kreuzwertheim
EFH, Neidenstein
Eldon, Büttelborn
Electronic Product Services Li, Düsseldorf
electronic sensor+resistor Gmb, Ottobrunn
Elektronikentwicklung und Datenverarbeitung (EDO), Hockenheim
Elna Transformatoren, Sandhausen
elspec, Geretsried
ELV Electronic, Leer
EM TEST GmbH, Kamen
Engineering Design Team, USA, Beaverton
ERNI Electronics GmbH, Adelberg
ERSA GmbH, Wertheim
eurodis Enatechnik, Quickborn
Euromicron GmbH, Mittenaar 3
Europa-Lehrmittel, Verlag
Eurostor, Filderstadt
EWF, Eppingen
Faber Industrietechnik GmbH, Mannheim
Fairchild Imaging, Miltitas, USA
Farben Specht, Bammental
Farnell GmbH, Oberhaching
Farnell Electronic Services, Möglingen
Farnell in One, Deisenhofen
Faulhaber GmbH & Co KG, Schönaich
FCT Electronic, München
Fels Spedition, Heidelberg
Fisba, St. Gallen
Fischer Elektronik GmbH & Co., Lüdenscheid
FlowCAD EDA-Software Vertrieb, Feldkirchen
Fluke Deutschland GmbH, Fellbach
FPS-Werkzeugmaschinen GmbH, Otterfingv
Frank GmbH Frank GmbH
Franke, Aalen
Fresemann Andreas
Fritz Faulhaber, Schönaich
Future Electronics Deutschland, Unterföhring
GAD GmbH
Ganter, Walldorf
Gehrckens C. Otto GmbH, Pinneberg
Geier Metall-u. Stahlhandel, Mannheim
Genoma Normteile, Hameln
Gerwah Päzision GmbH
GFI Elektro GmbH, Heidelberg
Glenair Electronic GmbH, Steinbach
GLT, Pforzheim
Göbel, Horst, Ludwigshafen
Goodfellow
Gould Nicolet Meßtechnik, Dietzenbach
Grandpair, Heidelberg
Grulms-Pneumatik, Grünstadt
GRW, Würzburg
Gummi Körner, Eppelheim
Gummi-Plast Schild, Gernsheim
Gutekunst, Pfalzgrafenweiler
Häcker, Weinsberg
Häfele Leiterplattentechnik, Schrießheim
Hahn u. Kolb GmbH, Stuttgart
Handelsvertretung Schaffland, Leverkusen
Hasberg Schneider GmbH, Bernau/Chiemsee
Heidenhain Dr. Johannes GmbH, Traunreut
Helukabel GmbH, Hemmingen
Hema, Mannheim
Herz, Leister Geräte, Neuwied
Heuser GmbH, Heidelberg
Hewlett-Packard Direkt GmbH, Böblingen

Hilger und Kern, Mannheim
Hilma-Römheld GmbH, Hilchenbach
HKi GmbH, Weinheim
HM Industrieservice, Waghäusel
Hoffmann, München
Hoffmann Nürnberg GmbH, Nürnberg
Hommel-Hercules Werkzeughandel, Viernheim
Hormuth, Heidelberg
Horn, Stutensee
Horst Göbel, Ludwigshafen
Horst Pfau, Mannheim
HOT Electronic, Taufkirchen
HTF Elektro, Mannheim
Huber+Suhner GmbH, Taufkirchen
Hummer+Rieß, Nürnberg
Igus GmbH, Köln
IBF Mikroelektronik, Oldenburg
Ineltek, Heidenheim
Infrared Labs, Tucson
Ingenieurbüro Steinbach, Jena
Inkos, Reute i.Breisgau
Invent GmbH
iSystem, Dachau
Ixxat Automation GmbH, Weingarten
Jacobi Eloxal, Altlussheim
Jarmyn, Limburg
Joisten+Kettenbaum, Bergisch Gladbach
Jumo GmbH & Co. KG, Fulda
JS-Gruppe, Hamburg
Kaiser+Kraft GmbH
Kaufmann, Crailsheim
KDM Ingenieurbüro, Brombachtal
Kerb-Konus-Vertriebs-GmbH, Amberg
Kniel GmbH, Karlsruhe
Knürr AG, Arnstorf
Knürr, München
Koco Motion GmbH, Dauchingen
Koelblin-Fortuna-Druck, Baden Baden
Kurt Norr & Co
KVT Canespa, Langenhagen
Labelident GmbH, Schweinfurt
Laflo Reinraumtechnik GmbH
Lagra Elektrotechnik GmbH, Neckargemünd
Lambda Electronics, Achern
Lapp Kabel GmbH, Stuttgart
Laser Components
Layher, Güglingen
Lehner Elektrotechnik, Birkenheide
Lemo Electronik, München
Lemo Elektronik GmbH, München
Leunig GmbH, Leinfelden-Echterdingen
Lineartechnik, Korb
Linux Land, München
LPKF CAD/CAM Systeme, Garbsen
LWS-Technik GmbH & Co.
Macrotron, München
Mädler, Stuttgart
Mankiewicz, Hamburg
Master-productions GmbH, Aystetten
MathWorks, Ismaning
Matsuo Electronics Europe, Eschborn
Matsushita Automation, Holzkirchen
Max Computer GmbH, Schönberg
Maxim GmbH, Planegg
Meilhaus Electronic GmbH, Puchheim
Memec Express, Unterhaching
Menges electronic, Dortmund
Mentor, Erkrath
Metabowerke GmbH, Nürtingen
Metrofunkkabel-Union GmbH, Berlin
Mitsubishi-Electric, Weiterstadt
Mobotix AG, Kaiserslautern
Mönninghoff, Bochum
Moll, Bleche und Verarbeitung, Hirschberg
Moxa Europe GmbH, Unterschleissheim
MSC Vertriebs GmbH, Stutensee
MTI GmbH, Baden-Baden
MTS Systemtechnik GmbH, Mertingen
Müller Elektronik, Friedrichshafen
Munz, Lohmar
Mura Metallbau, Viernheim
Nanotec, Finsing
Neolab Laborbedarf, Heidelberg
Newport, Darmstadt
Nickel Schalt- und Messgeräte, Villingen-Schwenningen
Niedergesess, Sandhausen
Nies Elektronic GmbH, Frankfurt
Noesse Datentechnik, Leverkusen
Noor, Viernheim
Nova Electronik, Pulheim
Oberhausen, Ketsch
OpenStorage, Wiesbaden
Otto Faber, Mannheim
Otto Ganter, Furtwangen
Orglmeister
Owis GmbH, Staufen
Oxford Instruments GmbH, Wiesbaden
Parametric Technology, München
Parcom, CH-Flurlingen
pbe Electronic, Elmshorn
PCE Group oHG
Pfeiffer Adolf GmbH, Mannheim
Pfister Büro
Phoenix Contact GmbH & Co., Blomberg
Pro~Com, Eislingen
Physik Instrumente GmbH, Karlsruhe
Phytec Messtechnik, Mainz
Phytron, Gröbenzell
Plastipol, Runkel
Prout Services+Handware GmbH, Darmstadt
PSC, Saarbrücken
PSI Tronix, Tulare, California, USA
Pühl A. GmbH
Püschel Electronik, Mannheim
Quarzglas-Heinrich, Aachen
Regional Electronic Distribution, Rodgau-Jügesheim
Radiall, Rödermark
Räder Gangl, München
Rala, Ludwigshafen
Rau-Meßtechnik, Kelkheim
Reeg, Wiesloch
Reichelt Elektronik, Sande
Reinhold Halbeck, Offenhausen
Rexel Deutschland HTF, Mannheim
Reith, Mannheim
Riekert & Sprenger, Wertheim
Retronic, Ronneburg
Rexim, Maulbronn
Riegler & Co. kG
Riekert & Sprenger, Wertheim
Rittal GmbH+Co. KG, Herborn
Roland Häfele Leiterplattentechnik, Schriesheim
Roth Carl GmbH & Co.KG, Karlsruhe
RS Components GmbH, Mörfelden-Walldorf
RSP GmbH, Mannheim
Rütgers, Mannheim
Rudolf, Heidelberg
RUF Elektrohandel GmbH & Co.KG, Mannheim
Rufenach Vertriebs-GmbH, Heidelberg
Scantec GmbH, Germering
Schaffner Elektronik, Karlsruhe
Schlossmacher Ingenieurbüro
Schrauben-Jäger AG
Schraubenladen, Villingen-Schwenningen
Schroff GmbH, Straubenhardt
Schuricht Distrelec GmbH, Bremen
Schulz Bürozentrum GmbH
Schuricht, Fellbach-Schmiden
Schwab Holz-Zentrum
Schweizer Elektroisolierungsstoffe, Mannheim
SCT Servo Control Technology, Taunusstein

