Max Planck Institute for Astronomy

Heidelberg-Königstuhl

Annual Report 2005

MAX-PLANCK-GESELLSCHAFT

Cover Picture:

The star forming association LH 95 in the Large Magellanic Cloud. This sharp image reveals a large number of low-mass infant stars coexisting with young massive stars, changing dramatically the picture that we had for stellar associations in the Magellanic Clouds; see chapter III.1.

This image is a part of the Hubble Space Telescope photo obtained by MPIA researchers and presented at the 2006 General Assembly of the International Astronomical Union in Prague, showing observations of with the Advanced Camera for Surveys.

Credits: Nasa, Esa, and Dimitrios A. Gouliermis (MPIA)

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Preface

This Annual Report provides an overview of the research 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 2005 has been an exciting year of new astrophysical discoveries and numerous positive developments at the MPIA. It has brought a rich scientific harvest of previous instrumentation developments. In particular, the MIDI instrument has provided spectacular new results on circumstellar disks and on active galactic nuclei. But also the SPITZER space mission has provided a wealth of new data.

2005 has also seen the arrival of a »new generation« of junior staff scientists: two new heads of research groups and a total of four new »junior research groups« were established at the MPIA. In part as a consequence of this rapid growth, the Institute has embarked on a thorough renovation and the first major expansion of its building.

The MPIA has also seen a number of other »firsts« in 2005. Among them the first year that CAHA was actually operated as a joint and equal Spanish-German operation and the first year of the »International Max-Planck Research School« for Astronomy and Cosmic Physics here in Heidelberg.

The Summer brought an almost overwhelming demonstration of the public's interest in the MPIA's mission and in Astronomy: more than 5000 people came to the open house.

Finally, the year 2005 brought good steady progress on crucial upcoming facilities, the LBT, 2^{nd} generation VLTI instruments and JWST instrumentation. These developments are sure to lay the foundation for future astronomical discovery.

In addition to brief presentations of current scientific results, we report in more depth on selected research fields at the Institute. We will continue these extended reports over the years, so that after several Annual Reports an overall picture of the research profile of our Institute will arise.

In our Annual Reports, we also want to showcase important events that took place at the Institute. At the same time, we let staff members and friends of the Institute get a word in, in order to draw a vivid picture of the working atmosphere at the Institute and of its development in course of time.

We wish the readers of this Annual Report new insights into the astronomical research carried out at our Institute.

Thomas Henning, Hans-Walter Rix

Heidelberg, August 2006

I. General

I.1 Scientific Goals

Understanding our Universe, the nature and evolution of the astronomical objects in it by using the known physical laws is at the heart of astronomy. And this goal has been the heart of the Max-Planck-Institute for Astronomy's mission, since it was established in 1967. To pursue its broad spectrum of astrophysical research, the MPIA has led the development and operation of telescopes and their instrumentation, and has executed a multitude of observing programs along with their analysis as well as theoretical modeling. Not limited to ground-based observing and the visible spectral range, the MPIA has also led space observatory instrumentation and has had a leading role in infrared astronomy. With its observational capabilities focused on survey and optical/IR wavelengths, MPIA is able to be at the forefront in this rapidly developing field.

The research at the institute is organized within two scientific departments: **Galaxies and Cosmology** (director: Hans-Walter Rix) and **Planet and Star Formation** (director: Thomas Henning). In addition to the longterm staff in these departments, there are five independent Junior Research Groups (three Emmy Noether groups supported by the German Science Foundation DFG, and two MPG groups), 37 post-docs and 45 students were working in these fields in the year under report. There is also a close cooperation within the »International Max Planck Research School« (IMPRS) for Astronomy and Cosmic Physics and the University of Heidelberg, e.g, in its activities for the Excellence Initiative.

The main research fields of the two departments have many common aspects both scientifically and practically: Obviously, star formation is closely related to the formation and evolution of galaxies. But also the instrumentation demands of both departments are quite similar.

Fig. I.1: The Max Planck Institute for Astronomy on the Königstuhl Mountain in Heidelberg.

Galaxies and Cosmology

We know that the Universe was rather »simple« and nearly homogeneous right after the Big Bang, yet now boasts 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 cluster of stars, stars and their planets.

The formation of this structure on scales of galaxies and larger can be understood if, and only if, it is assumed to be driven by gravitational instability arising from a dominant, but yet to be identified, dark matter component.

The galaxies we observe in the present-day universe are a central level in this hierarchical order, consisting of 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 qualitative appearance and structure that seem physically possible. For one thing, 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. In contrast to the broad range of parameters, observations have shown, particularly in the last 15 years, that only a tiny 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 quantities strongly correlate with all other quantities: massive galaxies are large; massive galaxies virtually do not contain 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 has 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. When and where any of these three mechanisms plays a role is subject of current research.

Specific questions arising from this overall picture are, e.g.:

- During which cosmologic 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 structure and morphology of galaxies and when does this 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?

The approaches used at 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.

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, 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 controling the onset of star formation remains one of the key open questions which has 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)millimetre 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)millimetre 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-mass stellar regime. Observations with space observatories such as ISO and SPITZER, as well as ground-based infrared and (sub)millimetre 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 millimetre 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 millimetre 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 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. With the detection of the first »Heidelberg« planets we are starting to harvest the fruits of a radial velocity project.

The theoretical programme 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 forms 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 and still is a driver 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 3.5 m telescopes are still scheduled for competitive observing programs. Since 2005 the observatory formally is jointly operated by the Max Planck Society (represented by the MPIA) and the Consejo Superior de Investigaciones Cientificas (CSIC) (represented by the IAA) as Centro Astronomico Hispano-Alemán, an organization of Spanish law.

Since 1997 the MPIA has been the coordinating institute for the German participation in the Large Binocular Telescope (LBT), which is under construction on Mt. Graham near Tucson, Arizona.

The MPIA also has a 2.2m telescope on La Silla, Chile, operated by the European Southern Observatory (ESO), with 25% 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. In many instances, ground- and space-based observations are complementary. Ground-based telescopes usually have larger mirrors and therefore a larger light-gathering power than space telescopes. By using cutting-edge techniques like adaptive optics and interferometry – where the MPIA has played a leading role in the development – they can also

Fig. I.2: The 3.5 m telescope on Calar Alto in its 43m tall dome.

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, e.g., in wide regions of the infrared spectral regime.

Since the pioneer days of infrared astronomy in the 1970s, the MPIA has been a leading instrument developer for this field of astronomy. In particular ISOPHOT, one of four scientific instruments aboard the world's first Infrared Space Observatory ISO of the European Space Agency ESA, was built under the coordinating leadership of the Institute. From 1996 to 1998, ISO Aquired excellent data, particularly in the so far inaccessible far-infrared range. The know-how gained with ISO has enabled the institutes prominent role in new space projects like the HERSCHEL Space Telescope and the James Webb Space Telescope (JWST). At present, astronomers at the MPIA are also actively participating in legacy science programs with SPITZER Infrared Observatory.

The new generations of instruments for 8m-class telescopes and space missions are too large and expensive to be built by a single group, such as the MPIA. At present, the Institute is therefore participating in, or leading a number of international collaborations for building new large telescopes and scientific instruments, thereby gaining access to the world's most important observatories. In the southern hemisphere, this 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, MPIA is participating in the Large Binocular Telescope (LBT) in Arizona. This extraordinary telescope will be equipped with two mirrors of 8.4 m diameter each, fixed on a common mount, making it the world's largest single telescope. In the fall of 2005, the LBT had »first light« with the first of the two primary mirrors. Both collaborations enable MPIA's astronomers to observe the northern and the southern sky with first-class telescopes. At the same time the Institute is participating in studies for the instrumentation of next-generation large telescopes, the so-called Extremely Large Telescopes (ELTs, cf Chapter IV.2).

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

Ground-based Astronomy – Instrumentation

Over the last decade, MPIA has made great efforts in developing adaptive optics systems to achieve diffraction-limited imaging (in the near-IR) from the ground. The construction of the ALFA adaptive optics system at the 3.5 m telescope on Calar Alto was completed in 2001. Currently, this work is continued with the development of a multiconjugate adaptive optics system. First light for the novel wavefront sensor PYRAMIR developed in the adaptive-optics laboratory at the Institute is expected for 2006. Experience gained in this work is already being incorporated into the development of new instruments for the VLT and LBT.

Instrument contributions of the Institute in the ESO Very Large Telescope on Cerro Paranal (Fig. I.3) are of major importance both at the MPIA and ESO. In 2001, the CONICA high resolution infrared camera – forming the NACO system together with the NAOS adaptive optics system – was successfully put into operation.

The construction of a common Laser Guide Star Facility (LGSF) is in its crucial stage, to be used at the NACO and SINFONI instruments at the VLT, both of which are equipped with their own adaptive optics system. The heart of LGSF is PARSEC, a high-performance laser that illuminates the high-altitude sodium layer of the terrestrial mesosphere at 589 nm wavelength, thus providing the adaptive optics systems with a sufficiently bright artificial guide star. Since June 2003, the LIDAR diagnostic instrument built at MPIA is being tested in Garching. Final tests of the total LGSF consisting of PARSEC, a special fiber optics, and the projection telescope took place in the first half of 2005. The first successful operation of the PARSEC laser is also expected for 2006.

The work on ALFA, CONICA and PARSEC has been in close collaboration with the MPE in Garching, combining the expertise of two leading groups.

At the end of 2002, MIDI saw first light. It is the first interferometric instrument at the VLT and is used in the mid-infrared range. Meanwhile, this instrument allowed very successful interferometric observations in the mid-infrared with a resolution of only a few hundredths of an arcsecond. At present, the MPIA is a leader in the development of second-generation VLT/VLTI instruments.

Fig. I.4: Large Binocular Telescope (LBT), located on Mt. Graham in Arizona. (Image: LBTO)

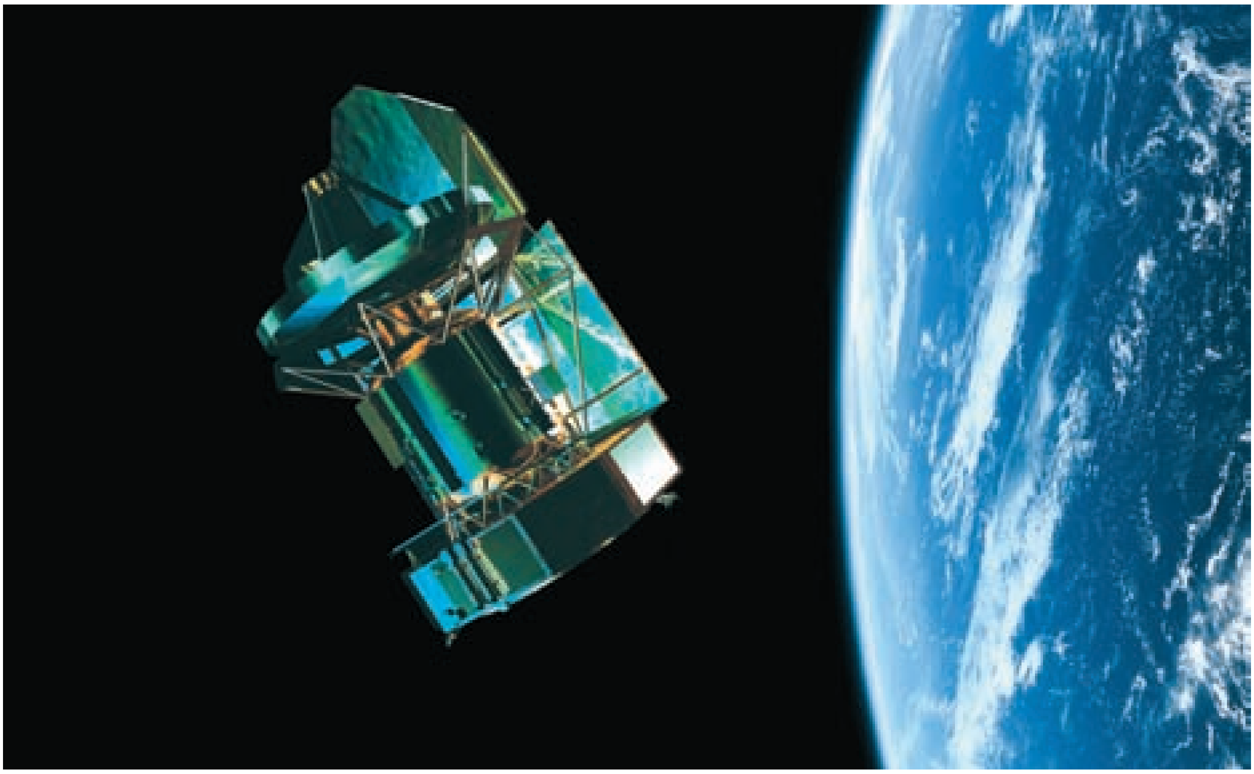


Fig. I.5: The European HERSCHEL Infrared Observatory, to be launched in 2008.

The institute is co-leading in SPHERE (the former PLANET FINDER), aimed at searching and characterizing extrasolar planets with extreme adaptive optics. At the same time, the MPIA, together with institutes in Geneva and Leiden, is developing the »differential delay lines« for the PRIMA system, that enable ultra-precise astrometry. Another project – in collaboration with the Observatoire de Nice – is the extension of the VLT Interferometer, a project called MATISSE (the former MIDI24/APRÉS-MIDI), to combine the light of the four main telescopes of the VLTI, thus allowing image reconstruction.

Together with the University of Arizona as well as Italian and other German institutes, MPIA is a partner in an international consortium which is building the Large Binocular Telescope (LBT, Fig. I.4). This large telescope consists of two mirrors of 8.4 m diameter each, fixed on a common mount. Together, the two mirrors have a light-gathering power equivalent to a single 11.8 m mirror. This will make the LBT the world's most powerful single telescope. Furthermore, the unique design of the double mirror will allow observations with the telescope acting as a Fizeau interferometer. In this mode, the spatial resolution of the LBT will correspond to that of a single mirror 22.8 m in diameter.

Under the leadership of the Landessternwarte Heidelberg, the German partners are building the LUCIFER near-infrared spectrograph for the LBT (Chapter IV.5). MPIA is providing the total detector package and developing the overall design of the cryogenic system. While the integration and tests of the instrument are carried out in the laboratories of MPIA, the planning and building of the LBT interferometer, which will be equipped with an adaptive optics system, is in full swing. MPIA leads the development of LINC (the beam combining, diffraction-limited camera (Chapter IV.4), which ultimately will allow interferometric imaging over a wavelength range between 0.6 and 2.2 μm. For this project, a consortium with colleagues from the Max-Planck-Institut für Radioastronomie in Bonn, the Universität Köln and the Astrophysical Institute in Arcetri near Florence was formed, lead by the MPIA. LINC is currently the largest ground-based instrumental development of the institute.

Space-based Instrumentation

The MPIA continues to lead the ISOPHOT archive effort in the ISO project of the European Space Agency ESA. Meanwhile, numerous papers have been published that are based on ISO measurements and the ISOPHOT instrument built under the coordinating leadership of the Institute. The MPIA runs the ISOPHOT data center where first of all software and calibration procedures for the automated data analysis were developed. The ISO database is planned to be part of a globally accessible »virtual observatory« for all wavelength ranges.

The experience gained with ISOPHOT was decisive for the MPIA's crucial role in the construction of the PACS infrared camera (and spectrometer) (Chapter IV.11). This instrument will operate aboard the European HERSCHEL Infrared Observatory. The launch of this 3.5-m-space-telescope is scheduled for 2007 (Fig. I.5).

The MPIA is the lead institute in Germany for the development of instrumentation for the successor to the HUBBLE Space Telescope, the James Webb Space Telescope (JWST) (Fig. I.6). 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 (Chapter IV.1). This instrument designed for the mid-infrared range from 5–28 μm, 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 (Chapter IV.1), 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 pre-

Fig. I.6: Possible design of the JWST, with the large primary mirror and the characteristic solar screen.

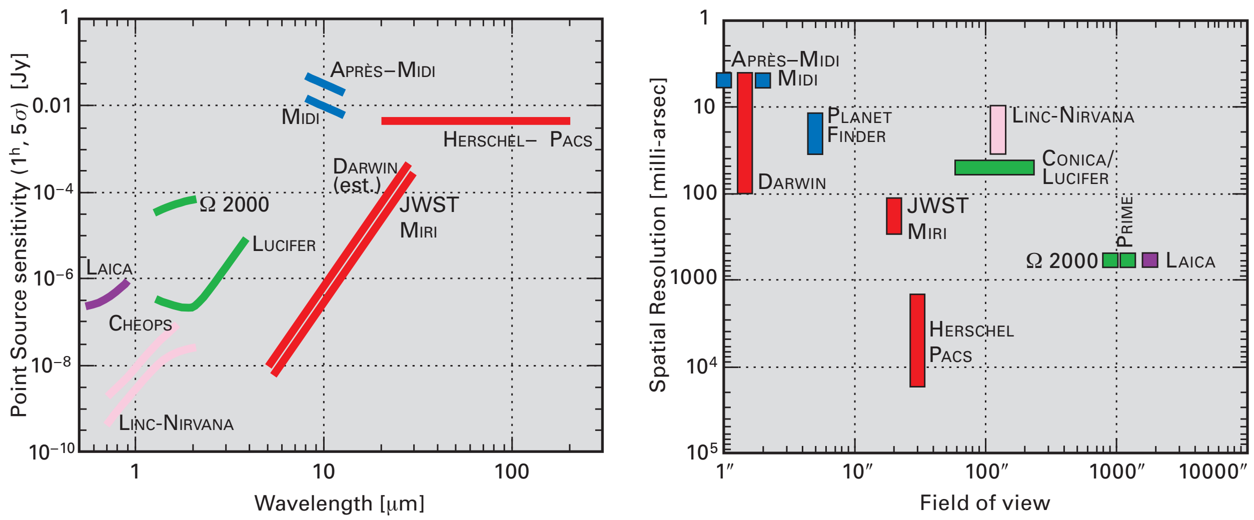


Fig. I.7: The Institute's major instruments. *Left:* sensitivity as a function of wavelength; *right:* spatial resolution as a function of the field of view.

cision-optical hearts of MIRI and NIRSPEC the MPIA is also closely cooperating with Carl Zeiss Optronics, Oberkochen. The MPIA has been representing Germany since 1998 within the DARWIN Science Advisory Team. DARWIN is a space interferometer to be launched by the European Space Agency ESA not before 2015. In the plan it will comprise up to eight telescopes orbiting the Sun at the Lagrangian point L2, at 1.5 million kilometer distance from Earth. This observatory will be used for imaging and spectroscopy of extrasolar planets in the mid-infrared range. At present, the Institute is carrying out preparatory technology studies.

MPIA also contributes to 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. With this the satellite will measure positions, magnitudes and radial velocities of one billion stars plus 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 needs 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).

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

Its location in Heidelberg embeds the MPIA into an exceptionally active astronomical environment. Cooperation with the department Kosmophysik of the MPI für Kernphysik and with the institutes of the Center for Astronomy Heidelberg (ZAH), established on January 1st 2005, are manifold (the ZAH consists of the Landessternwarte, the Astronomische Rechen-Institut, 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 Heidelberg 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 I.4). In addition, MPIA supports the University of Heidelberg in its activities for the Excellence Initiative.

Nationally, cooperation with the MPI für extraterrestrische Physik in Garching and the MPI für Radioastronomie in Bonn as well as with numerous 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 for short), located at MPIA, also emphasizes the Institute's leading role in Germany in this trend-setting astronomical technique. The goal is to coordinate efforts made by German institutes in this field and to request the interests of German 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 (the former APRÉS-MIDI) – 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, was 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. Apart from MPIA, the following institutes are participating in FRINGE: the Astrophysikalische Institut Potsdam, the Astrophysikalische Institut der Universität Jena, the Kiepenheuer-Insitut für Sonnenphysik in Freiburg, the MPI für extraterrestrische Physik in Garching, the MPI für Radioastronomie in Bonn, the Universität Hamburg, and the I. Physikalische Institut der Universität zu Köln.

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

Fig. I.8: Distribution of German partner institutes of MPIA

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

Within OPTICON, the Calar Alto Observatory with its 2.2m and 3.5m telescopes is participating in the COMET program that includes a total of 20 European telescopes. Observing teams from every country of the EU and associated countries that have been allocated observing time at the telescopes by the CAHA Program Committee get free access as well as scientific and technical support in the realization of their observations. For this service, CAHA is compensated financially from OPTICON.

The MATISSE study at MPIA mentioned above is supported by OPTICON and the European Interferometry Initiative (EII), as is the software work on image reconstruction for LINC-NIRVANA (Chapter IV.4).

OPTICON is also supporting a so-called Joint Research Activity (JRA) of MPIA with the Osservatorio Astrofisico di Arceti and the University of Durham and other partners. Within JRA a prototype of a multiple-field-of-view

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

wavefront sensor is being built – a special type of multi-conjugate adaptive optics system. This project is dealing with problems arising with adaptive-optics image field correction for the extremely large next-generation telescopes.

Together with the universities of Braunschweig, Chemnitz, Dresden, Jena, and Leiden, MPIA is participating in the DFG Research Group »Laboratory Astrophysics«. This is field of research is being pursued at 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. Further partners are: University of Durham, Institute for Astronomy in Edinburgh, University of Oxford, University of Groningen, Osservatorio Astronomico Capodimonte in Naples, and ESO in Garching.

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 SIRTF) has started its planned two and a half years 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 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 Colleagues of other institutes, MPIA is responsible for the data reduction of the spectroscopic data. 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. 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.

The Sloan Digital Sky Survey (SDSS) 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-American, Japanese, and German institutes. MPIA was the first, of now 12, European partner institutes in SDSS, the only one to participate since the inception of surveying. In exchange for material and financial contributions to the SDSS from MPIA, a team of scientists at the Institute gets full access to the data. In 2005, the »original« SDSS was completed, but an extension, focusing e.g. on Milky Way structure was approved.

ARENA (Antarctic Research European Network for Astrophysics): This network comprises 21 partners from research and technology from seven European countries and Australia. The goal of this cooperation is the long-term development of the Antarctic (particularly of the site DOME C) for observations in the optical and infrared regime.

I.4 Teaching and Public Outreach

Students are coming from all over the world to the Institute to carry out the research for their diploma or doctoral thesis. A majority of these students complete their studies at the University of Heidelberg. For that reason, a number of scientists at the MPIA give lectures there.

Students of earlier semesters also can do some scientific work at the MPIA. So 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 problems, 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, made a successful start (Chapter V.4) on 2005. The school offers 40 PhD students from all over the world a three year education under excellent conditions in experimental and theoretical research in the field of astronomy and cosmic physics. It is sponsored by the five astronomical research institutes in Heidelberg.

The Institute's mission also includes the educating and informing of the general public about results of astronomical research. So members of the Institute give talks at schools, adult education centers and planetaria. They also appear at press conferences or on radio and television programs, in particular on the occasion of astronomical events which 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 which is very popular among teachers of physics and mathematics in Baden-Württemberg is held regularly in autumn at MPIA.

A special highlight in the year under report has been the open house (Chapter V.2). On September 25th, more than five thousand visitors came to the Institute to inform themselves about the scientific and technical projects of MPIA at a total of 34 stations and to learn news from the field of modern astronomy. In 2005, the MPIA participated again in the Girls' Day, a nationwide campaign intended to encourage schoolgirls to inform themselves about professions that still are mainly male-dominated. At various stations about 60 schoolgirls got a general idea of the work of an astronomical institute (Chapter V.9).

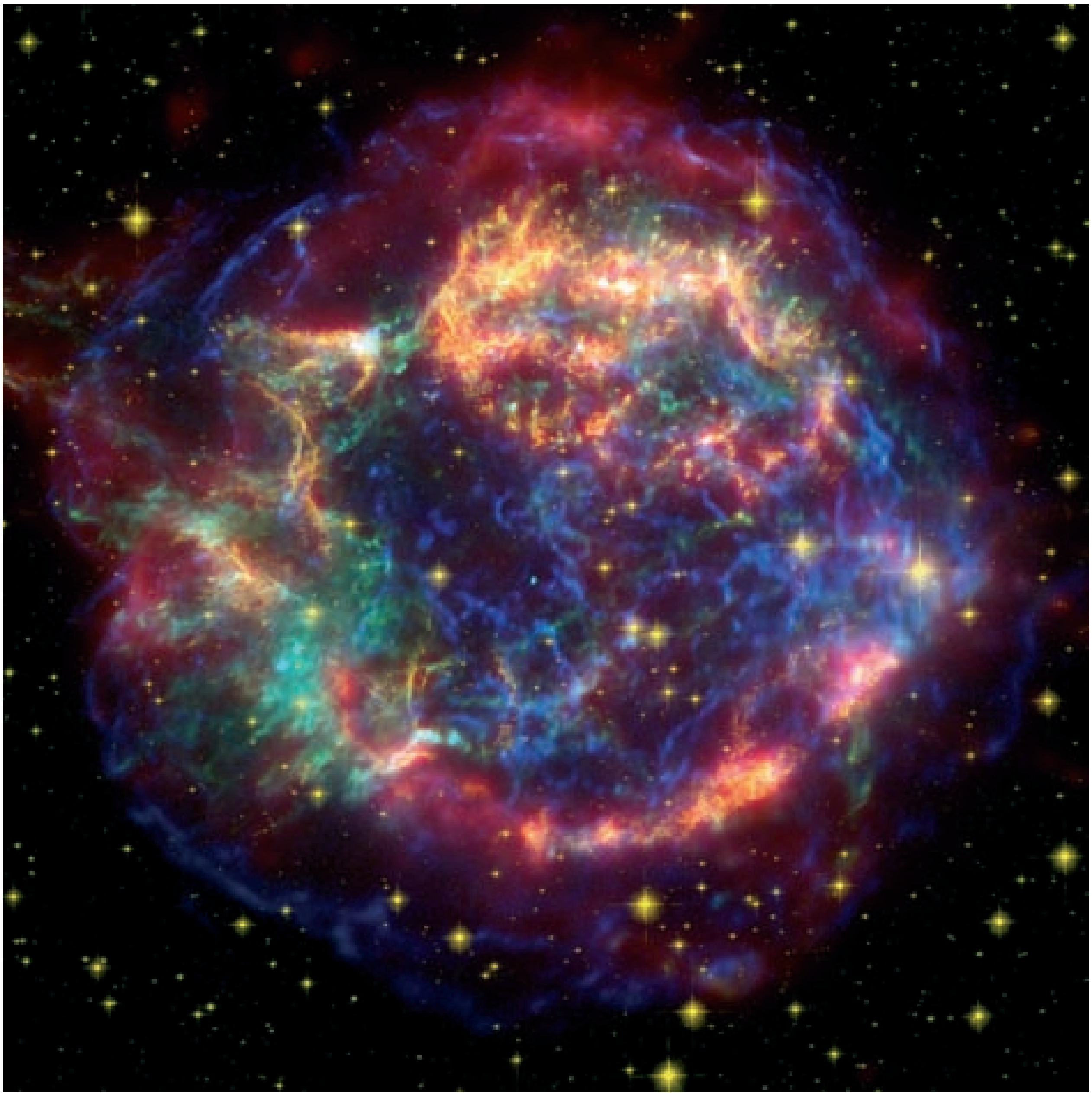
Finally, the monthly astronomical journal Sterne und Weltraum (Stars and Space, SuW), co-founded 1962 by Hans Elsässer, is published at the MPIA. This journal is intended for the general public but also offers a lively forum both for professional astronomers and for the large community of amateurs in this field.

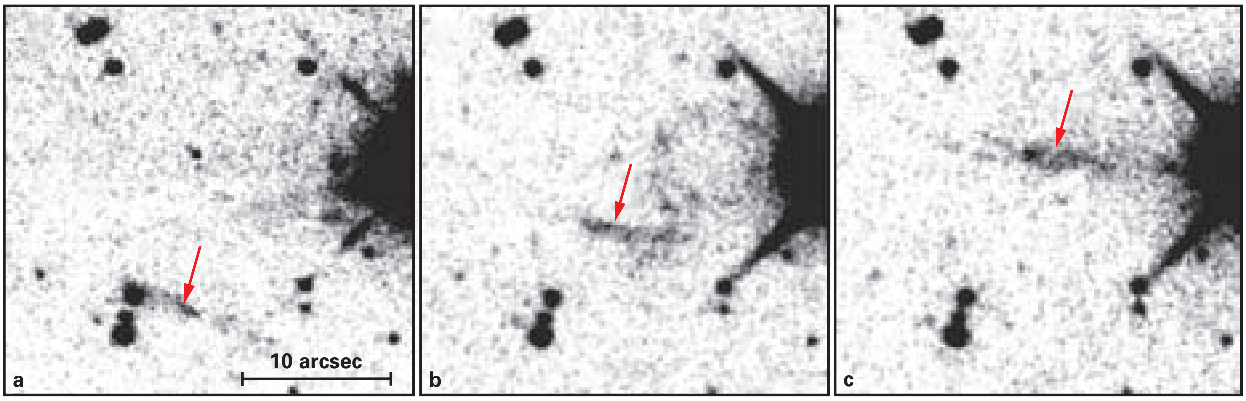
Great interest was shown in the *School project*, which has been initiated the previous year in cooperation with the Academy of Advanced Training of Teachers of the Land Baden-Württemberg, Donaueschingen, and with the support of the Klaus Tschira Foundation. For selected articles published in SuW, detailed didactic materials are developed each month and made freely available in the internet. About four times a year training courses for teachers based on these materials are held at the Academy. In their regular physics lessons, teachers and students will thus be able to deal with current research issues presented in generally comprehensible terms in SuW.

II. Highlights

II.1 Light Echoes Allow an Insight into the Active Past of Cassiopeia A

Cassiopeia A is the youngest known supernova remnant in our Galaxy. Although unrecorded at the time, it must have exploded around 1680. The nebula, lying at a distance of about 11 000 light years, is one of the best-studied celestial objects. It is therefore astonishing that only recently have astronomers succeeded in detecting light echoes in the infrared range around the supernova remnant. These originate from interstellar dust that was heated by the flash of the supernova explosion and by flares of the central neutron star in the recent past – a surprising result since the optical search for such echoes had been unsuccessful so far and the central body had been assumed to cool down slowly and uneventfully. These landmark observations were made by astronomers at the MPIA.





The nebula Cassiopeia A (Fig. II.1.1) was created when a star of about 20 solar masses had used up its nuclear fuel and exploded as a type II supernova. As a result, its outer envelope was ejected into space, while the central core collapsed into a neutron star about 20 kilometers across. The age of this supernova remnant, about 325 years, can be determined from the cloud's velocity and size.

The team of astronomers observed Cassiopeia A for the first time in November 2003 with the Spitzer Space Telescope in the infrared range at 24, 70, and 160 µm wavelength. On the 24-µm-exposure, two prominent lobes appear on opposite sides of the central body at a distance of 45 and 36 light years, on the left and right sides, respectively. In order to study them in more detail, the team conducted follow-up observations using the Multiple Mirror Telescope on Mount Hopkins and the 3.5m telescope of the Calar Alto Observatory. These infrared images revealed that some structures within the lobes had apparently moved with considerable speed (Fig. II.1.2). If this were real motion, the dust clouds would have had to move at about 50 percent of the speed of light. Velocities this high have never been observed in comparable cases. To follow up, the scientists once more observed Cassiopeia A with Spitzer in December 2004 – in these images, too, significant changes were found, compared to the images obtained the year before (Fig. II.1.3 and II.1.4).

Because of the extremely high velocities involved, these differences cannot be explained by real motions of the dust clouds. The astronomers interpret this phenomenon as a light echo. The central neutron star experienced an outburst of energetic radiation, probably in the gamma and X-ray range. This flare propagated at the speed of light into space and successively came across the randomly distributed gas and dust clouds within the supernova remnant. The dust heats and then glows in the infrared until it cools down again. Meanwhile, the flare recedes farther from the central star. Therefore, over the course of time, a trail of dust filaments emerges which light up and then fade again. They mark, so to speak, the propagation front of the flare, only mimicking a real motion of the filaments.

Fig. II.1.1: False-color image of Cassiopeia A, obtained with the Chandra X-ray satellite (*blue and green*), the Hubble Space Telescope in the optical (*yellow*), and the Spitzer Space Telescope in the mid-infrared range (*red*). Stars and the gas enriched with heavy elements by the supernova explosion glow particularly in the optical range while infrared emission reveals warm dust in the remnant. The central neutron star (little box) is only visible in the X-ray range.
(Photo: Nasa/JPL-Caltech)

Fig. II.1.2: Apparent motion of a dust filament, imaged *(a)* in May 2004, *(b)* in October 2004, and *(c)* in January 2005 at a wavelength of 2.2 µm. The observations were made with the Multiple Mirror Telescope *(a)* and the 3.5 m telescope on the Calar Alto *(b, c)*.

With a simple three-dimensional model, it was possible to infer when the flare must have occurred from the observed apparent motion of the clouds. A detailed analysis showed that there are at least two independent echoes in Cassiopeia A. One appears to have originated from the 1680 supernova explosion itself, while the other arose from recent outbursts, one of which must have occurred around 1953.

Such behavior suggests that the central source in Cassiopeia A is a »soft gamma repeater«. These are presumably neutron stars with strong magnetic fields, objects known as magnetars. The cause of the outbursts is not yet clear. According to one theory, the extremely strong magnetic field in these objects can cause quakes within the crust of the neutron star, resulting in enormous gamma ray outbursts.

So far, only a few magnetars are known. If the astronomers have really detected such an object in the center of Cassiopeia A, it would be the first one for which the date of creation and the progenitor were known exactly. In this context, it is also of interest to ask what caused the two dust lobes. This bipolar structure indicates that the exciting energy wave was collimated and directed. But it is also possibile that the excited dust itself has

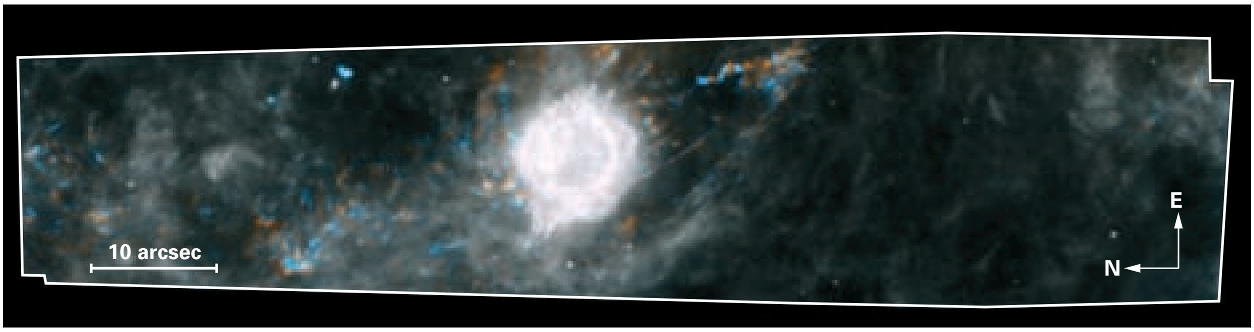


Fig. II.1.3: The surroundings of Cassiopeia A at a wavelength of 24 µm, imaged with Spitzer on November 30th, 2003 *(blue)* and on December 2nd, 2004 *(orange)*. Unchanged structures – like the remnant itself and large parts of the galactic cirrus – appear white. The infrared light echo outside the circular white remnant is seen as a colored *(blue and orange)*, bipolar structure which apparently is receding from the center of the supernova.

the observed, mainly bipolar distribution. This could be explained by strong, collimated winds blowing from the massive star before it exploded.

Additional observations with the Spitzer Space Telescope have provided new clues to the origin of the light echoes. A recently-obtained, even larger 24-µm image revealed light echoes out to a projected distance of more than 300 light years around the supernova remnant. Earth-bound, near-infrared follow-up studies of these newly discovered filaments confirmed the rapid apparent motions already found for the echoes closer in. Moreover, in October 2005, it was possible for the first time to detect the echoes at visual wavelengths as well.

Further observations are planned in the future, including spectroscopy of some of the particularly bright filaments. Since the emission observed in the visible range is very probably dust-scattered light from the 1680 explosion, the exact type of the supernova could be deduced from the spectrum – more than three centuries after the light of the explosion first reached the Earth. This would be another spectacular finding. It would allow us to connect the very well-studied remnant of Cassiopeia A with the physics of the explosion.

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Stephan Birkmann, Sascha Quanz.
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University of Arizona;
Rutgers University, Piscataway;
Space Science Institute, Boulder)

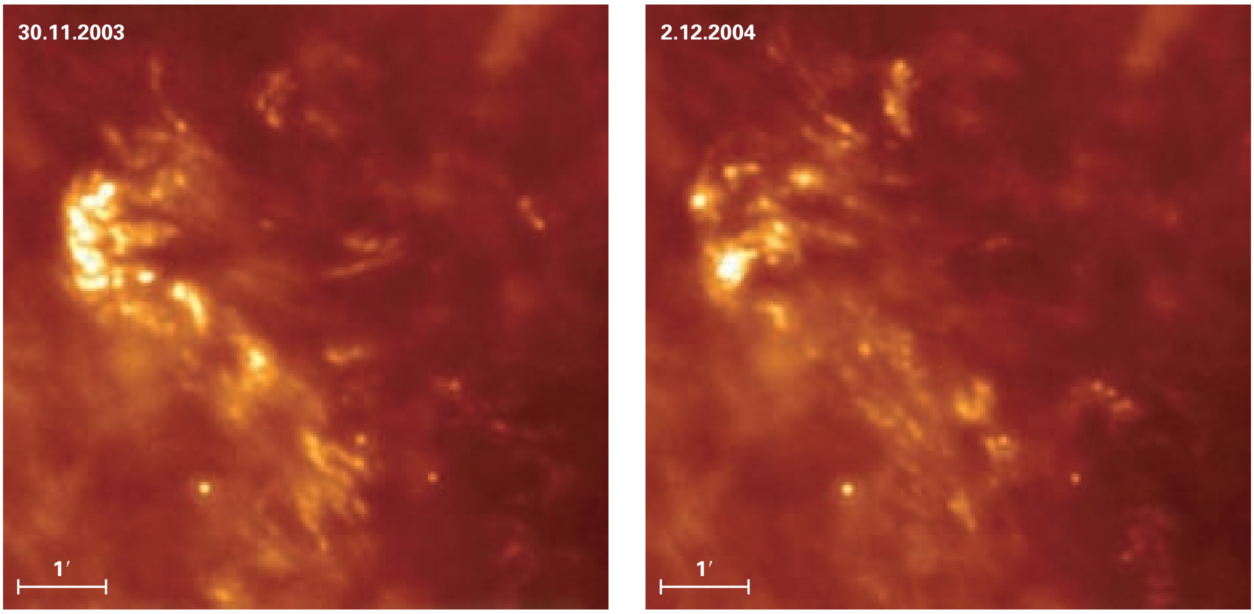


Fig. II.1.4: Spitzer images of one of the two lobes, taken at a wavelength of 24 µm at a one-year interval. The morphological changes are clearly visible.