SE Spezial-Electronic AG, Bückeburg
Seifert mtm Systems, Ennepetal
Segor Electronics GmbH, Berlin
Seifert mtm Systems, Ettlingen
SEW Eurodrive, Bruchsal
Siegburg Spectra Computersysteme GmbH
Siemens IC-Center, Mannheim
Sigmann Elektronik GmbH, Hüffenhardt
SolidLine AG, Wiesbaden
Spaeter, Viernheim
Spezial Elektronik AG, Bückeburg
Sphinx, Laudenbach
Sphinx Connect GmbH, Stuttgart
Spindler & Hoyer, Göttingen
Spoerle Electronic, Dreieich
Stahlschlüssel Wegst GmbH
Steinbach M. Ingenieurbüro
Stöhr Armaturen, Königsbrunn
StraSchu Leiterplatten GmbH, Oldenburg
Suco-Scheuffele, Bietigheim-Bissingen
Synatron, Hallbergmoos
Tandler, Brauen
Tautz GmbH, Gladbeck
Teldix GmbH, Heidelberg
Team Arrow, Untereisesheim
Teseq GmbH, Berlin
THK, Düsseldorf
Thorlabs, Grünberg
ThyssenKrupp Schulte
TMS Test- und Meßsysteme, Herxheim/Hayna
TopCart, Erzhausen
Tower Electronic Components, Schriesheim
transtec AG, Tübingen
Trivit AG, Ravensburg
TS-Optoelectronic, München
TWK-Elektronik, Karlsruhe
Vacuumschmelze, Hanau
VBE Baustoff+Eisen, Heidelberg
Vereinigte Baustoff-und Eisen GmbH
Vero Electronics, Bremen
Vision Engineering LTD, Emmering
Vision Systems GmbH, Norderstedt
W. & W. Schenk, Maulbronn
Wamser Buero Service, Mannheim
Werner Bauer GmbH & Co., Heilbronn
Wiesemann u. Theis GmbH, Wuppertal
Wietholt Heinrich GmbH
Wikotec, Bramsche
Wilhelm Gassert, Schriesheim
WS CAD Electronik, Berk Kirchen
Witter GmbH, Heidelberg
WIKA, Klingenberg
Würth Elektronik GmbH & CO. KG, Künzelsau
Yamaichi Electronics, München

Conferences, Scientific, and Popular Talks

Conferences Organized

Conferences Organized at the Institute

Meeting with LBTO representatives on the progress of LINC-NIRVANA and LBT software development, MPIA, January 24 – 25 (Martin Kürster)

LBT and consortium internal LINC-NIRVANA Software Delta Design Review, MPIA, January 31 (Martin Kürster)

4th MPIA Student Workshop, March 24 – 31, Dorio, Lago di Como (Martin Hennemann, Jutta Stegmaier, Florian Rodler)

LINC-NIRVANA consortium meeting, Padova (Italy), March 28 – 29 (Martin Kürster)

Calar Alto Colloquium, MPIA, May 2 – 3 (Klaus Jäger)

Meeting on the "Astronomy Year 2009", MPIA, May 9 – 10 (Jakob Staude)

Meeting with LBTO representatives on the progress of LINC-NIRVANA and LBT software development, MPIA, May 10 – 11 (Martin Kürster)