II.2 AB Doradus C: Young, Low-mass Star is Twice as Massive as Expected

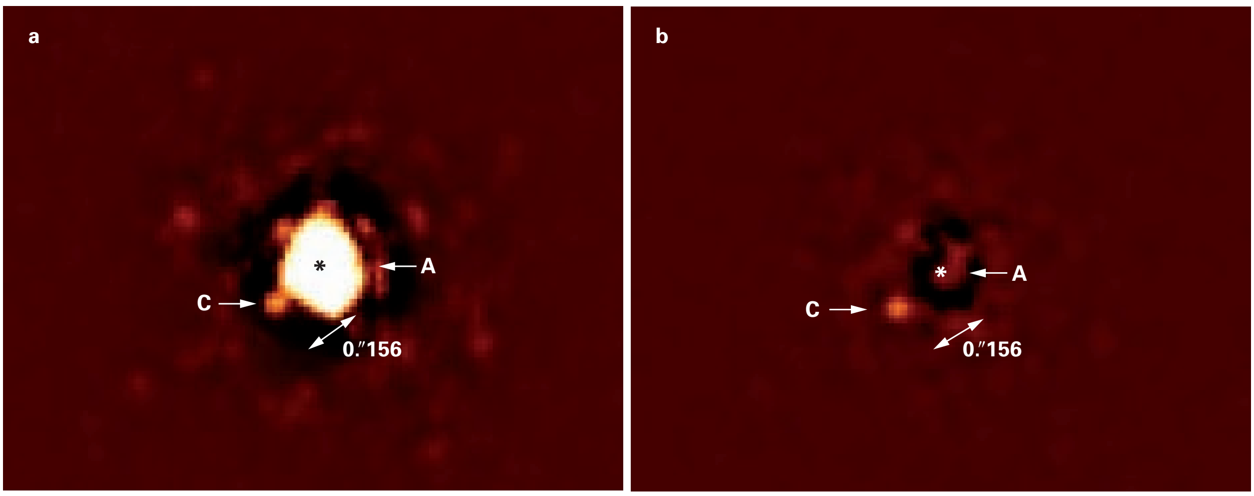
Mass is one of the most fundamental parameters of stellar evolution. It determines, among other things, the luminosity, temperature and lifetime of a star. The determination of mass therefore is one of the fundamental tasks of astronomy. However, in general, astronomers measure the luminosity of a star and then indirectly infer the mass via a mass-luminosity relation. This relation is well-established for evolved, massive stars, but up to now could not be calibrated for young, low-mass stars - in particular for brown dwarfs. Here one has to rely completely on evolutionary models. Now, for the first time, astronomers at the MPIA, together with colleagues from Spain and the USA, have derived the mass of a young, very low-mass star from astrometric data for the given luminosity. Surprisingly, the value turned out to be twice as high as was expected from theory. This will have far-reaching consequences, e.g., for the hitherto assumed frequency of brown dwarfs and planets in young stellar clusters.

During their formation, young brown dwarfs and planets are hot and bright, and then cool down over the course of time. Thus they are observed best during an early evolutionary stage. One star that has previously been searched for low-mass companions for a longer period is AB Doradus. Its small distance from the sun of 14.94 pc (49 light years as measured by HIPPARCOS) and its relatively well-known age of 50 million years make it ideal for this kind of study. It is of spectral type K1 and still in its pre-main-sequence stage. Since the early 1990s this star is known to have a companion at a distance of 9 arcseconds (corresponding to 135 AU). The two bodies were named AB Dor A and B.

Astronomers at the MPIA, together with colleagues from Spain and the USA, have observed this binary using a recent upgrade of the NACO infrared camera built at the MPIA. The new instrument, called NACO Simultaneous Differential Imager (NACO SDI), is extremely well-suited for finding low-mass stars and brown dwarfs in the close vicinity of a star. The NACO-SDI camera is equipped with an adaptive optics system which removes the blurring caused by atmospheric turbulences. The ancillary optics SDI divides the light of an individual star into four identical images at adjacent wavelengths inside and outside the infrared methane absorption band that is typical for low-mass objects. On suitably chosen differential images of these four exposures, the bluish primary star with its bright halo almost completely disappears, rendering the low-mass, cool and reddish companion clearly visible.

Using this instrument on one of the 8m telescopes of the Very Large Telescope (VLT), the astronomers detected a companion separated only 0.07 arcsec (1 AU) from AB Dor B. The two objects were then designated as AB Dor Ba and Bb. At the same time, another previously unknown companion was found at a distance of only 0.156 arcsec (2.3 AE) from AB Dor A. This object, called AB Dor C, is about one hundred times fainter in the near infrared range than AB Dor A. Thus it is the faintest companion object ever imaged so closely to a star (Fig. II.2.1). Earlier attempts to detect AB Dor C with the HUBBLE Space Telescope failed, which clearly emphasizes the superior performance of NACO-SDI.

Fig. II.2.1: The discovery image of AB Doradus C, obtained with the NACO-SDI camera built at the MPIA. *Left:* Image taken with NACO at a wavelength of 1.625 μm. *Right:* The companion is clearly visibly as a result of the differential effect of the SDI.



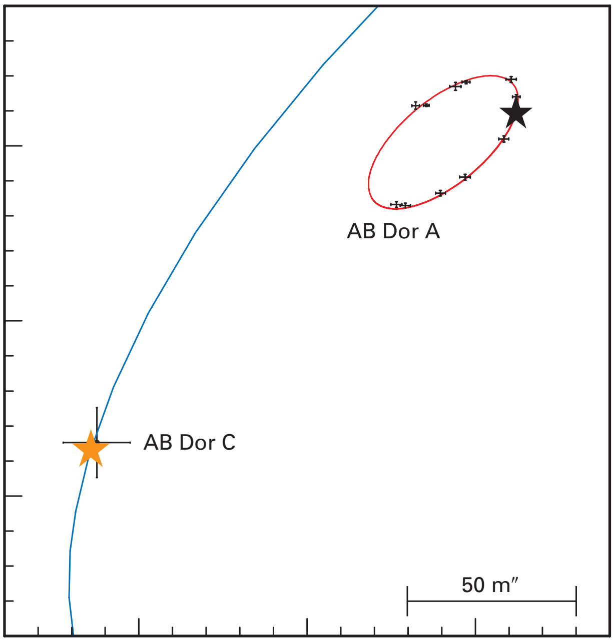


Fig. II.2.2: The orbits of AB Dor A and C, determined from astrometric data.

The supposed binary therefore actually is a quadruple system composed of two close pairs orbiting one another at a distance of about 135 AE. The orbit of AB Dor C around A (Fig. II.2.2) allows the orbital parameters to be determined and thus, for the first time, enabling the mass of such a low-mass star to be calculated from astrometric observations. AB Dor C gravitationally acts on its central star while both stars are moving around a common center of gravity. Such observations of the so-called reflex motion had already been performed in previous years with VLBI, and Hipparcos and could now be used to reconstruct the orbit. As it turns out, AB Dor C is moving on a highly elliptical orbit ($e = 0.59$), taking 11.75 years to complete one period.

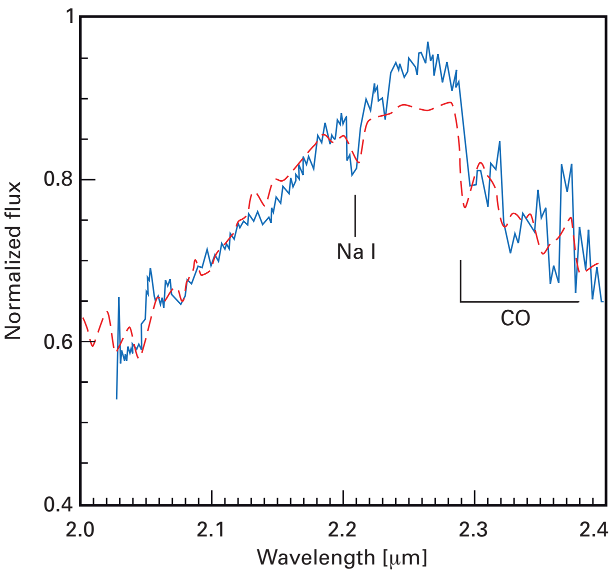
The known mass of AB Dor A of 0.865 solar masses and the orbital parameters yielded a mass of 0.09 solar masses for AB Dor C (corresponding to 93 Jupiter masses). Thus the object is just above the upper limit of 0.07 solar masses for brown dwarfs. From the magnitudes measured at three near-infrared wavelengths, a spectral type of $M_7 – M_9$ could be derived for AB Dor C. In order to determine the type more precisely, the astronomers took a spectrum of the object using the Naco adaptive optics spectrograph. The spectrum best matched a spectral type of M_8 (Fig. II.2.3) which is assigned a temperature of 2600 K. The luminosity of AB Dor C was determined from the measured infrared fluxes to be 0.0018 solar luminosities.

In this manner, the physical parameters of this low-mass star were determined and could be compared to the predictions made by theoretical models. Surprisingly, the companion was cooler by 400 degrees and 2.5 times fainter than expected for the given mass based on the latest theoretical models (Fig. II.2.4). In other words: current models yield masses that are only half as large for such young, low-mass objects.

This significantly affects the interpretation of a number of observations. Thus many young, low-mass objects were found by infrared surveys in the area of the Orion star-forming region. With the help of theoretical evolutionary tracks, a majority of them had been classified as brown dwarfs. According to the new findings obtained for AB Dor C, many of them should now be considered to be low-mass stars. The existence of so-called free floating planetary objects should also now be considered with caution. These low-luminosity objects also located in the Orion Nebula had been classified as planets. If the masses were underestimated here, too, by a factor of two, these objects may be misidentified brown dwarfs.

This work illustrates the danger of using evolutionary tracks for low-mass stars and brown dwarfs. In order to obtain a reliable calibration of the mass-luminosity-relation, more cases such as AB Dor C must be found. However, such objects are extremely rare. Only one percent of all stars have close low-mass companions, and only one percent of all stars in the solar neighborhood are young. Therefore, the fact that this measurement could be performed at all can be considered a real stroke of luck. A verification of these results with more objects would be desirable.

Fig. II.2.3: Spectrum of AB Dor C in the near-infrared range.



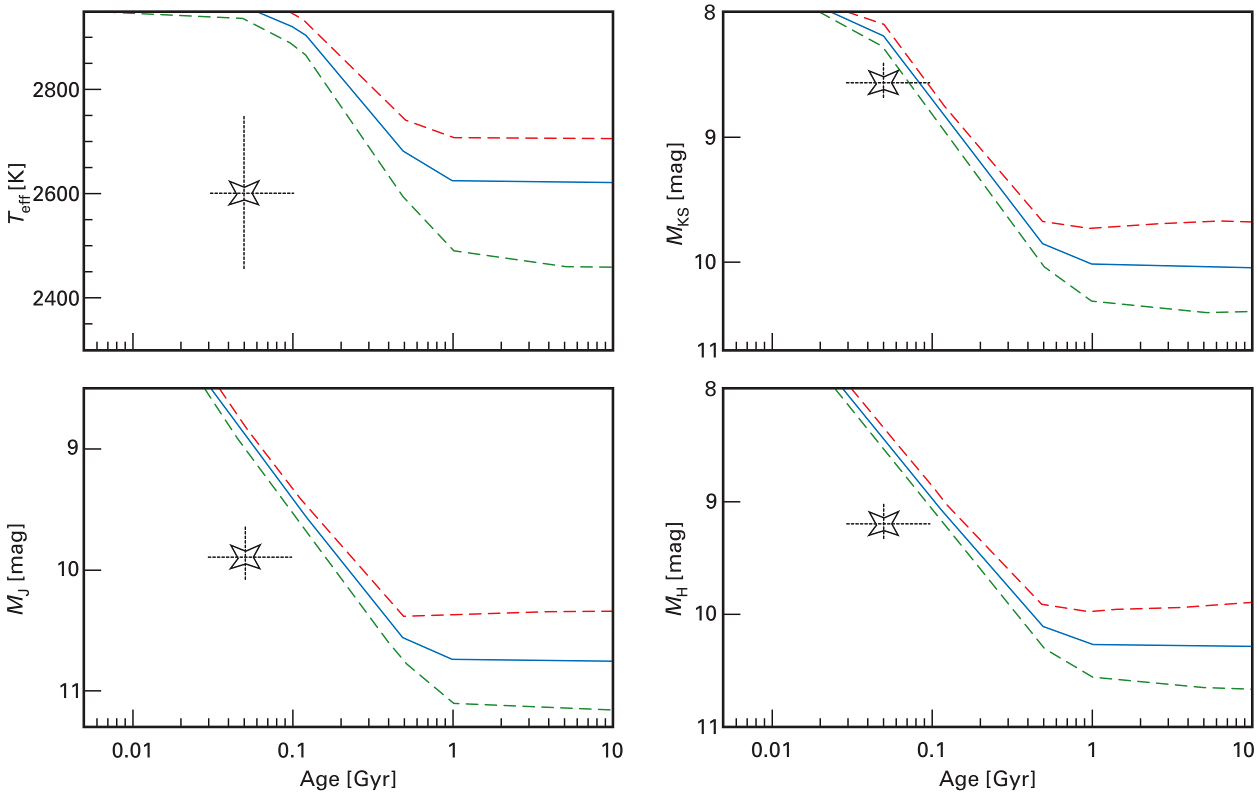


Fig. II.2.4: Comparison of the determined physical quantities of AB Dor C (star symbol) with the results of theoretical models (lines).

(Rainer Lenzen, Wolfgang Brandner. Participating institutes: Steward Observatory, University of Arizona, Universitad de Valencia, Harvard-Smithsonian Center for Astrophysics, European Southern Observatory.)

II.3 The First Heidelberg Extrasolar Planet

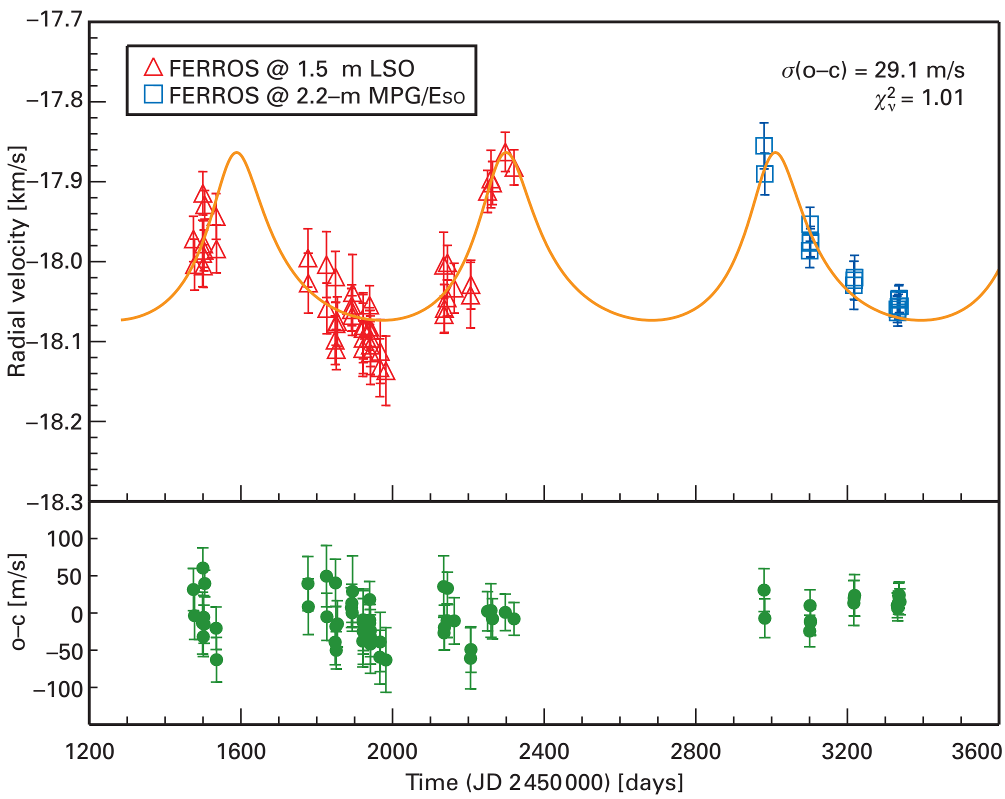
Since 1995, more than 180 extrasolar planets have been discovered. The majority of them orbit solar-like stars. Until now, only very few discoveries of substellar companions around giant stars are known , for instance. An international team of astronomers under the leadership of the MPIA has detected a planet around a red giant star. The mass of the star is about two solar masses. The star HD 11977A has a planetary companion of at least 6.5 Jupiter masses at a distance of just under 2 AU. This finding provides an important contribution to theories on the formation and evolution of planetary systems.

Large extrasolar planet search programs so far concentrated on solar-like stars. For these kind of stars, the precise stellar radial velocity method has been established. It is of great interest to investigate whether other stars which are different than the sun also have planets. Among them are stars of different mass ranges and evolutionary stages.

Main-sequence stars which are more massive than the sun are not suitable for the precise radial velocity method. These stars are hotter than the sun, thus their stellar spectra contain fewer absorption lines. Usually they also rotate faster than solar type stars. This leads to strong spectral line broadening so that the radial velocities cannot be measured accurately. When main-sequence stars of intermediate (1.5 – 4 $M_{\odot}$) or even higher masses evolve, the atmosphere becomes cooler so that there are more spectral lines. While the star is moving towards the red giant branch, it rotates slower and the atmosphere cools because of the expansion of the stellar envelope. This makes the accurate measurement of the radial velocities easier. However, there are other effects to be considered. Red giants possess higher stellar activity compared to solar-like stars, for example: large star spots or stellar oscillations. Nevertheless, these phenomena can be identified from the spectroscopy and distinguished from variation in the radial velocity induced by the presence of unseen companions.

Since 1999, the international team of astronomers had already monitored the red giant HD 11977, which is 216 light years away from Earth within a study of the physics of evolved stars. The target sample consists of about 200 giant stars from spectral type G and K. The observations

Fig. II.3.1: Variations of the radial velocity in HD 11977, measured with FEROS from October 1999 to November 2004.



were carried out with FEROS at the 1.5m ESO telescope on La Silla. In 2002, the astronomers identified for the first time a periodic radial velocity variation in HD 11977, which corresponds to the presence of the substellar companion. After FEROS was moved to the 2.2m MPG/ESO telescope, the team continued observations with this more powerful telescope. Stellar activity has been ruled out as the cause of the radial velocity variation from detailed analysis of the stellar spectra. The only plausible explanation of the variation is then the presence of a substellar companion. Until November 2004, the astronomers measured two cycles of the periodic oscillation that could definitely be attributed to the gravitational effects of an unseen companion (Fig. II.3.1).

With the orbital period of 711 days and the mass of the central star of 1.9 solar masses, the team derived the minimum mass of the companion ($m \sin i$) of 6.5 M_J (M_J: mass of Jupiter, i: inclination angle of the orbit against the line of sight). The HIPPARCOS astrometric measurements, the upper limit for the companion's mass is 66 M_J which is below the upper limit of 75 M_J for brown dwarfs. Assuming the mean value of $<\sin i> = \pi/4$ for randomly oriented inclination angles yields a mass for the companion of $M = 8.3$ M_J. Thus, the mass of the companion is within the planetary mass regime (upper limit: 13 M_J).

Table: Astrophysical Quantities of HD 11977 and its Companion.

HD 11977	
spectral type	G5III
visual brightness	4.68
distance	66.5 pc
mass	1.91 $M_\odot$
radius	10.1 $R_\odot$

HD 11977B	
mass	6.5 – 66 M_J
orbital period	711 Days
orbital radius	1.93 AU
eccentricity	0.4

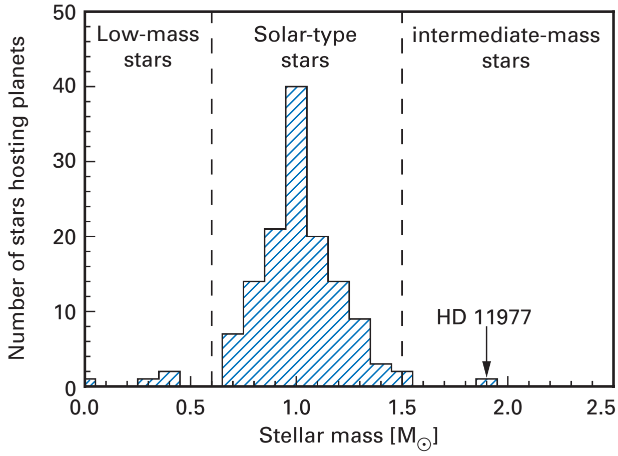


Fig. II.3.2: Mass distribution of stars with known planets and substellar companions, respectively. HD 13189 has been excluded because of the great uncertainty of its mass.

It still cannot be decided whether HD 11977B is a planetarey or a brown dwarf companion. Until now, only two more massive stars are known to have substellar companions: HR 7329 (2.9 $M_\odot$) and HD 13189 (2 – 7 $M_\odot$, see Fig. II.3.2). More observations of these stars will discern whether substellar companions around massive stars are unusual or it is an observational bias.

It is not clear yet if there is a dependency between the frequency of planet formation and stellar mass. Red giant stars are indeed of interest because there are still open questions such as how planets evolve when their central star has used up his hydrogen supply and is leaving the main-sequence stage.

(Johny Setiawan, Jens Rodmann.
Participating institutes:
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Thüringer Landessternwarte, Tautenburg,
European Southern Observatory, Garching,
Kiepenheuer-Institut für Sonnenphysik, Freiburg,
Universidade Federal do Rio Grande do Norte, Natal,
Osservatorio Astronomico di Trieste, Triest.)

II.4 Planetesimal Formation by Gravitational Instability

According to current views planet formation in protoplanetary disks takes place in several stages. At first dust particles collide and stick together, growing eventually to the size of planetesimals. Planetesimals then accumulate gravitationally and finally reach the sizes of planets. Many individual steps in the sequence of processes that leads to the formation of planets are not yet understood. Among other things the role of various kinds of turbulence has not been possible to model satisfactorily so far because of insufficient computing power. Theorists at the Institute have now studied numerically the influence of magnetorotational and Kelvin-Helmholtz turbulence. One surprising result has been that turbulence does not impede the gravitational formation of planetesimals – as it was expected – but can even stimulate it.

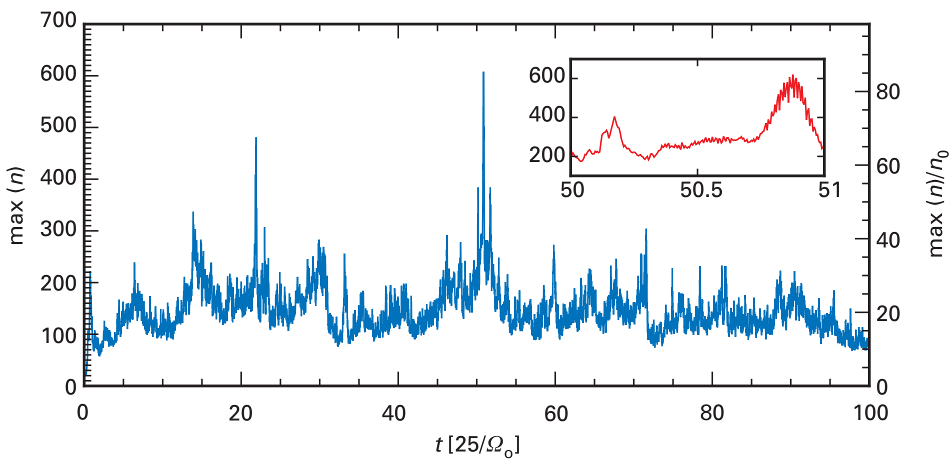
During the first stages of planet formation small dust particles collide and stick to each other (coagulate). The necessary relative velocities are provided to the particles by Brownian motion. The speed decreases with increasing particle mass, however, and therefore can only play a role during the earliest stage of growth. In the further course of events the ever growing particles sink are sinking towards the mid-plane of the developing protoplanetary disk under the influence of the protostar's gravity. As the sedimentation speed increases with growing particle mass, here too relative velocities between the dust grains occur, resulting in more collisions and further growth. This way, the grains may achieve diameters of several centimeters when they arrive at the mid-plane of the disk.

In the mid-plane the dust density is relatively high so that the particles will now collide more frequently and can grow to planetesimals of several kilometers size. But at the same time there are several mechanisms counteracting this growth. Microscopic particles can only coagulate if they collide with speeds that are not too high. The same is true for collisions of small dust particles and meter-sized rocks. Above a certain velocity the dusty bodies just rebound from one another. It is even worse for collisions between macroscopic bodies. Two rocks will never stick together, no matter what their velocities are during collision. Above a critical relative speed the bodies will even destroy one another. Where this threshold lies is still debated – probably at some ten meters per second. In addition, meter-sized bodies will lose angular momentum because of their friction with the gas of the disk and thus will drift on spiral orbits towards the central star. Estimates show that within about one hundred years a rock this size can come close enough to the star to vaporize. In order to avoid this fate it has to grow within this short period of time by at least one order of magnitude, corresponding to an increase of mass of three orders of magnitudes. According to current theoretical models, however, the growth during this phase requires at least 1000 years.

Magnetorotational Turbulence Concentrates Rocks

The second problem (the high drift rates of the rocks) relates to disks with a laminar flow of gas and dust. However, it has already been suspected for some time that turbulence may play a major role here. Turbulence

Fig. II.4.1: Number of particles within one grid cell as a function of time for meter-sized rocks. The particle density reaches a value up to eighty times higher than the average density. Time is given in units of orbits.



not only causes a diffusion of the smallest dust particles, it also creates relative velocities between rock-sized bodies that are not coupled to the gas any longer. On the one hand more collisions will occur, on the other hand a local concentration of the rocks will develop. So for instance, boulders up to several meters across can be captured this way in vortices. Such vortices can form in the so-called magnetorotational turbulence (MRI turbulence).

MRI turbulence is an interplay of shear flows and magnetic fields that can be visualized more or less the following way. Shear flows can cause turbulence. This is known, e.g., from fast sports cars where the circumfluent air can become turbulent. The skill of car designers is to shape the car in such a way that the turbulence is minimized since the developing vortices increase the drag. Spoilers and streamlining help to shift the occurrence of turbulence as far behind the sports car as possible.

Such a shear flow also occurs in gaseous disks surrounding young stars. Close to the star the gas flows faster than further out. Experiments and analytical studies have shown that the flow in disks does not easily become turbulent since the circumstellar disk rotates very fast. The related angular momentum stabilizes the shear flow, acting like a spoiler on a sports car.

Now the effect of the magnetic fields is added. The gas surrounding the young star is probably is ionized, and the charge carriers couple to the magnetic field lines. These lines pass through the disk like elastic bands, trying to prevent the shear. So the inner region of the disk is slowed down and the outer part is sped up. However, this destabilizes the flow in the disk to such an extent that it becomes turbulent, forming vortices. The magnetic fields thus act like a forest of antennas screwed onto one's sports car: the drag is increased enormously as the flow around the car becomes turbulent – despite all spoilers.

Theorists at MPIA simulated numerically the phenomenon of MRI turbulence in the disks around young stars. Two million particles represented rocks moving in a gas. Friction could be varied by a parameter. Then the MRI turbulence of the gas was included in the simulation in order to study the effect of this phenomenon on the motion of macroscopic bodies. Since a complete three-dimensional treatment of the entire disk is far beyond the computing power of present-day computers the simulation had to be limited to a volume within the disk. Values for a radial density gradient and a pressure gradient were each varied over a range expected for protoplanetary disks. The sizes of the rocks was assumed to be ten centimeters as well as one and ten meters.

The simulations performed with various parameters showed surprising results. The MRI turbulence produces vortices in the gas that have a slightly higher density and a marginally higher pressure than their environment. These condensations survive in the disks for some orbital periods, corresponding to some ten or – in the outer regions of the disk – even hundred years. Then they disperse, but might form again somewhere else.

The vortices rotate in different directions and can be distinguished, as in the earth's atmosphere, into cyclones and anticyclones according to their sense of rotation. Interestingly the solid bodies move towards the anticyclones, remaining captured there. Cyclones, on the other hand, disperse the particles. This effect even increases with the size of the particles, reaching a maximum for meter-sized bodies: Here the local concentration of the bodies is a hundred times higher than on average while the effect is much lower for the small grains and for larger objects (Fig. II.4.1 and Fig. II.4.2). The motion of the particles towards the anticyclone regions is caused by the pressure gradient existing there. These accumulations of large bodies survive for a while even when the gas vortices that had created them already have dispersed.

A second interesting result was that the MRI turbulence slows down the drift of the rocks towards the central star mentioned above. Compared to a laminar disk this velocity is reduced by up to 40 percent (Fig. II.4.3).

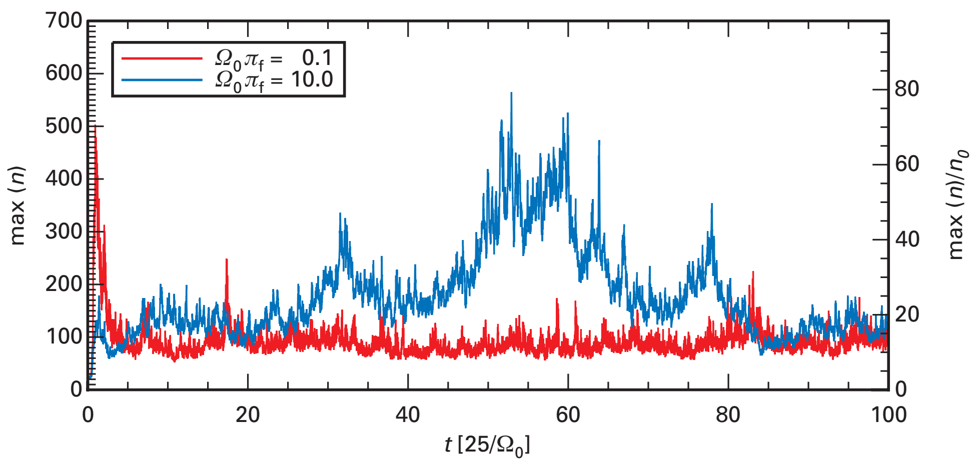


Fig. II.4.2: Like Fig. II.4.1, but for particles 10 cm (lower curve) and 10 m across. Clearly evident is the higher-than-average concentration of the large boulders.

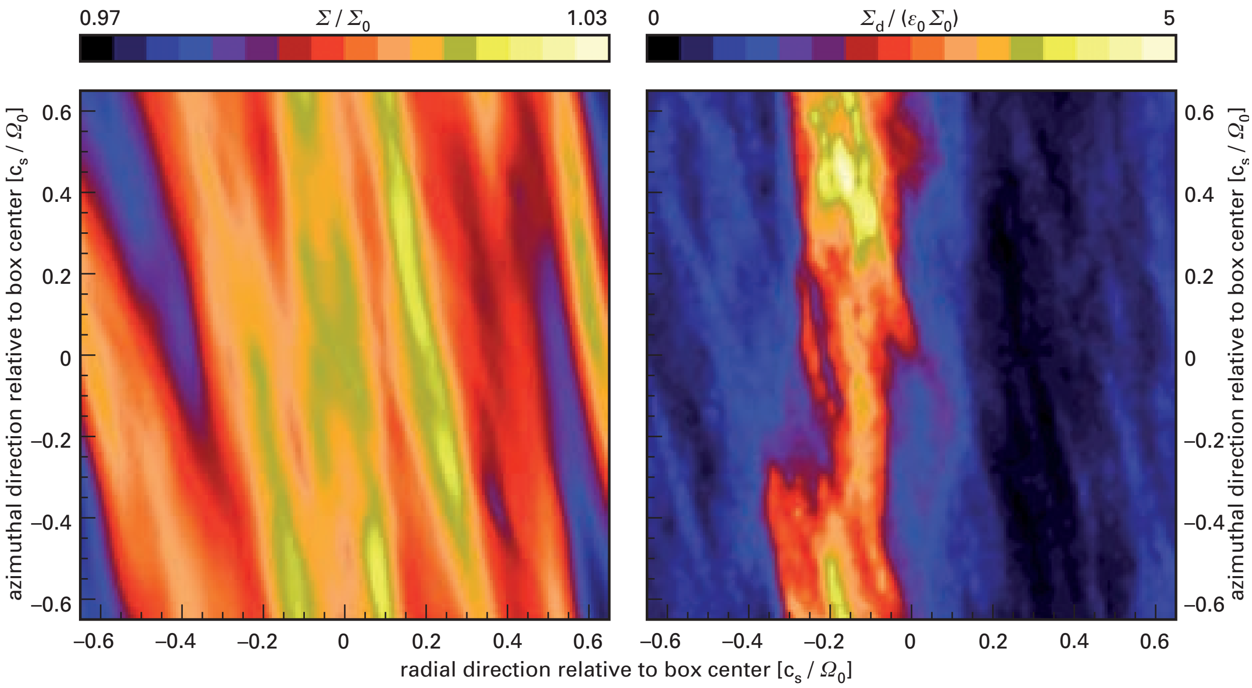


Fig. II.4.3: Looking from above the disc we see the integrated column density of the gas *(left)* and particles *(right)* in a corotating box. While the gas density within the vortices is varying only slightly compared to the average value of the surroundings, considerable density concentrations occur for the particles. $c_0 / \Omega_0 \approx 1$ AU.

However, only global simulations of the entire disk could show how these processes would affect the formation scenario of planetesimals. It nevertheless seems plausible that the concentration of bodies in the anticyclones favors further gravitational accumulation.

It is not clear yet whether the reduced drift speed suffices to prevent the bodies from premature vaporization. Anyway, MRI turbulence appears to benefit the formation of planetesimals. A simple estimate shows the concentration in the clumps to be high enough for the individual rocks to feel their mutual gravity. Gravity may be strong enough now to prevent the dispersion of the clump. This could result in a collapse of the dust clump, finally forming a kilometer-sized planetesimal. The numerical experiment for this is in preparation.

Kelvin-Helmholtz Turbulence

It has been known for a long time that MRI turbulence is prevented in too weakly ionized disks since the magnetic fields do not couple to neutral gas. But now a second form of instability occurs that must have a considerable effect on the protoplanetary disk and the formation of planetesimals: the Kelvin-Helmholtz instability (KH instability for short). It develops in a dusty gas disk in the following way: At first the dust sinks towards the mid-plane of the disk (sedimentation) which otherwise would have been prevented by MRI turbulence. In a protoplanetary disk temperature and density decrease with increasing distance from the central star. Therefore a radial pressure gradient exists, causing the gas to rotate more slowly than it would on a pure Keplerian orbit. The dust on the other hand does not react to the pressure gradient but only feels the gravity. It therefore revolves on Keplerian orbits. When the dust/gas ratio in the central plane of the disk gets high enough, the dust will drag the gas particles along, forcing them also to adopt the velocity of a Keplerian orbit. Consequently the gas is moving faster in the central plane than above and below. Therefore a vertical velocity shear occurs, resulting in the occurrence of a KH instability.

The turbulent gas motion setting in can cause the dust to be whirled out of the central plane, thus preventing a gravitational accumulation of dust to planetesimals. More than twenty years ago, this process already had been considered an obstacle to the growth of dust grains to planetesimals. Correspondingly, there were many different suggestions to solve this problem. In a numerical simulation dust and gas have to be treated as two independent systems that are able to interact and move against one another – a demanding non-linear problem.

Again simulations were performed with particles of three different sizes: one centimeter, ten centimeters and one meter. Figure II.4.4 shows a result for centimeter-sized grains. In an initially Gaussian density distribution in the z-direction (top) vortices form in the mid-plane as the dust density increases, which even can break up the original dust disk at many places (bottom). The larger the particles the faster the process sets in since the larger par-

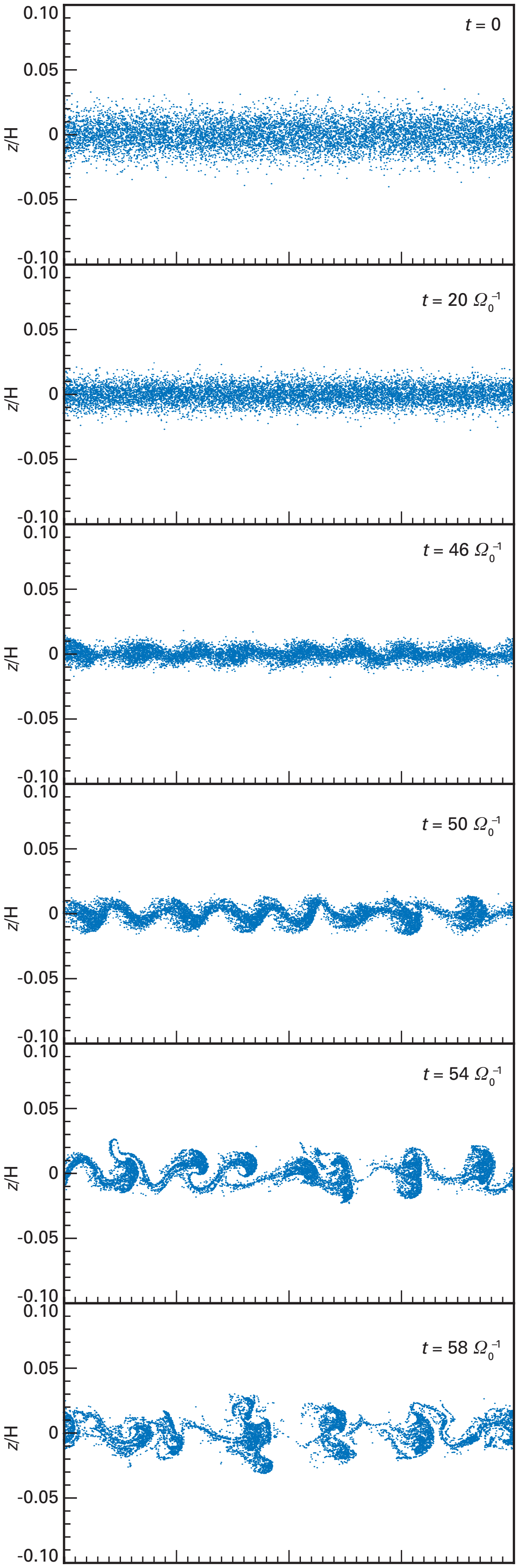


Fig. II.4.4: Centimeter-sized grains have concentrated around the mid-plane, while sinking towards it. Once a sufficient density is reached a Kelvin-Helmholtz instability sets in.