Wokshop on LBT Laser Guide Stars, MPIA, May 12 – 13 (Wolfgang Gässler)

Ringberg Workshop "The Impact of AGN Feedback on Galaxy Formation", May 20 – 26, Ringberg Castle (Rachel Somerville, Klaus Meisenheimer, Hans-Walter Rix, Fabio Fontanot, Andrea Macciò)

THINGS team meeting, Hirschhorn, May (Fabian Walter)

Meeting "Chemistry in Disks", MPIA, July 4 – 5 (Dmitri A. Semenov)

LINC-NIRVANA topical meeting on flexure tracking (1) and on assembly, integration and tests, MPIA, July 11 – 13 (Martin Kürster)

Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16-20 (LOC: Eric Bell, Anna Pasquali, Jochen Heidt (chair), Hans Hippelein, Klaus Jäger, Hans-Walter Rix, Christian Tapken; SOC: Klaus Meisenheimer, Somerville and others)

SPITZER Workshop, Heidelberg, July 18 – 20 (Jeroen Bouwman, Thomas Henning)

IMPRS Summerschool "The Milky Way Galaxy", Heidelberg, August 29 until September 5 (Christian Fendt)

LINC-NIRVANA topical meeting on flexure tracking (2), MPIA, September 4 (Martin Kürster)

Conference "Massive Star Formation: Observations confront Theory", Heidelberg, September 10 – 14, (Henrik Beuther, Thomas Henning, Maria Jannssen-Bennynck, Stefan Brinkmann, Cassie Falscheer, Maiken Gustafsson, Martin Hennemann, Thomas Henning, Hendrik Linz, Frank Richter, Boyke Rochau, Javier Rodon, Fylke Schmidt, Jürgen Steinacker)

Scientific Advisory Council, MPIA, October 8 – 9 (Klaus Jäger, Thomas Henning, Hans-Walter Rix)

LINC-NIRVANA consortium meeting, MPIA, October 15 – 16 (Martin Kürster)

MIRI European Consortium Meeting CD n. 10, MPIA, Heidelberg, October 24 – 26 (Oliver Krause)

Ringberg Conference "Astronomy with Laser Guide Star, Adaptive Optics", Schloss Ringberg, October 29 – November 2 (Wolfgang Brandner, Thomas Henning, Hans-Walter Rix, Stefan Hippler)

European Workshop NanoLum VII, Laboratory Astrophysics Group of the MPIA at the Friedrich-Schiller-Universität Jena, November 5 – 6 (Friedrich Huisken)

STAGES workshop, MPIA, November 5 – 7 (Eric Bell and Anna Gallazzi)

Retreat of the Galaxies and Cosmology Department, Schloss Ringberg, December 3 – 6 (Jelte de Jong)

External retreat of the Scientific Advisory Committee, Edesheim, Dezember 10 – 11 (Klaus Jäger)

Other Conferences Organized:

Coryn Bailer-Jones: Second Meeting of the GAIA Data Processing and Analysis Consortium Coordination Unit 8 (Astrophysical Parameters), Uppsala, June 14 – 15 (Chair); Third meeting of the GAIA Data Processing and Analysis Consortium Coordination Unit 8 (Astrophysical Parameters), Athens, December 13 – 14 (Chair)

Eric Bell: "A New Zeal for Old Galaxies", New Zealand, March (SOC), "Formation and Evolution of Galaxy Disks", Rome, October 1 – 5 (SOC)

Thomas Henning: DARWIN Meeting, Orsay, December 6 – 7

Ralf Launhardt: IAU Symposium 248 "A Giant Step: from Milli- to Micro-arcsecond Astrometry", Shanghai, 15 – 19 (SOC member)

Anders Johansen coorganised the Pencil Code User Meeting 2007 in Stockholm, August 14 – 17

Eva Schinnerer: 4th SPITZER Science Conference "The Evolving ISM in the Milky Way and Nearby Galaxies"

Jürgen Steinacker: SOC member of the ESO workshop n. 12 "Questions on Star and Massive Star Cluster Formation", Garching, July 3 – 6

Fabian Walter: splinter meeting "The Evolution of the ISM through Cosmic Times" at the Annual Meeting of the AG, Würzburg, September 24 – 28

Conferences and Meetings Attended, Scientific Talks and Poster Presentations

M. Arnold: International Conference on Molecules in Space & Laboratory, Paris, May 14 – 18 (poster)

Coryn Bailer-Jones: 2nd Meeting of the GAIA Data Processing and and Analysis Consortium Executive meeting, Brussels, January 26 – 27; "Data analysis, machine learning and applications" conference, Freiburg, March 7 – 9 (talk); 3rd meeting of the GAIA Data Processing and Analysis Consortium Executive meeting, Heidelberg, May 17 – 18; "Astronomical Data Analysis Software and Systems" conference, London, September 23 – 26 (talk, three posters); 4th meeting of the GAIA Data Processing and and Analysis Consortium Executive meeting, Torino, October 1 – 2

Eric Bell: German-Israeli Foundation Network on Galaxies workshop, 11 – 16 April; STAGES collaboration meetings, Nottingham, June 18 – 20, MPIA, November 5 – 7, PanSTARRS collaboration meeting, Baltimore, July 30 – Aug 2

Stephan Birkmann: Conference "Massive Star Formation", September 10 – 14, MPIA, Heidelberg; JWST Partner Workshop, June 11 – 12, Dublin; SPIE Optics and Photonics, San Diego, California, August 26 – 30 (talk)

Kris Blindert: "Tracing Cosmic Evolution with Clusters of Galaxies: Six Years Later" Sesto, Italy, 25 – 29 June (talk); "Galaxy Growth in a Dark Universe" Heidelberg, July 16 – 20 (talk)

Steve Boudreault: Annual Meeting of the Astronomical Society, Würzburg, September 24 – 28 (Poster)