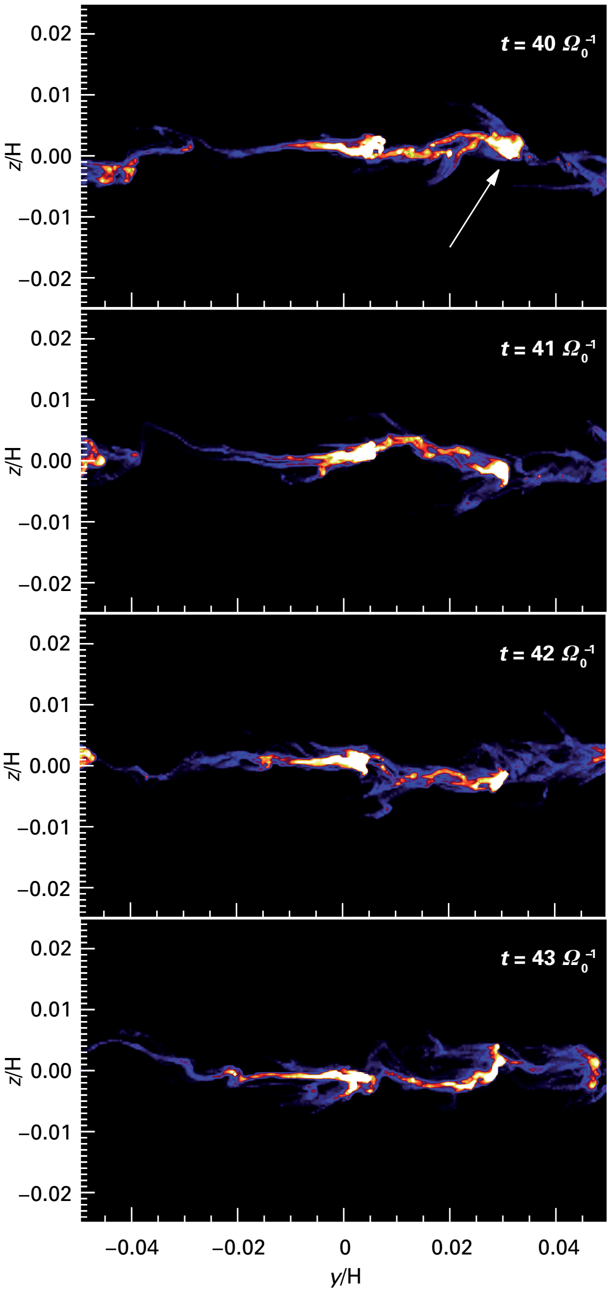


Fig. II.4.5: Time evolution of the particle density in the *y*- and *z*-directions of the disk for meter-sized boulders. Due to the KH turbulence some dust clumps oscillate around the mid-plane (*arrow*).

ticles fall faster towards the mid-plane central plane than the smaller ones. Furthermore, the large boulders are more strongly concentrated towards the mid-plane than the small ones: centimeter-sized pebbles have a scale height five times larger than meter-sized rocks.

The bodies are not distributed evenly around the mid-plane, however, but form dynamical dust clumps – as is shown in Fig. II.4.4. A time sequence of the simulations illustrates that the clumps are oscillating around the mid-plane (Fig. II.4.5).

As with the MRI turbulence, macroscopic bodies can accumulate in these vortices, too. Furthermore, dust-rich grid cells move faster than dust-poor ones. Consequently these cells collide more often and merge: So the particle clumps grow. Thus the KH instability triggers a clumping instability. It appears reasonable that such clumps, in which the densities can be up to several orders of magnitudes higher than in the surrounding disk, may fragment and form planetesimals sometimes. So we here have a quite similar case as with the MRI turbulence.

Future simulations will have to show how these individual processes are interconnected and how they affect the formation of planetesimals. Above all, 3D-simulations are needed here. First results indicate that the Keplerian shear within the disk slows down the development of the KH instability in the direction of the gas flow. Even so, a clumping instability still develops, though this time in radial direction towards the star. First simulations of the gravitational interaction of the rocks were started as well. Here the question is how long it takes for the dust clumps to accumulate to planetesimals.

All these computer simulations are only possible thanks to the new supercomputer PIA at MPIA (see Chapter IV.12). With its help theorists are expecting more exciting results on the formation of planetesimals. They are presently preparing the ultimate simulation where all effects will be included at the same time: Magnetorotational and Kelvin-Helmholtz instabilities as well as the gravitational interaction of the rocks.

Movies of the computer simulations can be found under: www.mpia.de/~johansen/research_en.php

(Anders Johansen, Hubert Klahr, Thomas Henning)

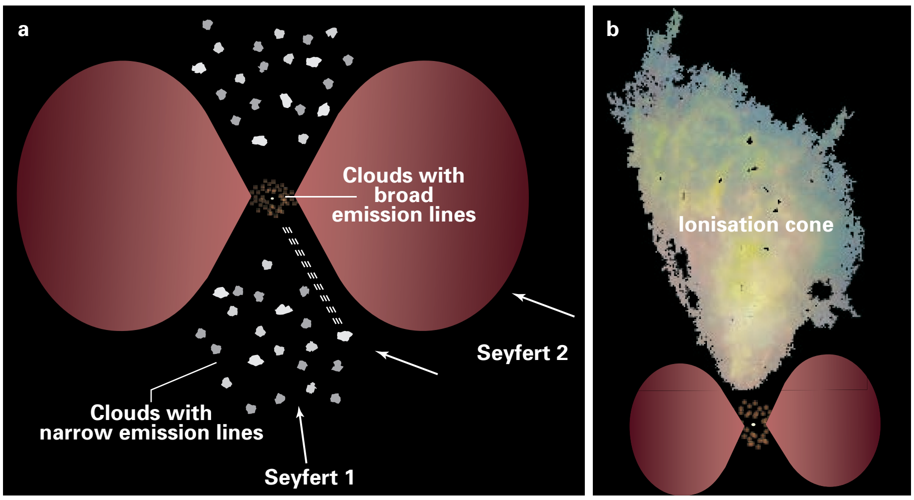
II.5 Dust Tori in Active Galactic Nuclei

Almost all galaxies appear to have a very massive black hole at their center. In many cases – for instance in our Milky Way – it is barely noticeable. But in a small percentage of galaxies, the black hole makes itself conspicuous through intense radiation emitted by matter in its vicinity. Such cases are called active galactic nuclei. For years, there has been indirect evidence that gas and dust accumulate in the outer sphere of influence of the black hole, forming a thick donut-shaped structure. However, even in the nearest galaxies, these »dust tori« are too small to be resolved with conventional single telescopes. Using the Mid-Infrared Interferometric Instrument (MIDI) at the VLT in Chile, astronomers at the MPIA have for the first time succeeded in directly imaging several dust tori. Comparisons to newly developed models allow them to reconstruct and study the infall of matter onto active galactic nuclei in detail. MIDI is the achievement of a German-Dutch-French cooperation under the leadership of the MPIA.

For many years, astronomers have suspected that many active galactic nuclei (AGN) are embedded in a thick torus of gas and dust. However, until 2003 it was impossible to verify this hypothesis by direct observations. The expected structures are too small. A simple estimate shows that in a typical AGN, the dust can be heated to several hundred Kelvin (300 Kelvin correspond to 27 °C) only within a radius of 1 to 10 light years (ly) around the black hole. At this temperature, the dust is warm enough to emit thermal radiation in the mid-infrared range, which can be detected best at wavelengths between 5 and 20 µm. Even in the nearest AGN of typical luminosity, 10 ly correspond to an apparent size of only 40 milliarcseconds (mas). This can be compared to viewing a 1-Euro coin from a distance of 113 km. Even at the short-wavelength end of the mid-infrared range, at 5 µm, an 8 m telescope can achieve a resolution of 100 mas at best, so every dust torus would appear as an unresolved point source.

Thus all evidence of the presence of such dust tori had been indirect until recently. A special type of AGN in the local universe, so-called Seyfert galaxies, play a particular role here. Two types are distinguished that differ significantly in their optical properties, while their dust emission in the mid- and far-infrared range appears to be very similar. This is easily explained if a dust torus exists in all Seyfert galaxies that presents a different appearance to us, depending on our viewing angle (Fig. II.5.1a). In Seyfert 1 galaxies, we look along the axis directly into the core of the AGN. We then observe the radiation emitted by the hot accretion disk and the rapidly orbiting clouds of hot gas. The disk emits a blue continuum while the clouds display the broad emission lines typical for Seyfurt 1. In Seyfert 2 galaxies, we view the dust torus edge-on, the dust absorption within the torus blocks our direct view of the accretion disk and the fast gas clouds. Only the slower gas clouds farther away from the black hole are still visible, which are also above and below the dust torus, emitting the narrow emission lines typical of

Fig. II.5.1: *a)* According to the unified model, the nuclei of Seyfert galaxies are surrounded by dusty tori. Depending on whether one is looking at the hot nuclear region or merely at the torus (*arrows*), one observes Seyfert 1 or Seyfert 2 galaxies. *b)* In the Seyfert 2 galaxy NGC 1068 a cone of ionized gas is flowing outwards from the centre of the dusty torus; the torus is shown enlarged by a factor of about 100 compared to the ionization cone.



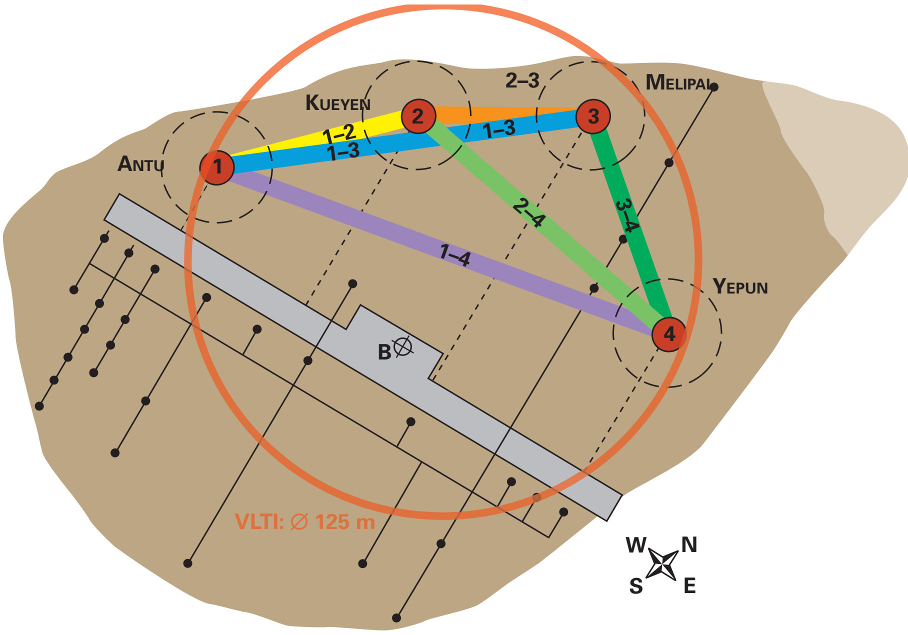


Fig. II.5.2: *Above* – The light paths of the four 8.2 m telescopes and of three auxiliary telescopes can be combined in the interferometry laboratory. *Below* – With MIDI, two of the large telescopes at the time can be combined, thus yielding six possible combinations. In this way, the resolving power of a 125 m telescope is achieved (*red circle*).

Seyfert 2 galaxies. Dust lying farther out hardly attenuates the emission of the warm dust in the inner region of the torus. Consequently, both types scarcely differ in the mid- and far infrared range.

Astronomers call this AGN model the »unified scheme« or unified model. It gained further support from two observational results. Firstly, it was possible to detect broad emission lines also in many Seyfert 2 galaxies by observing them in polarized light. This light reaches us after it has been scattered by particles located above and below the torus. Secondly, a cone of ionized gas can be observed in several Seyfert 2 galaxies (Fig. II.5.1b). This is explained by the fact that only a rather small channel is left open by the dust torus through which the ionizing radiation of the accretion disk can escape and excite distant gas clouds in the galaxy, causing them to glow. A major prediction of this model is that the geometry of the dust torus (the width of the channel) should be directly related to the opening angle of the ionization cone.

In 2003, our ability to observe AGN and other objects took a revolutionary leap forward. With the commissioning of the MID-infrared Interferometric Instrument (MIDI) at the Very Large Telescope (VLT) of the European Southern Observatory (ESO), for the first time it was possible to link the four 8 m telescopes for observations in the mid-infrared range (8–13 μm wavelengths). This enabled the VLT Interferometer (VLTI) to achieve the spatial resolution of a 125 m telescope. However, the light-gathering area only equals the sum of the individual telescopes (Fig. II.5.2).

The Earth's rotation is used to achieve as extensive an areal coverage as possible with the individual mirrors. It causes the positions of the individual telescopes to rotate within the periphery of 125 m in the course of the night, thereby gradually filling in the various areas of the »total telescope« with mirror surfaces. Unfortunately, the procedure is somewhat more complicated in reality. Since MIDI allows only two individual telescopes to be linked at a time, the six possible telescope combinations have to be realized bit by bit over the course of several nights.

As we will see, it often suffices in practice to use only a subset of the possible telescope combinations at a few angles of the Earth's rotation to get a first impression of the size and shape of an astronomical object. However, it is necessary to have a good model of the object observed for the interpretation of such incomplete observations. The essential parameters such as size, elongation, orientation and color distribution, then have to be deduced by matching the model to the observations.

Theoretical Models for Dust Tori

For this purpose, we have started a theory project parallel to the MIDI observations, in which we attempt to model the possible structure and observable properties of the dust tori in AGN.

A realistic model of AGN dust tori would have to take many physical aspects into account. These include a static balance between the gravitational forces of the black hole and the central star cluster on the one hand, and centrifugal forces like rotation and random gas motion on the other hand. Moreover, it would have to take time-dependent effects like gas inflow from the outside, local sources of dust and the stirring of gas by supernovae into consideration. In addition, the heating of the resulting

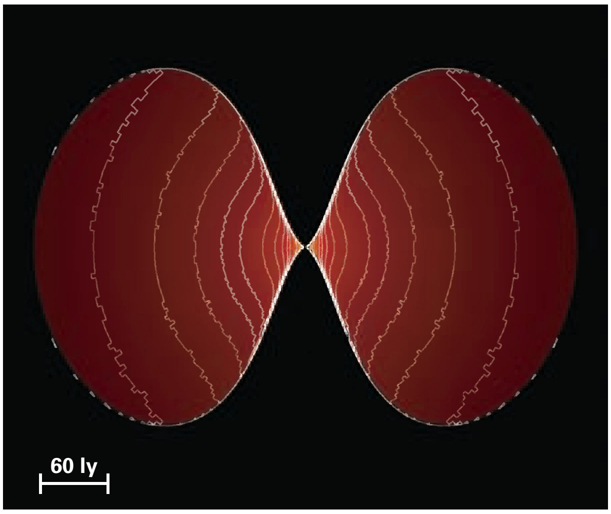


Fig. II.5.3: Temperature distribution in the model of a homogeneous torus. In the innermost region more than 1000 Kelvin are reached (orange). Towards the outside the temperature decreases continuously to about 100 Kelvin *(dark red)*.

complex gas and dust distribution by the accretion disk and the pathway for the escape of the resulting infrared radiation would have to be calculated each time. Such a model would need millions of spatial cells and thousands of time steps in the computer – far more than present-day computers can manage. We therefore approach the modeling in three steps of increasing complexity.

In the first step, we distribute gas and dust in an effective potential determined by the mass of the black hole and the central star cluster (mass, velocity distribution, rotation). In this way we try to reproduce the properties of a typical Seyfert galaxy. By illuminating this stationary and continuous dust distribution with the radiation of a hot accretion disk, one not only obtains the temperature distribution of the dust torus (Fig. II.5.3), but one can also derive images of the radiation escaping at various wavelengths. Figure II.5.4 shows the expected images of the torus for Seyfert 1 (upper panel) and Seyfert 2 galaxies. Notice that at shorter wavelengths ($\lambda = 5\,\mu$m) only the hot inner edge of the torus is discernible, while at longer wavelengths larger and larger regions of the torus are glowing. This is due to the decreasing temperature at increasing distances to the black hole.

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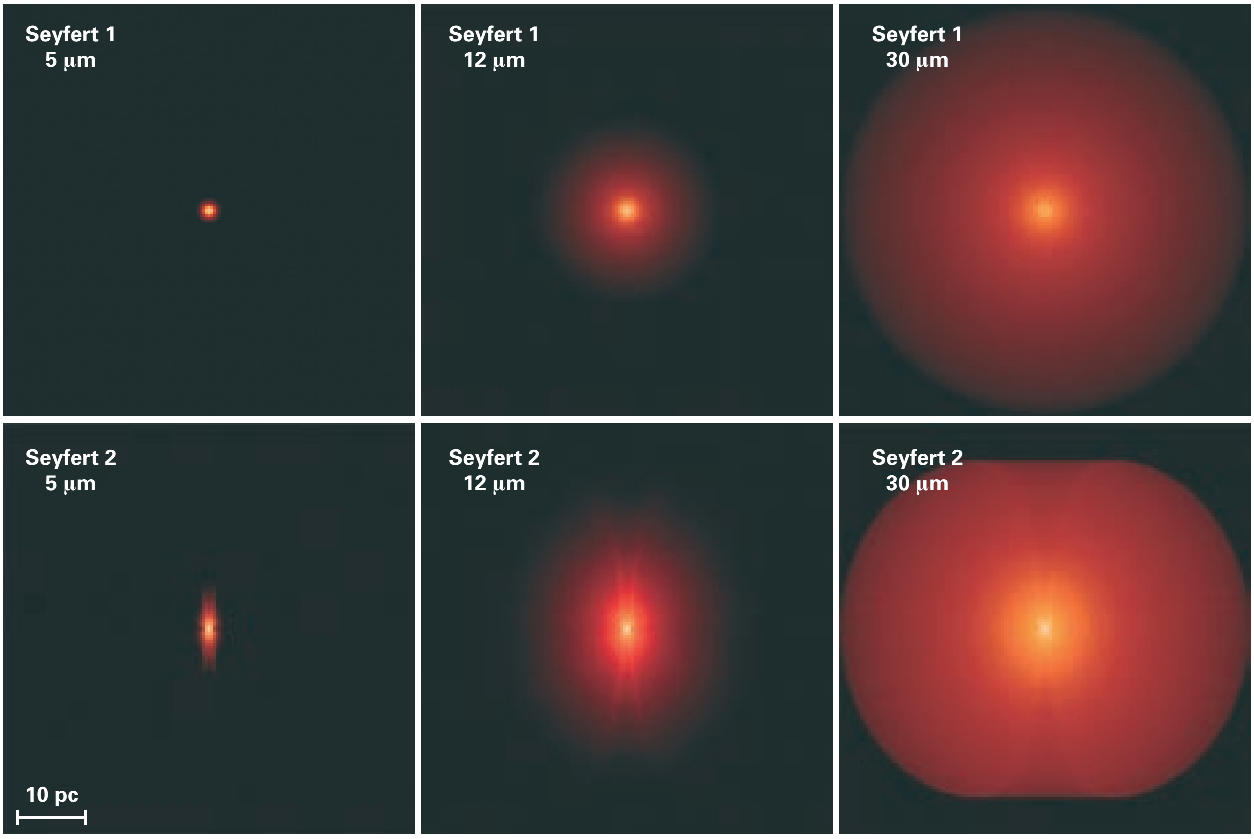

Fig. II.5.4: These mid-infrared images of the dust tori are predicted by continuous models. The upper panel shows the torus of a Seyfert 1 galaxy at wavelengths of 5, 12, and 30 µm. The lower panel shows the corresponding appearance of a Seyfert 2 galaxy at the same wavelengths. At short wavelengths only the inner, hot channel of the torus is glowing.

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The *second step* takes into account that realistic dust tori are not filled homogeneously with gas and dust. As in the molecular clouds of our Milky Way, the dust will instead arrange itself in clouds or filaments. We therefore calculated how the total spectrum and appearances of the torus change when a clumpy dust distribution is assumed (Fig. II.5.5). We find that clumpy tori reproduce the spectrum observed from Seyfert 1 galaxies better than continuously filled ones. Whether the resolution of the VLTI is sufficient to find direct evidence of the clumpiness depends on the number of clumps the tori of nearby AGN are made of.

In the *third step* we try to reproduce the dynamic processes that determine the structure and evolution of a torus in the central region of a galaxy. Stellar winds and planetary nebulae produce the dust. Supernovae provide the kinetic energy necessary to maintain the geometrically thick torus. Gravity and centrifugal force alone would create a thin disk from the inner edge of which matter would be sucked towards the black hole. Although our simulation will certainly not reach the spatial resolution needed to derive realistic images, we are confident that we will gain insight into fundamental properties and temporal variability of the tori in this way.

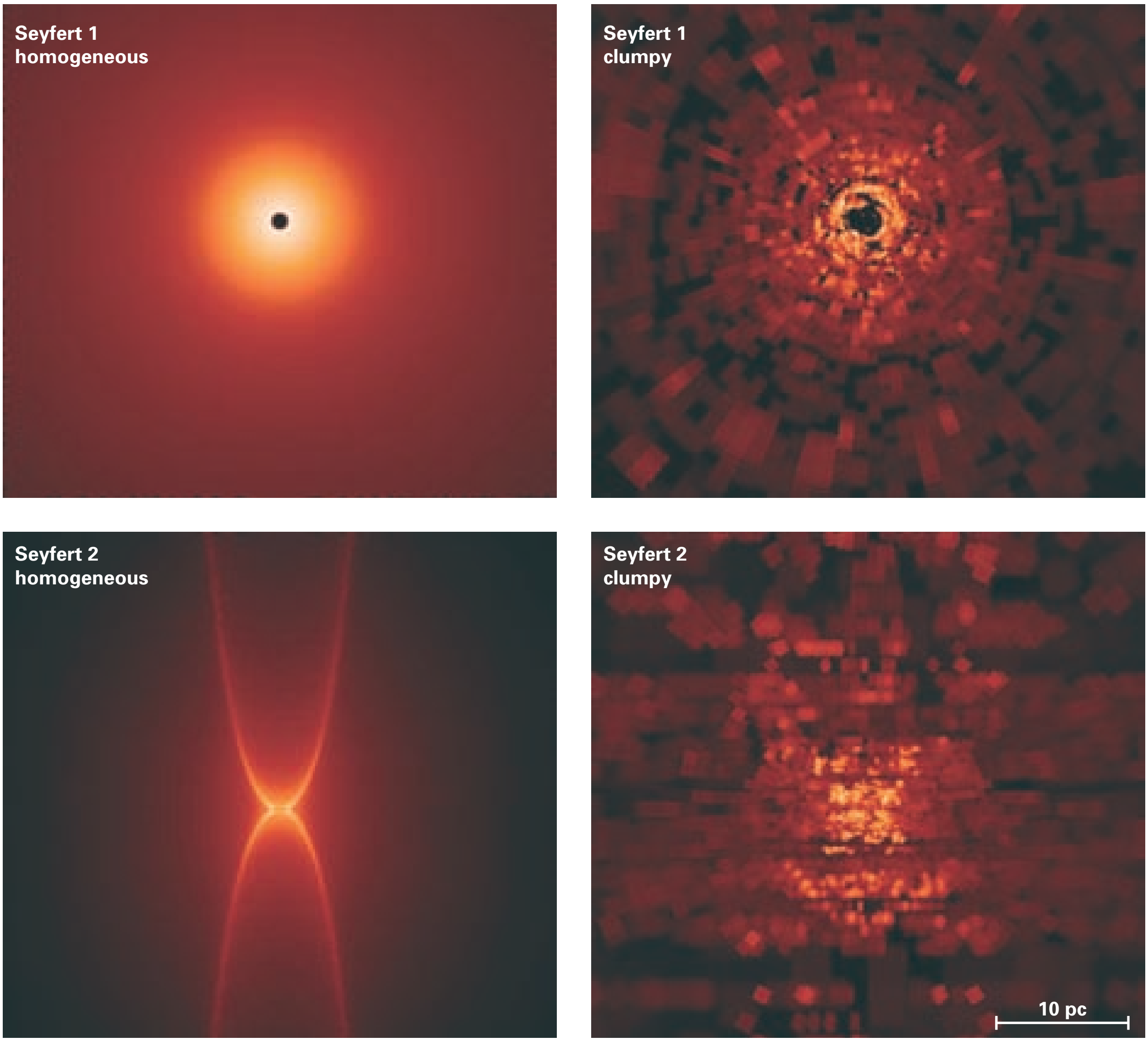


Fig. II.5.5: The dust tori in Seyfert galaxies are probably not filled homogeneously with gas and dust, but rather have a clumpy structure. Model computations for types 1 and 2 at a wavelength of 12 µm yield the images shown here.

Direct Detection of Dust Tori in Seyfert 2 Galaxies

There are two good arguments for first searching for direct evidence for the existence of dust tori in Seyfert 2 galaxies. Firstly, the unified scheme of Seyfert galaxies rests on the hypothesis that the dust in Seyfert 2 galaxies is distributed in a donut-shaped structure. Secondly, here we expect the torus to clearly dominate the mid-infrared radiation, whereas in Seyfert 1 galaxies it will most likely be be outshone by the long-wavelength end of the thermal spectrum of the hot accretion disk.

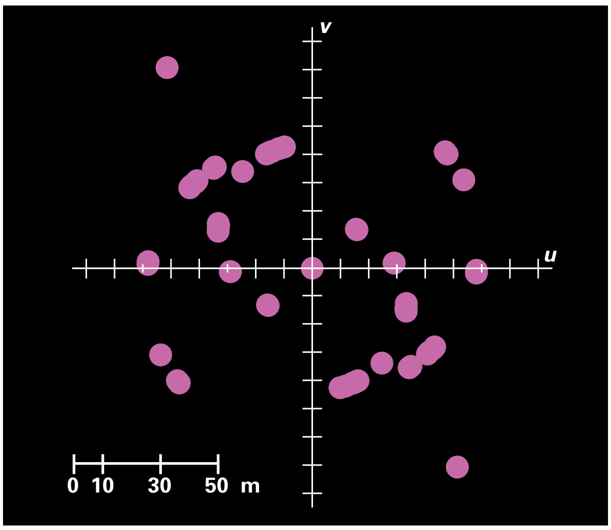
Our first successful observations with MIDI were made in 2003. Based on observations of the archetypical and brightest Seyfert 2 galaxy, NGC 1068, carried out with only two telescope combinations, we were able to show that a dust structure whose warm component is heated by the AGN actually exists in its core. At a temperature of about 300 Kelvin, it has a diameter of 11 ly and an overall height of 6.7 ly. In addition, we detected a hot dust component 3 ly across at most, lying deeply embedded within the warm dust. We interpret this component as the signature of the dust located at the inner surface of the torus – the axial channel – which is heated to temperatures near the evaporation temperature for the dust particles of 1500 K.

These findings unexpectedly closely match the prediction of our simple model (Fig. II.5.4). Though this should be qualified by emphasizing that with only two telescope combinations, it is impossible to determine the orientation of the dust structure independently. It was necessary to assume its symmetry axis based on the orientation of the known outflow phenomena in NGC 1068.

During four observing campaigns, we meanwhile succeeded in observing the nearest Seyfert 2 galaxy – the Circinus galaxy lying at a distance of just under 13 million ly – sufficiently often to be close to the ideal case of a well-filled aperture plane (Fig. II.5.6). For the first time, we are now able to reconstruct an image of the dust distribution without relying on model-dependent assumptions.

The observed sequence of combinations of two telescopes with a total of 15 different orientations, each containing about 20 spectrally resolved, independent measuring points (Fig. II.5.7), in principle allows us to reconstruct a very detailed model of the two-dimensional (projected on the celestial plane) distribution of the dust (including the temperature). However, we decided to do simple image reconstruction first, which is independent of specific model assumptions as far as possible. We as-

Fig. II.5.6: Aperture coverage for the observations of the Circinus galaxy with MIDI. Since each combination of telescopes is represented symmetrically with respect to the origin, the points cover twice the diameter of the entire telescope (see Fig. II.5.2).



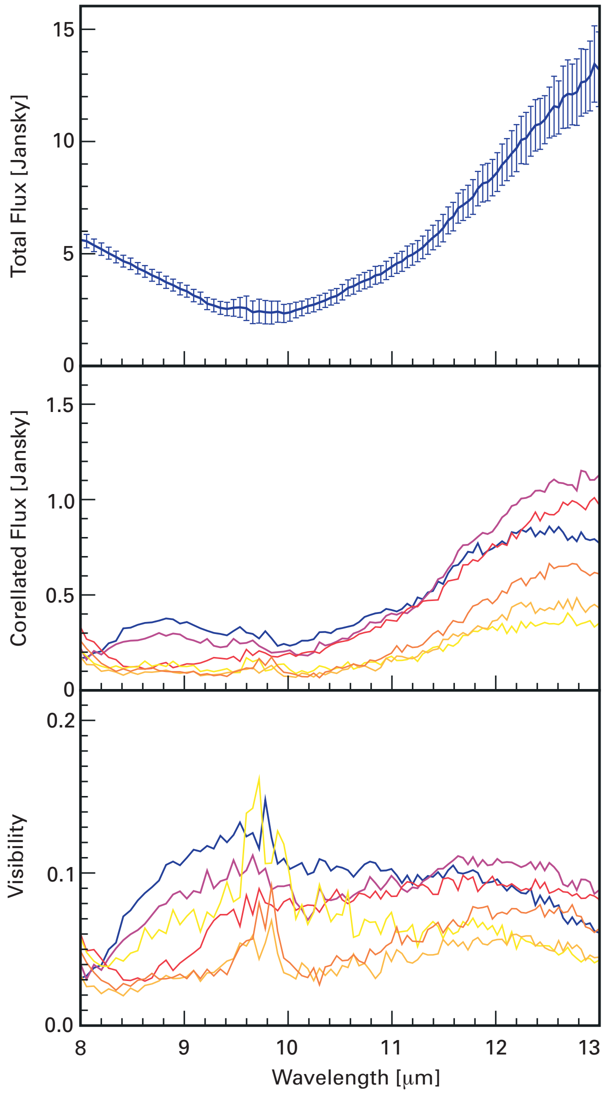


Fig. II.5.7: MIDI observations of the Circinus galaxy. *Above:* Total flux, measured with a single telescope. *Center:* correlated flux from two telescopes during one night, during which the projection on the sky of the baseline connecting the telescopes rotated from northeast-southwest (*yellow*) to southeast-northwest (*pink*). *Below:* the visibility – the quotient of correlated and total flux – is a coarse measure for the size of the torus.

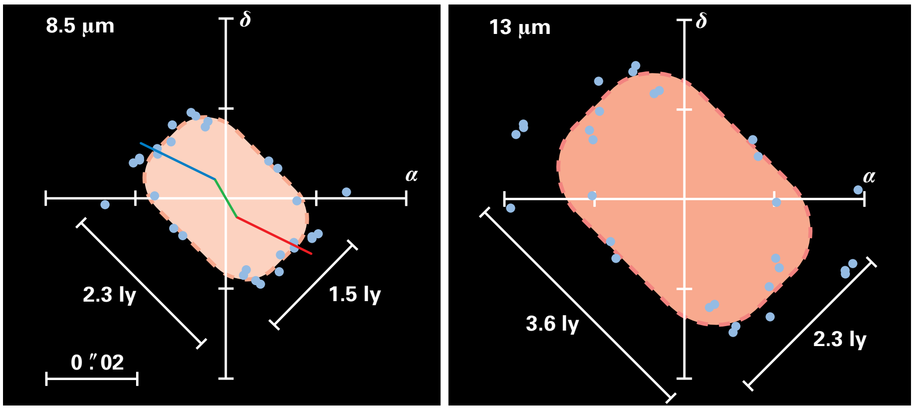
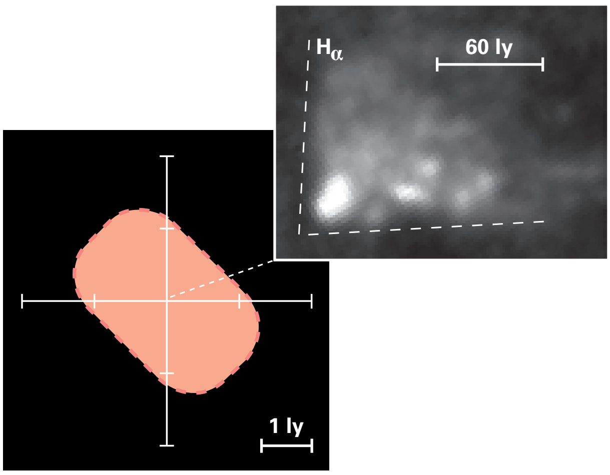


Fig. II.5.8: From the measured visibility (Fig. II.5.7) the effective size of the dusty torus of the Circinus galaxy can be derived – here shown for two wavelenghts. At the larger wavelength the torus appears larger – as expected.

sume that the brightness distribution of the dust emission can be approximated in all projections and all wavelengths by a Gaussian function. Under this assumption, the visibility observed (Fig. II.5.7) can be converted directly into a measurement of the effective width. The points in Fig. II.5.8 represent this reconstructed effective size of the dust distribution in the Circinus galaxy for two wavelength ranges ($\lambda = 8.5$ and 13 µm, cf. Fig. II.5.7). These wavelengths are nearly unaffected by absorption through silicate-dust grains.

With the help of this simple image reconstruction, we find the distribution of the dust to be box-shaped both at a wavelength of 12.5 µm (dominated by dust at about 300 K) and 8.5 µm (hotter dust). At 12.5 µm, the observed dimension of the box is 50×30 mas, corresponding to a diameter of 3.2 ly and a height of 1.9 ly. The size and orientation match other observations of the nucleus of the Circinus galaxy (Fig. II.5.9): For example, the symmetry axis of the ionization cone observed with HST is exactly perpendicular to the maximum extension (the plane of the torus) found. In addition, the region where Maser emission of molecular H_2O gas was found in well-ordered rotation exactly corresponds to our dust distribution. This proves that water vapor and dust are concentrated in the same regions.

Fig. II.5.9: The axis of symmetry of the ionized cone in the Circinus galaxy imaged by the HST is exactly perpendicular to the dursty torus, as reconstructed from the MIDI data. Note the different scales.



The actual vertical dimension of the dust distribution still has to be examined since an apparent height could be feigned by an inclined disk. Applying the most probable value for the orientation of the symmetry axis with respect to our line of sight (70°), we find the true height of the dust torus to be just under 1 ly. This leads us to the conclusione that the torus in the Circinus galaxy is relatively thin, the ratio of height to diameter here is about h/d = 0.25. In comparison, the relative thickness in NGC 1068 is h/d = 0.6. This finding is in excellent agreement with the observation that the ionization cone of the Circinus galaxy has a much wider opening angle than that of NGC 1068 (comp. Fig. II.5.9 to Fig. II.5.1b).

The previous MIDI-observations of the two nearest Seyfert II galaxies thus strongly confirm the picture of a central dust torus preventing a direct view of the accretion disk. In the future, comparison with high-resolution radio maps and millimeter observations with ALMA will enable us to study in more detail how the gas reservoir within the torus flows inwards, thus »feeding« the accretion disk.

Interferometric Observations of the Nucleus of the Radio Galaxy Centaurus A

At a distance of only 12 million ly, Centaurus A is the nearest radio galaxy. We have also observed it with MIDI. This data shows the mid-infrared emission to be dominated by an unresolved point source. Its diameter is apparently smaller than 0.6 ly. From comparison with observations at radio- and millimeter-wavelengths, we conclude that this emission does not originate from warm dust, but from synchrotron radiation of high-energy electrons spiraling in a magnetic field of 0.3 Gauß (Fig. II.5.10). We will not go into the details of this source here, but only state that we found no evidence of the presence of a central, AGN heated dust distribution in Centaurus A. Obviously there is a class of AGN which has no dust torus.

MIDI Observations of More Distant and Fainter Active Nuclei

In 2005 we also succeeded in observing the Seyfert 1 galaxies NGC 3783 and Markarian 1239 as well as the Seyfert 2 galaxy MCG-5-23-16 with MIDI. This is remarkable insofar as these sources are below the previously assumed brightness limit of the instrument (10 µm flux from the nucleus > 1 Jy). This shows that MIDI is also able to observe sources in the range of 0.5 Jy without stabilization of the fringe pattern with the help of the planned fringe tracker FINITO (which will operate at about 2 µm, but is not in operation yet). This encouraging news extends our list of possible extragalactic targets for MIDI from three sources (NGC 1068, Circinus, Centaurus A) to at least one dozen.

Based on the larger distance, the results obtained so far for the three sources mentioned above indicate that these cannot be resolved with the rather compact telescope combinations of the VLTI (Fig. II.5.2). The diameter of the expected dust torus is smaller than 10 mas. In the next step we will choose telescope combinations with larger separations. In fact, in order to fully prove the unified scheme, it is crucial to not only show that dust tori exist in Seyfert 2 galaxies. Evidence of similar tori in Seyfert 1 galaxies is just as important. Only this would prove the gas and dust reservoir within the torus to be essential for the high – compared to the mass of the black hole – mass-inflow-rate and the resulting high luminosities of the Seyfert nuclei.

Summary

Even in its first three years of operation at the VLTI, MIDI has demonstrated that interferometric observations in the mid-infrared range allow important insights into the processes within active galactic nuclei. Direct evidence of dust tori in Seyfert 2 galaxies not only confirms the unified scheme, but for the first time also opens up the opportunity to study the gas reservoir that seems to be responsible for the high luminosity of Seyfert galaxies and their big brothers, the quasars.

First results on the radio galaxy Centaurus A also allow us to work out the differences between Seyfert 1 galaxies (usually showing very weak radio emission) and radio galaxies. We are confident that we will also be able to detect the »missing link«, the tori in Seyfert 1 galaxies, with MIDI in the near future– or to disprove this theory. Thus the end of the first stage on the path to directly observing the physical processes in the center of active galactic nuclei may soon be reached. MIDI is paving the way towards a new era of extragalactic astronomy with interferometric techniques.