Jeroen Bouwman: PACS Consortium Meeting no. 29, MPE, Garching, Jan 19; PSF group Workshop, Dornburg/ Jena, Oct 14 – 17 (talk); 5th Planet Formation Workshop, Braunschweig, September 19-21 (talk); PACS Consortium Meeting no. 31, MPE, Garching, Germany, Nov 7; Workshop "Environnement des systemes stellaires jeunes", UJF, Grenoble, December 5 (talk)

José Caballero: II. Workshop AstroCAM, JÛvenes astrofÌsicos de la Comunidad de Madrid, Villaviciosa de OdÛn, Madrid, September 19 – 21 (Poster)

Andres Carmona Gonzalez: The 24th. Jerusalem Winter School in Theoretical Physics: The Lives of Low-mass Stars and their Planetary Systems, Jerusalem, December 27 – January 5 (talk); VLTI Summer School on Circumstellar Discs and Planets at Very High Angular Resolution, Porto, May 28 – June 8 (poster); IAU Symposium 249 "Exoplanets: Detection, Formation and Dynamics", Suzhou, China October 22 – 26 (poster)

Helmut Dannerbauer: Conference: "The origin of galaxies: exploring galaxy evolution with the new generation of infrared-millimetre facilities", Obergurgl, Germany, March 24 – 29 (talk): PACS Consortium Meeting no. 30, IFSI, Frascati, Italy, Jul 6 – 7; Conference: "From IRAS to HERSCHEL / PLANCK: Cosmology with infrared and submillimetre surveys", London, July 9 – 11; Conference: "Galaxy Growth in a Dark Universe", Heidelberg, July 16 – 20 (poster); AG Tagung, Würzburg, September 24 – 28 (poster); MIRI European Consortium Meeting CD no. 10, MPIA, Heidelberg, October 24 – 26

Jelte de Jong: SDSS collaboration meeting, Philadelphia, March 29 – April 1 (talk); Conference "The Milky Way Halo – Stars and Gas", Bonn, May 29 – June 2 (talk)

Cornelis Dullemond: Conference in Chamonix on Structure formation in the universe, May (talk); Jahrestagung der Astronomischen gesellschaft, Würzburg, September; Planet Formation Workshop, September (talk)

Sebastian Egner: Workshop "Science with Laser Guide Stars", October 28 – November 2, Ringberg Castle (talk); Seeing Symposium, March 22, Mauna Kea Weather Center, Kona, Hawaii (poster)

Christian Fendt: IAU Symposium 243, "Star-Disk Interaction in Young Stars", Grenoble, May; Workshop: "MHD disk winds, jets, outflows” (JETSET meeting) Heidelberg, March 30 – 31; IMPRS Coordinatoren-Treffen, Munich, October 25 – 26

Fabio Fontanot: Workshop “Galaxy Formation” , Jerusalem, April 11 – 16 (talk); Ringberg Workshop “The Impact of AGN feedback on Galaxy Formation”, May 20 – 26 (talk); X-ray 07 “Evolution of Accretion, Star Formation and Large Scale Structure”, Rhodos, July 2-6 (talk); conference “Galaxy Growth in a Dark Universe”, Heidelberg, July 16-20 (talk)

Wolfgang Gässler: LBT Software Workshop, Florence, October 1 – 2

Anna Gallazzi: STAGES collaboration meeting, University of Nottingham, Nottingham, June 18 – 20 (talk); Conference “Galaxy Growth in a Dark Universe”, Heidelberg, July 16 – 20 (poster)

Dimitrios Gouliermis: HERSCHEL Open Time Key Program workshop, ESTEC, Noordwijk, February 20 – 21 (poster); 41st ESLAB Symposium: The Impact of HST on European Astronomy, ESTEC, Noordwijk, May 29 – June 1 (poster); ESO Workshop: Twelve Questions on Star and Massive Star Cluster Formation, Garching, Germany, July 3 – 6 (talk); IAU Symposium No 246, “Dynamical Evolution of Dense Stellar Systems”, Capri, Italy, September 5 – 9 (talk); International Conference “Massive Star Formation: Observations Confront Theory”, Heidelberg, Germany, September 10 – 14 (poster); Planet and Star Formation Group Workshop, Dornburg Castle, Jena, October 14 – 17 (poster); Galaxies and Cosmology Department Retreat, Schloss Ringberg, December 3 – 6 (talk)

Roland Gredel: OPTICON board meeting, Venice, March 4 – 6; Workshop “Site Testing at Dome C”, Rome, June 11 – 13; Marie-Curie Training Network Meeting, Eastern European Enhancement, Bucharest, June 20 – 23 (talk); OPTICON Mid-Term Review, Corfu, September 7 – 11; Workshop “The Astrophysical Science Cases at Dome C”, Potsdam, September 17 – 18 (two talks); AG-Tagung Würzburg; September 24 – 26 (talk); ARENA Mid-Term Review, Bruxelles, October 22; ARENA CMC Meeting, Paris, 14 December

Maiken Gustaffson: Conference “Structure formation in the Universe”, Chamonix, May 27 – June 1; “Massive star formation: Observations confront theory”, Heidelberg, September 10 – 14 (poster)

Martin Hennemann: Conference “Massive Star Formation”, MPIA, September 10 – 14 (poster); AG Tagung, Würzburg, September 24 – 28 (poster); PSF-Workshop, Jena, Oktober 14 – 17 (talk); MIRI EC Meeting, MPIA, Heidelberg, October 24 – 26

Boris Häußler: MPIA Students workshop, Doria (talk); STAGES workshop, Nottingham, June 18 – 20 (talk)

Stefan Hippler: Conference “Astronomy with Laser Guide Star Adaptive Optics”, Ringberg Castle, October 29 – November 2 (Poster); Various GRAVITY consortium meetings including GRAVITY Phase-A Review Meeting at ESO, Garching, September 5 – 6; PSF Department Meeting in Jena, October 15 – 16 (talk)

Klaus Jäger: Calar Alto Colloquium, MPIA, 1. – 2.Mai; MPG-EU-Seminar (McCarthy) 15. – 16. Mai; Konferenz »Galaxy Growth in a Dark Universe«, Heidelberg, 16. – 20. Juli