(Klaus Meisenheimer, Konrad Tristram, Marc Schartmann, Sebastian Wolf, Thomas Henning, Hubert Klahr. Participating institutes: Landessternwarte Heidelberg; Leiden Observatory)

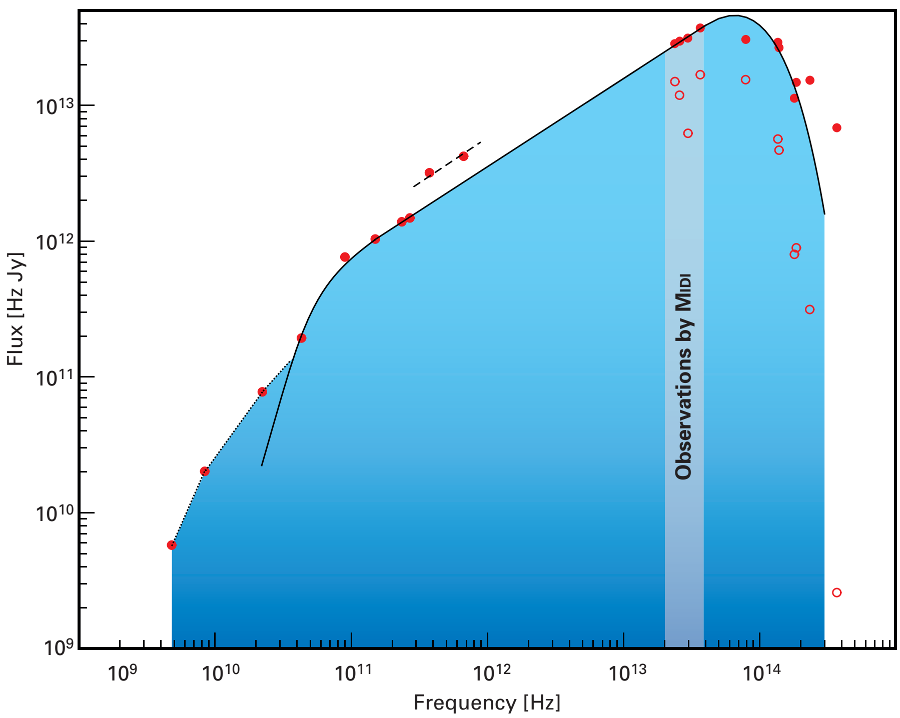


Fig. II.5.10: MIDI measurements of the nucleus of Centaurus A agree well with the observed spectrum of the nonthermal synchrotron radiation of this radio galaxy. Open circles: observed flux, full dots: corrected for foreground absorption.

II.6 Massive Star Clusters in the Centers of Spiral Galaxies

In the last decade, very compact, massive star clusters have been discovered in the very centers of spiral galaxies using the Hubble Space Telescope, even in galaxies that have no stellar bulge. Because of their small dimensions of typically about 30 light years, they are difficult to study. An international team of astronomers under the leadership of the MPIA spectroscopically observed nine such clusters for the first time, deriving fundamental quantities such as mass, chemical composition and the evolutionary stage. These nuclear clusters have sizes and masses comparable to the biggest globular clusters, they also have properties that are apparently unique to their positions at the center of a galaxy: they have multiple-age populations, hence an extended formation history, and some may show signs of an active galactic nucleus. The actual connection between these properties and their central, nuclear position remain yet to be explained.

The centers of galaxies have attracted special interest from astronomers for a long time because they often have very unusual properties. These include massive black holes (frequently surrounded by a hot accretion disk), regions of intense star formation, or extremely dense star clusters. Moreover, several correlations between the properties of the core region and those of the overall galaxy were found, indicating a close relation between the evolutionary history of both regions.

Even more than 20 years ago, it was suspected that the centers of many spiral galaxies host compact star clusters whose dynamics are largely independent of the remaining bulge and disk. But because of the insufficient resolution of the telescopes at that time, this hypothesis could not be verified. This changed fundamentally with the Hubble Space Telescope (HST), which enabled the detection of several »nuclear star clusters«. The most famous and best-studied examples are lying in the center of our Milky Way system as well as in the cores of the Andromeda Galaxy M31 and the Triangulum Galaxy M33. The latter cluster has a mass of about 5×10^5 solar masses. Most of these clusters have 10^6 to 10^7 solar masses and thus are typically somewhat bigger than massive globular clusters.

The existence of these clusters is a mystery. Particularly in spiral galaxies without a bulge, the gravitational potential from stars in the center is rather flat. Therefore, one would not expect a compact cluster to form there. They nevertheless are observed. These cases suggest that nuclear star clusters might be the initial stages of bulge development. At the same time, the compact appearance of the nuclear star clusters was reason to speculate that there may be a relationship between these clusters and the globular clusters of similar appearance and/or the ultra compact centers of some dwarf galaxies. However, there were no systematic attempts made to tackle this problem up until now. The new study has changed this.

A total of nine nuclear clusters were studied spectroscopically, all located at the (geometric) centers of spiral galaxies of types Scd to Sm (Fig. II.6.1). For all of them, imagesobtained with the WFPC2 camera of HST were already available. The spectra were obtained with the Uves instrument at the Very Large Telescope (VLT). Since the seeing disk was larger than the effective radii (0.″2) of the star clusters (which are about 7 to 75 million light years away) the spectra obtained are integrated and spatially unresolved (Table II.6.1).

In a first step, the astronomers used the Doppler-broadened widths of several absorption lines to determine the velocity dispersions in the clusters. From these values (ranging between 13 and 34 km/s), the cluster masses could be calculated using a dynamical model. Such modeling also requires estimates for the luminosities and effective radii. The latter could be obtained from the intensity profiles of the HST images, aided by deconvolution with the point spread function of HST. With luminosities between about 10^6 and 10^8 solar luminosities masses between 10^6 and 6×10^7 solar masses were derived. The biggest nuclear cluster (in NGC 7418) thus exceeds the most massive globular cluster of the Galaxy (Omega Centauri) by a factor of ten.

The photometric and spectroscopic data available and the derived physical quantities yielded fundamental properties of nuclear clusters that were be compared to those of globular clusters and ultra compact nuclei of dwarf galaxies. Comparing the projected mass density proved particularly useful. As shown in Fig. II.6.2, the nuclear clusters (filled squares) and the galactic globular clusters lie along a single sequence which defines the location of clusters of a constant radius of about 10 ly. Here the nuclear clusters occupy the upper region. However, there may be some bias, as since mainly luminous clusters were selected for the study. The ultra compact nuclei of dwarf galaxies lie in a band running more or less parallel below this sequence. This means that at a certain total mass, the nuclei of dwarf galaxies have lower mass densities than the nuclear star clusters. Clearly separated from these three groups is the locus of the bulges, or galaxy spheroids, and elliptical dwarf galaxies. Since there are no transition objects between these two groups, nuclear clusters are clearly not to be interpreted as the »smallest bulges«.

Fig. II.6.1: Three spiral galaxies with nuclear star clusters investigated within the new study: NGC 300, NGC 7424, and NGC 7793, imaged with a) HST, the b) VLT and c) SPITZER. These images illustrate the observational problem to discriminate the central star clusters from the surrounding stars of the galaxy. (Images: HUBBLE Heritage Team, NASA/ESA; NASA/JPL-Caltech/R. Kennicutt and the SINGS Team; ESA).

Quite a similar picture emerges when the phase space densities of the systems are compared which provide a measure of the gas dissipation that preceded the cluster formation. This quantity can be calculated from a combination of effective radius and velocity dispersion (Fig. II.6.3). Here too, globular clusters and nuclear clusters fall on a well defined straight band which now also contains the nuclei of dwarf galaxies, while elliptical galaxies and dwarf galaxies are clearly separated from them. In addition, there is a significant difference between the slopes of the two correlations, reinforcing the previous interpretation: nuclear star clusters probably are not progenitors of galaxy bulges.

Yet, marked differences between nuclear clusters and globular clusters arise when considering the spectral properties. The spectra obtained with UVES allowed determination of the ages of the star clusters. To this end, the MPIA team used three different methods: 1) a set of »spectral indices«, 2) fits of the observed spectra with synthetic spectra of a single-age stellar population, and 3) fits of the observed spectra with synthetic spectra of a stellar population of different ages. While the first method was successful with globular clusters, it had its difficulties with nuclear clusters because of their relatively

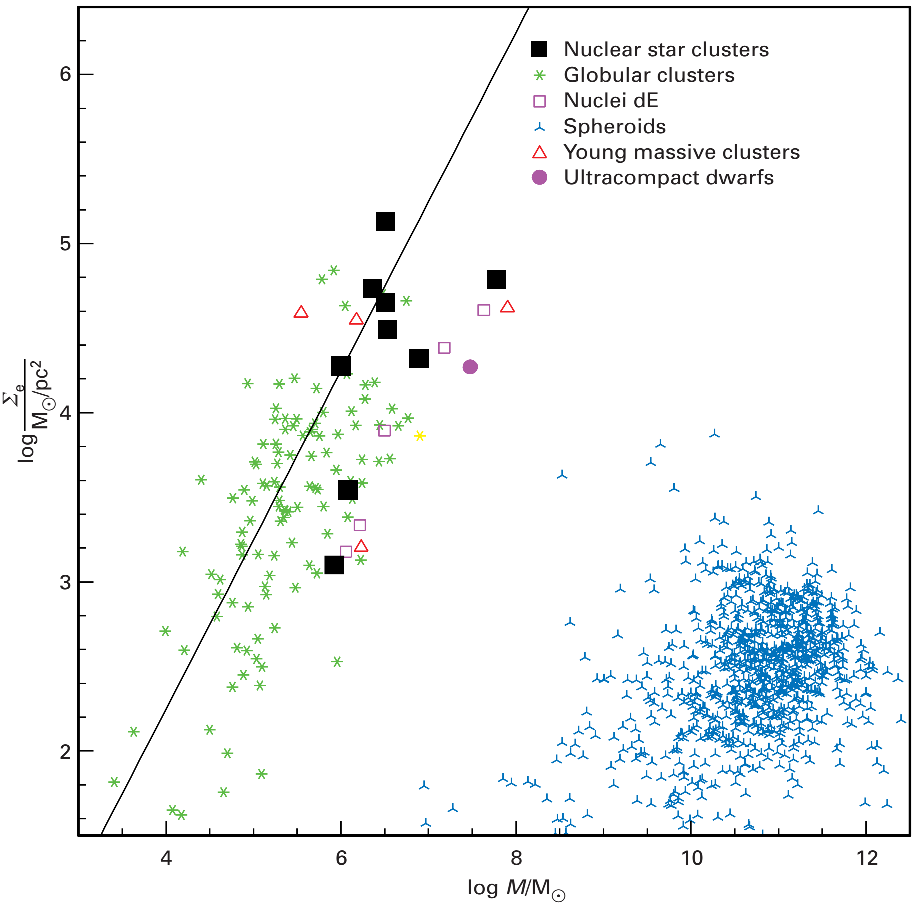


Fig. II.6.2: Projected mass density versus total mass. The nuclear clusters (filled squares) lie along a single sequence mainly defined by galactic globular clusters. Clearly separated from them are the spherical galaxies and the dwarf galaxies.

young ages. Therefore, the team tried to consequently further develop the second and third methods. The high quality of the data and the increasingly realistic synthetic spectra were particularly useful for this purpose. The third method was based on the finding that each population with any evolutionary history can be described by a series of instantaneous star formation events.

Spectral model fits assuming single-ages yielded estimates ranging from 10^7 to 3×10^9 years for the dominant stellar population of the respective cluster. The results were relatively independent of the metallicity assumed. When extended star formation histories were used to fit the spectra, somewhat higher mean ages of 4×10^7 to 10^{10} years were obtained throughout. The metallicity is generally slightly sub-solar but shows significant scatter

Table: II.6.1: Properties of nuclear clusters. Here d signifies the distance, t the mean age, Z the metallicity, t_{min} the time of the last star formation episode, and M the mass.

Galaxy	d [Mpc]	log(t)	Z	log(t_{min})	log($M/M_\odot$)
NGC 0300	2.2	9.49	0.004	8.00	6.02 ± 0.24
NGC 0428	6.1	9.27	0.02	7.48	6.51 ± 0.14
NGC 1042	18.2	10.05	0.02	7.00	6.51 ± 0.21
NGC 1493	11.4	9.76	0.008	7.00	6.38 ± 0.14
NGC 2139	23.6	7.61	0.05	6.48	5.92 ± 0.20
NGC 3423	14.6	9.75	0.008	7.00	6.53 ± 0.14
NGC 7418	18.4	9.05	0.008	7.00	7.78 ± 0.19
NGC 7424	10.9	9.11	0.008	7.48	6.09 ± 0.14
NGC 7793	3.3	9.29	0.008	8.00	6.89 ± 0.14

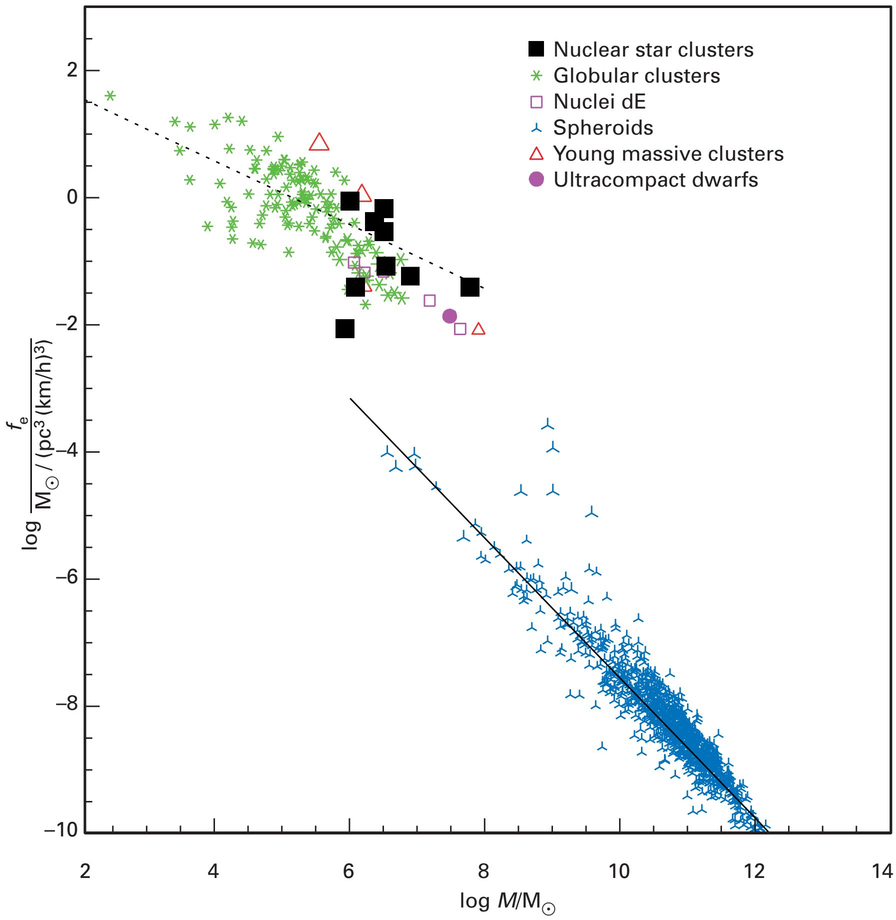


Fig. II.6.3: Phase space densities versus total mass for different types of stellar systems. Again a clear gap between the nuclear star clusters and globular clusters on the one hand and the spherical (dwarf) galaxies on the other hand is discernible. The dotted line marks the location of clusters fulfilling the virial theorem and having a radius of 10 ly. The solid line is the locus of systems meeting the virial theorem and a Faber-Jackson type relationship between mass and velocity dispersion.

between the individual clusters (Table II.6.1). Modeling extended formation histories, with multiple ages, always yielded better fits to the spectra than a single population. From these fits, the team was able to conclude that nuclear clusters, in contrast to globular clusters, generically have multi-age stellar populations.

Moreover, modeling with several stellar populations allowed us to determine the time of the last star formation episode tmin for each cluster. The average is 34 million years; none of the last episodes was more than 100 million years ago.

Obviously these nuclear clusters underwent repeated star formation episodes in the past and still do today. This again raises the question of how these compact, massive star clusters formed in the centers of so many spiral galaxies. Which processes induce recurrent star formation episodes? And it is still a mystery as to why no nuclear star clusters are found in the centers of some spiral galaxies that seem to be no different than others that do have them. Therefore, the team carried out more observations that will contribute to a better understanding of the fundamental properties of galactic centers in the future.

(Jakob Walcher, Hans-Walter Rix, Nadine Neumayer, in cooperation with: Space Telescope Science Institute, Baltimore; ESA/ESTEC, *Noordwijk; Observatories of the Carnegie Institution of Washington, Pasadena; Oxford Astrophysics, Oxford; Ohio University, Athens, USA; MPI für Astrophysik, Garching, and Institut d'Astrophysique de Paris)*

II.7 Observations of Distant Galaxies with Spitzer

Recent observations have convincingly established that over the last eight billion years, the mean star formation rate in the universe has declined by almost one order of magnitude. Both the cause of this phenomenon and which galaxy types are responsible for it are largely unclear. An international team of astronomers under the leadership of the MPIA investigated these questions by identifying almost 8000 galaxies on an infrared image taken with the Spitzer Space Telescope and combining their infrared fluxes with data from the Combo-17 and other surveys. Studies of local galaxies had already shown the infrared luminosities of galaxies to be a very good measure of the star formation rate. Using a special analysis technique, the scientists at the MPIA have now measured the mean infrared luminosities of galaxies (even of faint dwarf galaxies that would normally be undetectable) in great detail. This enabled them to determine the most accurate estimate to date of the evolution of the global star formation rate over the last eight billion years. These new results show that this rate has decreased by a factor of nine. Furthermore, the new Spitzer observations showed that this is mainly caused by the decline of luminous and ultra luminous infrared galaxies.

The massive stars in a young stellar population dominate the UV luminosity of a galaxy and often even its overall energy output. Large quantities of dust present in star-forming regions, however, absorb most of the UV emission. As a result, the dust heated by young stars radiates in the thermal infrared range. All observational estimates of the star formation rate therefore are based either on the measurement of the UV or the infrared luminosity. A complete census of the light from young stars in distant galaxies actually should include both UV and infrared fluxes.

Until recently, IR telescopes lacked the sensitivity and resolution needed for detailed observations of distant galaxies, particularly in the low-mass range. Now the Spitzer Space Telescope allows such observations in the wavelength range between 3.6 and 160 µm.

An international team under the leadership of the MPIA used the image of a field of $90' \times 30'$ taken with the »Multiband Imaging Photometer on Spitzer« (Mips) at a wavelength of 24 µm. It is considered a mosaic image, since the field of view of Mips is only $5\rlap{.}'4 \times 5\rlap{.}'4$. The Mips field covers the area of the Chandra Deep Field South X-ray image and also coincides with the Combo-17 survey (Classifying Objects by Medium-Band Observations with 17 Filters) of MPIA and the Gems image from the Hubble Space Telescope.