Knud Jahnke: MPG Workshop “SNWG selection seminar”, Garching, March 6 (talk); conference “The Impact of AGN feedback on galaxy formation”, Ringberg Castle, May 20 – 26; COSMOS meeting New York, June 11 – 14 (talk); STAGES project meeting Nottingham, June 18 – 20 (talk); conference “Galaxy Growth in a Dark Universe”, Heidelberg, July 16 – 20 (two posters)

Viki Joergens: Conference “Multiplicity in Star Formation”, Toronto, May 16 – 18 (talk); Conference “Extreme Solar Systems”, Santorini, June 25 – 29 (talk); 3rd PSF group workshop, Jena / Dornburg, October 14 – 17 (talk)

Anders Johansen: “From Stars to Planets”, Gainesville, April (talk); PSF Workshop 2007, Jena, October (talk)

Ulrich Klaas: PACS Consortium Meeting#29, MPE, Garching, Germany, 19 Jan; PACS Consortium Meeting #30, IFSI, Frascati, Italy, July 6 – 7; PACS Consortium Meeting#31, MPE, Garching, Germany, November 7

Hubert Klahr: Conference “From Stars to Planets”, Gainsville, FL, April 14 (talk); 5th Planet Formation Workshop, Braunschweig, September 20 – 22 (talk)

Rainer Klement: 37th Saas-Fee Advanced Course of the Swiss Society for Astrophysics and Astronomy: The Origin of the Galaxy and Local Group Mürren, Schweiz, March 4 – 10; Conferencez: Galaxy Growth in a Dark Universe, Heidelberg, July 16 – 20; IMPRS Summer School: The Milky Way Galaxy, Heidelberg, August 29 – September 5; GC Department Retreat, Schloss Ringberg, December 3-6 (talk)

Kirsten K. Knudsen: ASTRON, Dwingeloo, Netherlands, January (seminar); Conference “Galaxy Growth in a Dark Universe”, Heidelberg, July (poster)

Sergey Koposov: SEGUE Meeting, Philadelphia, March 31 – April 1 (talk); SDSS-II Collaboration meeting, Philadelphia, March 29 – 31 (talk); Symposium “Galaxies in the Local Volume” Sydney, July 8 – 13 (talk); Workshop “The Globular Clusters – Dwarf Galaxies Connection”, Ann Arbor, August 27 – 29 (talk)

Oliver Krause: PACS Consortium Meeting #30, IFSI, Frascati, May 24 – 25; MIRI European Consortium Meeting no. 9, ASTRON, Dwingeloo, June 4 – 6; JWST Partner Workshop, June 11 – 12, Dublin; Space Cryogenics Workshop, Cryogenic Society of America, Huntsville / USA, July 11 – 13; Conference “Massive Star Formation”, September 10 – 14, MPIA, Heidelberg (poster); Astrophysics in the Next Decade, Marriott, Tucson, September 24 – 28 (poster); MIRI European Consortium Meeting, MPIA, October 24-26; SPIE Optics and Photonics, San Diego, California, August 26 – 30

Jaron Kurk: “Obscured AGN Across Cosmic Time”, Seeon, June 5 – 8 (talk); “Galaxy growth in a Dark Universe” Heidelberg, July 16 – 20 (talk); “Panoramic Views of Galaxy Formation and Evolution” Hayama, Japan, Dec. 11 – 16 (talk)

Martin Kürster: LBT splinter meeting, Jahrestagung der Astronomischen Gesellschaft, Würzburg, Sept. 24 – 28

Ralf Launhardt: Workshop "Multiplicity in Star Formation", Toronto, May 16 – 18 (talk); IAU Symposium 248 "A Giant Step: from Milli- to Micro-arcsecond Astrometry Shanghai, October 15 – 19 (talk); IAU Symposium 249 "Exoplanets: Detection, Formation and Dynamics", Suzhou, October 22 – 26 (talk)

Dietrich Lemke: Mond Symposium, DGLR Bremen, 14 – 16 March; JWST Partner Workshop, June 11 – 12, Dublin; MIRI Steering Committee Meeting, MPIA, Heidelberg, June 27; AG Tagung, Würzburg, September 24 – 28 (poster); European Space Cryogenics, ESTEC, Noordwijk, November 27 – 30 (talk)

Rainer Lenzen: GRAVITY Meeting, MPE Garching, March 13; E-ELT mid term review meeting, ESO Garching, March 14; ARENA Conference, Tenerife, March 26 – 28; GAVITY kick-off meeting, Garching, May 2-3; DUNE-meeting, Bonn, June 5 – 6; MIDIR-meeting, Leiden, August 29 – 30; GRAVITY meeting, MPE Garching, September 5 – 6; PSF meeting, Jena, October 15 – 17; Pan-STARRS review, Honolulu and Maui, November 1-2; PANIC Preliminary Design Review, IAA Granada, November 21 – 22

Hendrik Linz: "Massive Star Formation: Observations confront theory", Heidelberg, September 10 – 14 (talk)

Nicolas Martin: Workshop "Astronomical Probes of the Nature of Dark Matter", Irvine (USA), 22 – 24 March (talk); Conference "The Milky Way Halo Stars and Gas", Argelander Insitut für Astronomie, Bonn, 29 May – 2 June (talk); Workshop "The Globular Cluster – Dwarf Galaxy Connection", Ann Arbor (USA), August 27 – 29 (talk); International Max Planck Research School 2007 "The Milky Way Galaxy: Dynamics – Evolution – Matter Cycle", Heidelberg, August 29 – September 5 (talk)

Eva Meyer: MPIA Student Workshop, Lago di Como, Italy, March 24 – 31 (talk); 11th Vatican Observatory Summer School, Castel Gandolfo, Italy, June 10 – July 6 (talk); PSF Meeting, Jena, October 15 – 17

Friedrich Müller: ESMATS – The European Space Mechanisms and Tribology Symposium, 19 – 21 September, ESTL, Liverpool / UK (poster)

Nadine Neumayer: Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16 – 20

Marie-Helene Nicol: Calar Alto Colloquium, MPIA, May 1 – 2; Galaxy Growth in a Dark Universe, Heidelberg, July 16-20 (poster); STAGES Workshop, MPIA, November 5 – 9 (talk); Galaxy and Cosmology group retreat Schloss Ringberg, December 3 – 7 (talk); The 1st SUBARU International Conference "Panoramic Views of Galaxy Formation and Evolution", Shonan Village, Japan, December 11 – 16 (poster)

Markus Nielbock: Conference "Massive Star Formation", September 10 – 14, MPIA, Heidelberg (poster)

Dominik A. Riechers: January 5 – 10: 209th Meeting of the American Astronomical Society, Seattle (PhD talk); COSMOS Collaboration Meeting, American Museum of National History, New York, June 11 – 14; Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16 – 20 (Poster)

Hans-Walter Rix: "HSTs cosmological imaging surveys", HST Symposium, Norwijk, Niederlande, May 30 – 31 (talk)

Florian Rodler: Extreme Solar Systems Conference, Santorini, June (poster); PSF workshop, Jena, October (talk)

G. Rouillé: International Conference on Molecules in Space & Laboratory, Paris, May 14 – 18 (talk)

Christine Ruhland: 4th MPIA Student Workshop, March 24 – 31, Dorio, Italy (talk); Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16 – 20 (Poster); IMPRS Summer School "The Milky Way Galaxy", Heidelberg, August 29 – September 5; 6th NEON Observing School, Asiago, September 4 – 17 (talk); STAGES Workshop, Heidelberg, November 5 – 7; Galaxies and Cosmology Department Retreat, Schloss Ringberg, December 3 – 6 (Vortrag)

Marc Schartmann: Workshop "Obscured AGN Across Cosmic Time", Kloster Seeon, June 5 – 8; AG Meeting Würzburg, September 24 – 29 (talk)

Silvia Scheithauer: PSF Workshop, October 14 – 17, Jena (talk); RADECS Conference, September 10 – 14, Deauville / France (poster); ESMATS – The European Space Mechanisms and Tribology Symposium, September 19 – 21, ESTL, Liverpool / UK (poster)

Eva Schinnerer: HERSCHEL Open Time Key Program Workshop, Noordwijk, The Netherlands; COSMOS Team Meeting, New York; "Frontiers of Astrophysics: A Celebration of NRAO's 50th Anniversary", Charlottesville, USA (poster); IAU Symposium 245: "Formation and Evolution of Galaxy Bulges", Oxford, UK (talk); ESO ALMA community day, "Surveys for ALMA", Garching (talk); Workshop "Gas Accretion and Star Formation in Galaxies", Garching" (poster); AG Tagung, Würzburg, LBT Splinter Meting (talk)

Markus Schmalzl: Conference "Massive Star Formation: Observations confront Theory", Heidelberg, September 10 – 14 (poster)

Dmitri A. Semenov: "Chemistry in Disks", Bordeaux, January 31 – February 3 (talk); Molecules in Space and Laboratory, May 14 – 18, Paris (talk and poster); Transformational Science with ALMA, 22 – 24 June, Charlottesville, Virginia (poster); PSF meeting in Jena, 10 – 12 October (talk)

Kester W. Smith: GfKl Meeting, Freiburg, Germany, March 7 – 9 (talk); Milky Way Halo meeting, Bonn, Germany, May 29 – June 2 (poster); ADASS, London, September 23 – 26 (poster)

Jutta Stegmaier: RADECS Conference, 10 – 14 September, Deauville / France (poster); DGLR Symposium "To the Moon and Beyond", Bremen, March 14 – 16; SPIE Optics and Photonics, San Diego, California, August 26 – 30

Jürgen Steinacker: 7th AstroGrid-D workshop at the Technische Universität München, Garching, June 12 (talk)

Christian Tapken: Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16 – 20 (poster); Lyman-α Workshop, Paris, October (talk)

Robert Tubbs: VLTI training school “Circumstellar disks and planets at very high angular resolution”, Porto, Portugal, May 28 – June 8 (talk, poster); IAU Symposium 248 “A Giant Step: from Milli- to Micro-arcsecond Astrometry”, Shanghai, PR China, October 15 – 19 (poster); IAU Symposium 249 “EXOPLANETS: Detection, Formation and Dynamics”, Suzhou, PR China, October 22 – 26 (poster)

Fabian Walter: Meeting of the DFG Priority Program Bad Honneff, January; “HERSCHEL Open Time Key Projects”, Noordwijk, February; NRAO User's Committee meeting, Charlottesville, May; PanSTARRS meeting, Baltimore, July; “ALMA Community Day / ALMA Surveys”, Garching, September

Invited Talks, Colloquia

Coryn Bailer-Jones: 2nd Heidelberg Astronomy Summer School, Heidelberg, September (Lecture on GAIA)

Eric Bell: “Galaxy Growth in a Dark Universe”, Heidelberg, 16 – 20 July (invited talk); “Formation and Evolution of Galaxy Disks”, Rome, 1 – 5 Oct (invited talk); University of Strasbourg, 19 October (invited lecture); University of Leiden, 15 Nov (invited lecture); University of Wisconsin, 31 Oct (invited lecture)

Hendrik Beuther: Jahrestagung der Astronomischen Gesellschaft, Würzburg, September (Biermann prize lecture); Workshop “Star Formation Through Cosmic Time”, Santa Barbara Kavli Institute for Theoretical Physics (invited lecture)

Joe Carson: NASA Ames, November (invited lecture)

Sebastian Egner: SUBARU Telescope, Hilo, Hawaii, 11 December (invited talk)

Fabio Fontanot: Padova Observatory, 22 February (seminar)

Christian Fendt: Conference “High Energy Phenomena in Relativistic Outflows”, Dublin, 24 – 28 September (invited review); EAS Symposium No. 3 “Violent Phenomena in Young Stars”, Yerevan, August (invited review); IAU Symposium 243: “Star-Disk Interaction in Young Stars”, Grenoble, May (invited review); JETSET School & Workshop “Numerical MHD and Instabilities, Visualization techniques and virtual reality”, Torino, January (invited talk)

Anna Gallazzi: University of Oxford, Oxford, November 20 (colloquium)

Dimitrios Gouliermis: Observatory, University of Munich, July 2 (seminar); Max-Planck Institute for Radioastronomy, Bonn, November 23 (colloquium); Argelander-Institut für Astronomie, Bonn, 23 November (seminar); Department of Astronomy, Astrophysics & Mechanics, University of Athens, 18 December (lecture)

Roland Gredel: Observatoire de Strasbourg, July 13 (invited lecture); JENAM, Yerevan, August 20-24 (two invited talks)

Boris Häußler: Lunch talk seminar, univeristy of Nottingham, May 17

Martin Hennemann: Helsinki Observatory, November 21 (colloquium);

Thomas Henning: Joint Astronomy Colloquium Munich, Garching, Januar 25 (invited talk); University of Hamburg, Februar 8 (colloquium); Conference “From Stars to Planets: Connecting our Understanding of Star and Planet Formation”, Gainesville, April 11 – 14 (invited talk); Conference on the “150th Anniversary of Gothardís birth”, Szombathely, May 31 – June 3 (lecture); Nobel Symposium “Physics of Planetary Systems”, Stockholm, June 18 – 22 (invited talk); Meeting “Massive Star Formation: Observations Confront Theory”; Heidelberg, September 10 – 14 (invited talk); 2nd ARENA Conference “The Astrophysical Science Cases at Dome C”, Potsdam, September 17 – 21 (invited talk); KITP, Santa Barbara, November 5 – 16 (Star Formation Through Cosmic Time Program, invited talk); ETH Zürich “Physikalisches Kolloquium”, November 28 (colloquium); Symposium at the Occation of Arne Ardebergís Retirement, Lund Observatory, November 29 (invited talk).

Friedrich Huisken: Fachbereich Chemie der Technischen Universität Kaiserslautern, May 25 (invited talk)

Viki Joergens: Conference “Extreme Solar Systems”, Santorini, June 25 – 29 (invited talk)

Anders Johansen: Astrophysics seminar, Copenhagen University, November; MHD Lunch Seminar, Laboratoire de Radioastronomie ENS, Paris, November; Fachbeirat MPIA, October; Seminar, DAMTP, University of Cambridge, June; Seminar, CITA, University of Toronto, April; Oberseminar, TU Braunschweig, February; Seminar, Sterrewacht Leiden, January; Seminar, Stockholm Observatory, January

Hubert Klahr: Nobel Symposium 135 “Physics of Planetary Systems”, Stockholm June 18 – 22 (invited talk); KITP – Star Formation Through Cosmic Time, Santa Barbara, CA, 30 November (invited talk); Universität Bern, 19 Dezember (Kolloquium)

Dietrich Lemke: “Astronomy from the Moon”, Colloquium Talk, University of Helsinki, June

Hendrik Linz: TLS Tautenburg, October 17 (invited talk)

Nicolas Martin: Institute for Astronomy, University of Hawaii, Honolulu, USA, March 6 (colloquium); UCLA, Department of Physics and Astronomy, Los Angeles, March 26 (colloquium); MPI für Extraterrestrische Physik, Munich, June 5 (colloquium)

Markus Nielbock: HERSCHEL Space Observatory: Status und Wissenschaft, December 11, Ruhr-Universität Bochum (colloquium)

Anna Pasquali: ASU in Tempe/Arizona (invited talk)

Paola Re Fiorentin: University of Ljubljana, Dept. Mathematics and Physics, June 6 (invited lecture)

Dominik A. Riechers: 80th Annual Scientific Meeting of the Astronomische Gesellschaft: "Cosmic Matter", Würzburg, September 24 – 29 (invited talk); Conference "Galaxy and Black Hole Evolution: Towards a Unified View", Tucson, USA, November 28 – 30 (invited talk)

Hans-Walter Rix: Conference "Dynamics of Galaxies", St. Petersburg, August 6 – 9 (invited talk); "Spectroscopy of Lensed Arcs", NIRSPEC IST Meeting, Lyon, Frankreich, November 19 – 20 (invited talk)

Florian Rodler: Institute for Astronomy, University of Vienna, January 30 (invited lecture)

Marc Schartmann: "The Impact of AGN feedback on galaxy formation: theoretical modelling and observational signatures", Ringberg Castle, May 20 – 26 (invited talk)

Eva Schinnerer: Workshop "The Impact of AGN Feedback on Galaxy Formation", Ringberg (invited talk)

Dmitri A. Semenov: ITA seminar, January 17, Heidelberg (talk); Ledien Observatory, December 6, (talk)

Kester W. Smith: 10th Italian Korean meeting on relativistic Astrophysics, Pescara, June 25 – 30 (invited talk)

Jürgen Steinacker: Conference "New Trends in Radiation Hydrodynamics", Stockholm, May 10 (invited talk); Workshop "Tracing Dust in Spiral Galaxies: radiative transfer studies in the dawn of a new generation of observing facilities", Ghent, May 14 (invited talk); ESO Workshop on 12 Questions on Star and Massive Star Cluster Formation, Garching, July 4 (invited talk); Conference "Massive Star Formation: Observations confront Theory", Heidelberg, 11 September (invited talk); Grand Challenge Problems in Computational Astrophysics Reunion Conference II, Lake Arrowhead, 13 December (invited talk)

Frank Van den Bosch: Kavli Institute for Cosmological Physics, February 7 (colloquium); Center for Cosmology and Particle Physics, NYU, New York, February 9 (colloquium); Chicago Conference "Clusters of Galaxies as Cosmological Probes", Aspen Center for Physics, February 12 – 16 (invited talk); Observatoire Strassbourg, March 23 (colloquium); GIF Workshop "Galaxy Formation", Jerusalem & Haifa, Israel, April 12 – 15 (invited talk); Workshop "Modeling Galaxy Clustering" Aspen Center for Physics, June 11 – 29 (invited talk); Aspen Center for Physics, Colorado, June 28 (colloquium); Conference "Galaxy Growth in a Dark Universe", Heidelberg July 16 – 20 (invited talk); Department of Astronomy, University of Massachusetts, Amherst, November 2 (seminar)

Fabian Walter: Cambridge Colloquium, February (invited talk); NRAO 50th Anniversary, Charlottesville, June (invited talk); "Galaxies in the Local Universe", Sydney, July (invited talk); "Gas Accretion and Star Formation in Galaxies' MPA/ESO, Garching, September (invited talk)

Sebastian Wolf: Technical University Berlin (Colloquium); Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), Taiwan (Colloquium); Landessternwarte Heidelberg (Colloquium); Astronomisches Recheninstitut, Heidelberg (Colloquium); University of Heidelberg, Faculty of Physics (Habilitationsvortrag); University Kiel (Colloquium)

Lecture Series

Hubert Klahr: VLTI Summerschool "On the FRINGE", Porto, May 28 – June 8

Martin Kürster: "Extrasolar Planets: Observations", Split International Winter School of Astrophysics (SIWA), Split (Croatia), 19-24 February

Sebastian Wolf: Summer School "Circumstellar Disks and Planets" in the frame of the EU Marie Curie Research Training Network "On the FRINGE", Porto, June (Co-Organization and Teaching); Seminar Series on "Extrasolar Planets", International Academy VIII of the "Studienstiftung des Deutschen Volkes", Rot an der Rot, July (Co-Organization and Teaching)

Popular Talks

Helmut Dannerbauer: "Sternentstehung im jungen Universum", Lecture Series "Astronomy in the Afternoon", Planetarium Mannheim, November 20

Cornelis Dullemond: "Geburtsstätten der Planeten: Gas- und Staubscheiben um junge Sterne", MPIA Lecture Series "Astronomy on Sunday Morning", June 10

Roland Gredel: "Riesenteleskope – Neue Giganten für den Blick ins All", MPIA Lecture Series "Astronomy on Sunday Morning", July 22

Maiken Gustaffson: "Formation of Stars and Planets", Fysikshow Workshop for High School students, Aarhus University, Aarhus, Denmark

Boris Häußler: "Vom Urknall bis heute", Planetarium Mannheim, May 22

Thomas Henning: "Extrasolare Planetensysteme: Die Entdeckung neuer Welten" MPIA Lecture Series "Astronomy on Sunday Morning", July 8

Stefan Hippler: "Warum funkeln die Sterne? – Astronomie mit den modernsten Teleskopen der Welt.", Gießen University, February 17; talk at the Planetarium Mannheim, February 23; Rotary Club, Mosbach, August 6; Robert-Mayer-Volks- und Schulsternwarte Heilbronn, December 14

Klaus Jäger: "Galaxien und Terabytes – Optische Astronomie im Zeitalter moderner Großteleskope", BOGy, MPIA, February 12; "Geheimnisvolle Quasare – einem Rätsel auf der Spur", Planetarium Mannheim, April 17; "Virtuelle Planetarien", Girls' Day, MPIA, April 26; "Galaxien und Terabytes – Optische Astronomie im Zeitalter moderner Großteleskope", Starkenburg-Sternwarte Heppenheim, May 22; "Galaxien und Terabytes – Optische Astronomie im Zeitalter moderner Großteleskope", BOGy, MPIA, October 22

Ulrich Klaas: "Kosmische Katastrophen und Sternentstehung", Planetarium Mannheim, September 18

Hubert Klahr: "Magnetische Stürme und Planeten auf der Wanderchaft", MPIA Lecture Series "Astronomy on Sunday Morning", June 17

Oliver Krause: "Das James Webb Weltraumteleskop – ein neues Fenster zum Kosmos", Planetarium Mannheim, October 5; "Das James Webb Weltraumteleskop – ein neues Fenster zum Kosmos", FH Rüsselsheim, November 16

Christoph Leinert: "Warum ist der Himmel nachts dunkel? – Das Olbers'sche Paradox", Planetarium Mannheim, Oktober 16

Dietrich Lemke: "Der große Orion-Nebel", Planetarium Wolfsburg, February 15; "Zurück zum Mond", MPIA Lecture Series "Astronomy on Sunday Morning", July 1; "Zurück zum Mond", Sternfreunde Nordenham, November 13; "Zurück zum Mond", Rotary Club Schwetzingen/Walldorf, November 8

Hendrik Linz: "Blick ins All bei langen Wellen: Vergangenheit und Zukunft der Radioastronomie", MPIA Lecture Series "Astronomy on Sunday Morning", July 15

Nadine Neumayer: "Schwerkraftmonster in galaktischen Zentren: Wie wiegt man Schwarze Löcher?", MPIA Lecture Series "Astronomy on Sunday Morning", June 24

Sascha P. Quanz: "Auf der Suche nach der zweiten Erde – Planeten und Ihre Entstehung", Jahresvortrag der Astronomischen Vereinigung Weikersheim e.V., Bad Mergentheim, November

Hans-Walter Rix: "Andere Welten, andere Universen? Die Grenzen kosmologischer Schlussfolgerungen", Vortragsreihe "Zukunftsfragen der Gesellschaft", Mainzer Akademie der Wissenschaften und der Literatur, Mainz, February 23; "Das neue Bild der Milchstraße", VHS Rüsselsheim, May 18; "Wie es Licht wurde im Universum", Conference "Galaxy Growth in a Dark Universe", Heidelberg, July 16-20

Hermann-Josef Röser: "Suche nach entfernten Galaxienhaufen", Volkssternwarte Darmstadt, September 29

Florian Rodler: "Das 70-cm-King-Teleskop des MPIA", Die Nacht der Wissenschaft, MPIA, November 10

Jutta Stegmaier: "Sterne, die vom Himmel fallen – die Leoniden kommen", Die Nacht der Wissenschaft, MPIA, November 10

Jürgen Steinacker: "Das ungelöste Rätsel der Sterngiganten", Nacht der Wissenschaft, MPIA, November 10

Sebastian Wolf: "Planeten um unsere Sonne und um andere Sterne", Nacht der Wissenschaft, MPIA, November 10

Publications

In Journals with Referee System

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