Within Combo-17, a large area of the sky was imaged through 17 filters and the magnitudes of galaxies were measured in the corresponding color bands. Up to a redshift of $z \approx 1$ (about half the age of the Universe), this allows us to classify galaxies and determine their redshifts with an accuracy of a few percent. The decisive prerequisite for the project was the large field of view of the Wide Field Imager camera (WFI) developed under the leadership of the MPIA and built in collaboration (ed) with Eso. It is operated at the 2.2-m MPG/Eso telescope on la Silla, Chile and has a field of view of $32' \times 33'$, corresponding approximately to the area of the full moon.

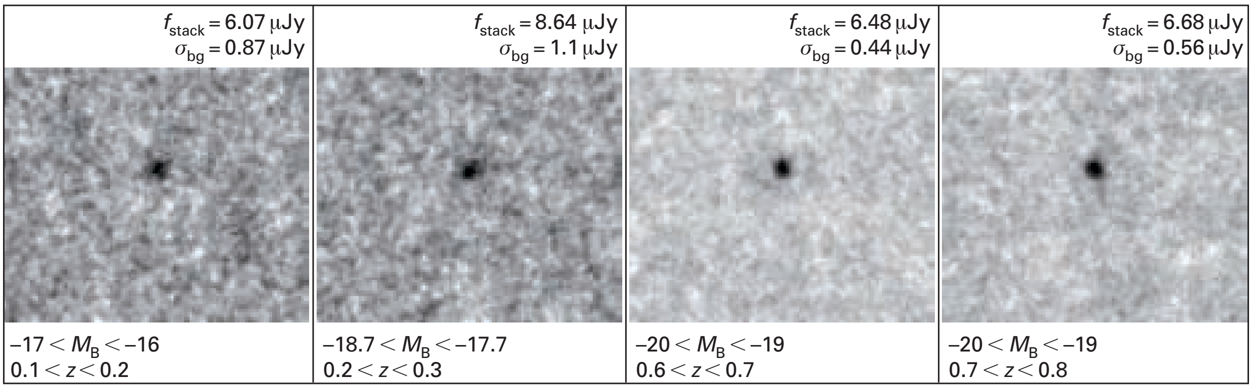


Fig. II.7.1: The mean thermal–IR emission for classes of galaxies in four different redshift bins, $0.1 < z < 0.8$. As hardly any of these galaxies are detected individually, the Mips images for all galaxies of a given B-band in a redshift bin were »stacked«, providing a clear statistical detection of the dust heated by young stars.

The Combo-17 colors are used to identify stars, quasars, and different types of galaxies such as elliptical, spiral and starburst galaxieswith specially developed software. A total of roughly 25 000 galaxies are recorded, making Combo-17 one of the most extensive and deepest surveys in the world.

Even with the improved sensitivity of Spitzer (IR flux larger than 83 μJy at 24 μm), only galaxies with unusually high star formation rates can be measured as individual objects in the thermal infrared range. At a redshift of $z = 0.7$, the lower limit is about six solar masses per year – a few times larger than the SFR in the Milky Way. However, the combination of the Mips data with the redshifts and positions from Combo-17 was used to significantly improve the detection threshold with the help of »stacking«. This method works according to the following principle: based on the Combo-17 data, a set of one hundred galaxies is defined (for example blue galaxies in the redshift range of $z = 0.7$ that are as bright as the Milky Way system). Then the Mips frames are centered on the coordinates of these galaxies and added up. Most of the time, even when none of the objects are visible individually, the stacking yields a significant measurement of the mean infrared flux. This technique was previously used for X-ray and submillimeter images, but it is novel for infrared images.

In this way, it was possible to reduce the lower limit for the measured infrared fluxes by a factor of five (for $0.7 < z < 1.0$) and ten ($z < 0.7$), respectively, below the previous limit for the Mips images and to determine star formation rates less than one solar mass per year. Finally, the mean redshifts and mean magnitudes at 24 μm and 2800 Angström as well as in the Johnson-U-, V-, and B-bands were available for various sub-classes for a total of almost 8000 galaxies.

This sample was divided into nine groups with redshifts between $z = 0.1$ and $z = 1$, corresponding to a maximum look-back time of almost eight billion years. Fig. II.7.1 shows examples of four sub-classes of galaxies with their infrared fluxes in four redshift ranges. Notice the low infrared fluxes lying far below the previous threshold of 83 μJy.

The Relationship Between IR Luminosity and Star Formation Rate

In nearby galaxies that can be studied in detail, a relationship was found between the ratio of the IR and UV luminosities (L_{IR}/L_{UV}) and the absolute blue-band magnitude (B). Galaxies with a low B magnitude also show a low L_{IR}/L_{UV} ratio: the higher the star formation rate, the higher the dust extinction, and the higher the fraction of UV radiation converted into IR radiation.

With the data set available, this empirical relationship can now be tested for more distant galaxies. In order to do this, however, the overall infrared luminosity from 8 to 1000 μm had to be calculated from the 24-μm fluxes. This was achieved by fitting typical spectral distributions for various galaxy types to the measured spectral data. This method yields rather imprecise infrared fluxes, but within the uncertainties, the ratio of L_{IR}/L_{UV} to B seems

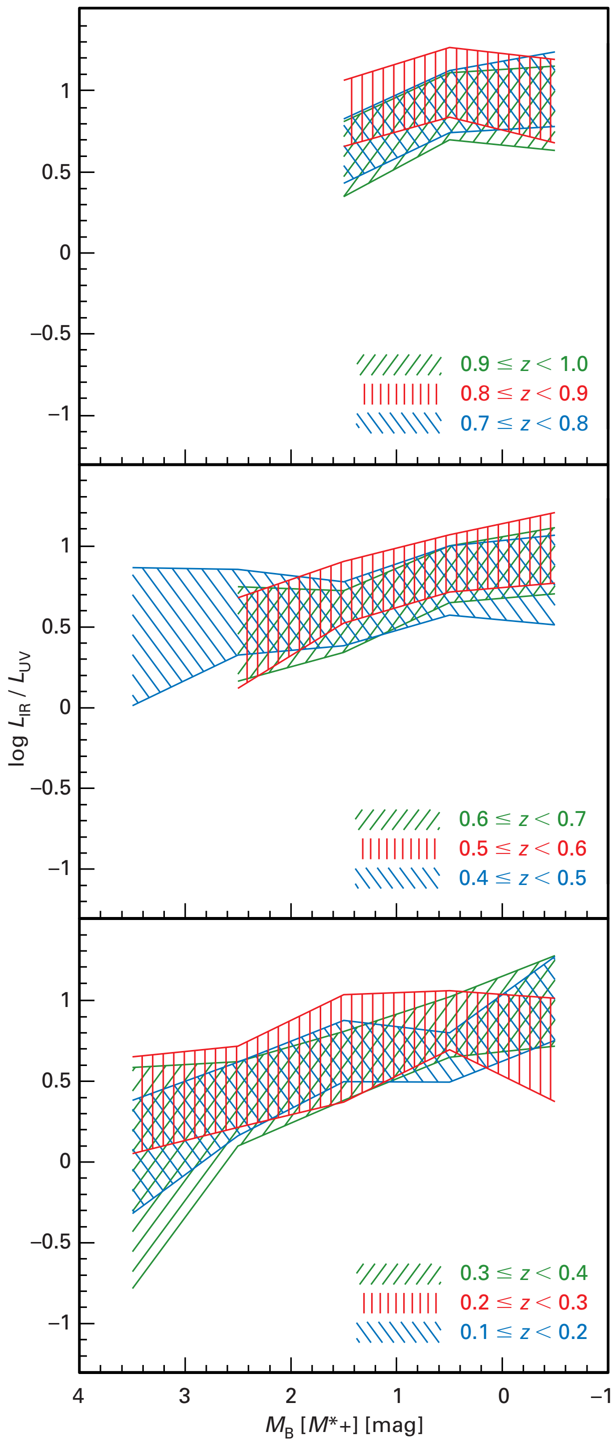


Fig. II.7.2: Correlation between the L_{IR}/L_{UV} ratio (i.e. the absorbed vs. escaping radiation from young stars) and the B magnitude for various redshift ranges: the more luminous a galaxy is, the higher the fraction of IR radiation. This holds at all redhifts (bottom to top panel).

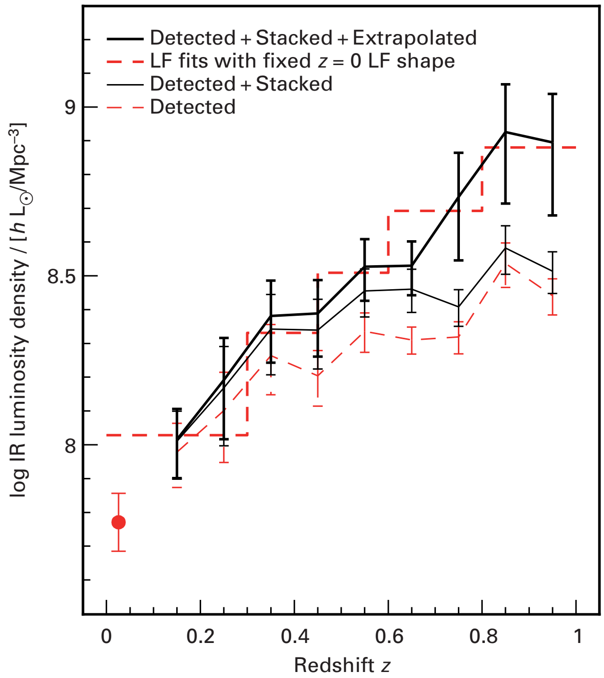


Fig. II.7.3: IR luminosity density as a function of redshift (*solid line*), reflecting the decay of the global star-formation rate for $z \approx 1$ to the present. The red dot in the lower left indicates the value for the present-day universe. The red dashed line represents the results of another, independent study.

to resemble that of local galaxies, at least for $z < 0.8$ (Fig. II.7.2).

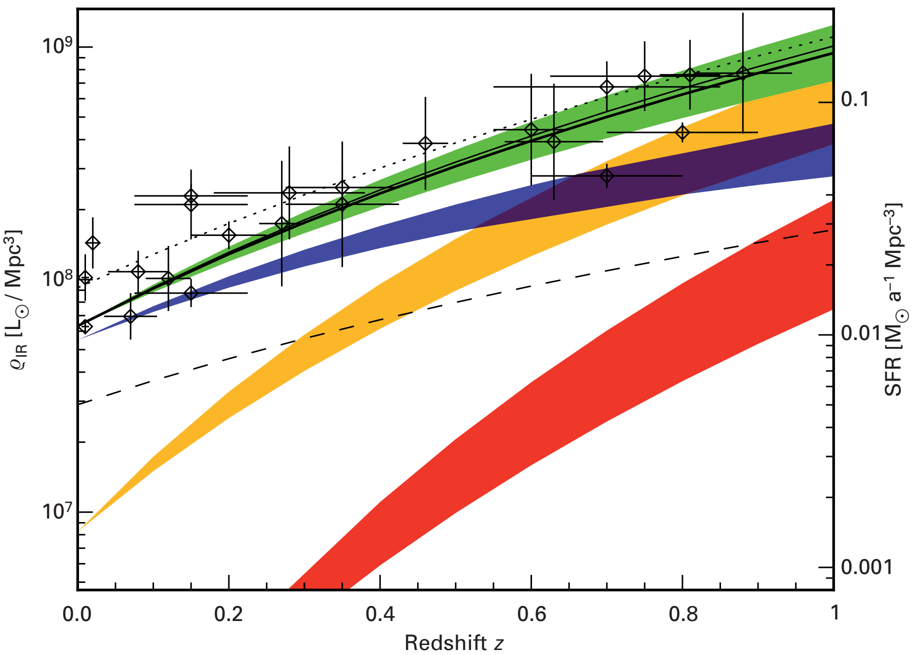
The question now was how to convert the measured fluxes at 24 μm (corresponding to a rest wavelength of 15 μm), which is a measure for the thermal IR, as well as the 380-nm-flux, which is a measure for the UV, into a star formation rate. These two quantities should be crucial: in the UV we are directly observing the emission of the young, hot stars while in the IR we are seeing the light from these same stars that has been absorbed by dust and subsequently re-radiated. The overall UV flux from 1216 to 3000 Angström has to be calculated from the COMBO-17 magnitudes measured at 2800 Angström with the help of an empirical relationship. The star formation rate then follows from a formula containing the sum of the UV and IR luminosities.

The essential result of this study is that all galaxies clearly follow the trend seen in local galaxies, according to which the luminosity ratio L_{IR}/L_{UV} increases with the star formation rate. This is true at least to a redshift of 0.8, the redshift limit of this study.

Finally, astronomers were able to calculate the cosmic star formation rate from the IR luminosity. Compared to previous work, this was particularly significant because the new data account for the contribution from faint galaxies that were missing from previous samples. The result shows the overall IR luminosity (within a unit volume that is co-moving with the expansion of the Universe) as a function of redshift (Fig. II.7.3). We see that the thermal IR luminosity has decreased by a factor of nine over the last eight billion years.

These results demonstrate that the star formation rate has strongly decreased in the second half of the life of the Universe. The crucial question now is which galaxy types are primarily responsible for the dramatic decline of the cosmic star formation.

Fig. II.7.4: Evolution of the IR energy density, total (*green*) and for different galaxy types. *Blue:* low-luminosity galaxies (L_{IR}, 10^{11} $L_\odot$), orange : LIRGs, *red*: ULIRGs. The solid line shows a decrease with a power-law dependence on redshift and an exponent of 3.9.



The Disappearance of Luminous and Ultra-luminous Infrared Galaxies

To investigate this question, astronomers studied a subset of about 2600 relatively bright galaxies on the MIPS image with IR fluxes larger than 80 μJy. This sample is dominated by luminous (LIRG) and ultra luminous infrared galaxies (ULIRG). In the wavelength range from 8 to 1000 μm these galaxies have luminosities between 10^{11} and 10^{12} solar luminosities or more.

The newly analyzed data clearly shows that these two galaxy types were significantly more frequent in the past, and that they provided the major part of the total luminosity density in the infrared range (Fig. II.7.4). At a redshift of $z = 1$ LIRGS (pictured in orange in the figure) contribute about 70 percent of the infrared radiation, while ULIRGS (red) contribute about ten percent. Subsequently, the number of LIRGS and ULIRGS has strongly decreased, and about five billion years ago ($z < 0.5$), low-luminosity galaxies (blue) started to dominate the IR luminosity density – these are actually close to »normal« spirals galaxies.

On the whole, the density of galaxies with IR luminosities higher than 10^{11} solar luminosities has decreased by more than a factor of 100 over the last eight billion years, with a particularly strong decline of ULIRGS. This suggests that these galaxies extremely rich in dust with high star formation rates were much more frequent in an earlier era of the Universe ($z > 1$) than at $z = 1$. They may be responsible for the peak of the cosmic star formation rate at redshifts between 2 and 3. Further evidence that the fraction of dust-rich galaxies was much larger in the past is also indicated by the fact that IR luminosity density decreases with the redshift raised to almost the fourth power. Over the same period of time, the UV density (the direct stellar radiation not absorbed by dust) has decreased with the redshift raised to only the second power.

Thus the new IR images obtained with the SPITZER telescope allowed astronomers to study the evolution of cosmic star formation over the last eight billion years in detail. The accuracy of the results crucially depends on the calculation of the overall luminosities from a few observed spectral data points. Therefore observations in the mid- and far-infrared range (e.g. with HERSCHEL) as well as in the submillimeter and millimeter range (with ALMA) will yield more accurate results in the future.

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Instituto de Estructura de la Materia, Madrid;
Space Science Institute, Boulder;
National Optical Astronomy Observatory, Tucson)

II.8 Dynamics, Dust, and Young Stars

Computer Simulations of Merging Galaxies

During close encounters or collisions of galaxies huge tidal forces occur that whirl up and compress the dust and gas in the galaxies. This induces a steep increase of star formation in dense dust filaments that absorb a major part of the galaxy light. In some nearby galaxy pairs this process can be studied in detail. In distant stellar systems, however, this is impossible. Here, one has to infer the star formation rate from luminosities in certain wavelengths ranges averaged over the entire galaxy. With the help of extensive computer simulations, a theorist at MPIA and her colleagues showed how the star formation rate, dust absorption, and observed appearance of the galaxy change during a merger. They derived an analytical formula based on the simulations, which can be used to predict the dust absorption. These results will considerably improve galaxy evolution models.

While stars in the Milky Way virtually never collide, galaxy collisions, by comparison, are rather frequent. In fact, they are a central mechanism of galaxy evolution. The most famous example of two merging galaxies are NGC 4038 and NGC 4039 at a distance of 63 million light years, jointly called the Antennae (Fig. II.8.1). In the collision zone, huge clouds of dust are stirred up. In many places the collision caused the clouds to condense and to form new stars. In this kind of galaxy interaction, the star formation rate can increase from a few solar masses per year to 30 to 50 solar masses per year; for a short time the rate can be even higher.

Fig. II.8.1: The Antennae in an overall view *(left)* and imaged with the HUBBLE Space Telescope in detail *(right)*. (Photo: B. Whitmore, NASA/ESA).

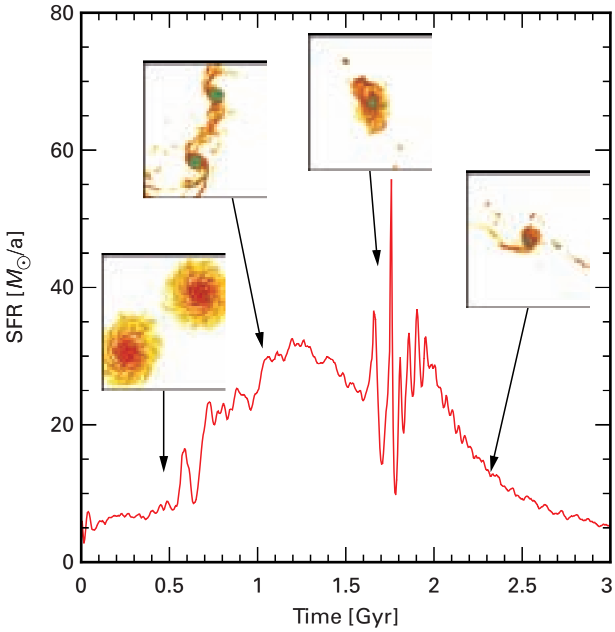


Fig. II.8.2: Star formation rate as a function of time for the merger of two Milky Way-like Sbc galaxies. The small figures illustrate the distribution of the gas at various stages of the merger event from a viewpoint perpendicular to the orbital plane.

In these starburst galaxies, the most massive and luminous stars dominate the radiation in the UV and blue spectral range. But at the same time, dust clouds absorb a large fraction of the light. Therefore the regions of the most intense star formation may not be visible at all in the UV or optical. But these young stars heat the dust, which then glows in the infrared. These galaxies then appear as ultra luminous infrared galaxies (ULIRG) with total luminosities of more than 10^{12} solar luminosities. The peak of the dust emission is at around 100 microns, which in distant galaxies is shifted towards longer wavelengths, so that these galaxies glow brightly in the submillimeter and millimeter wavelength range.

Observationally, high star formation rates are always linked to the presence of dense dust clouds. In numerous simulations, theorists have tried to account for this effect in order to be able to interpret the observations or to support simulations of galaxy evolution. However, previous attempts either neglected the presence of dust or else assumed very simplified geometries for the galaxies, which clearly could not apply to the complex merging systems.

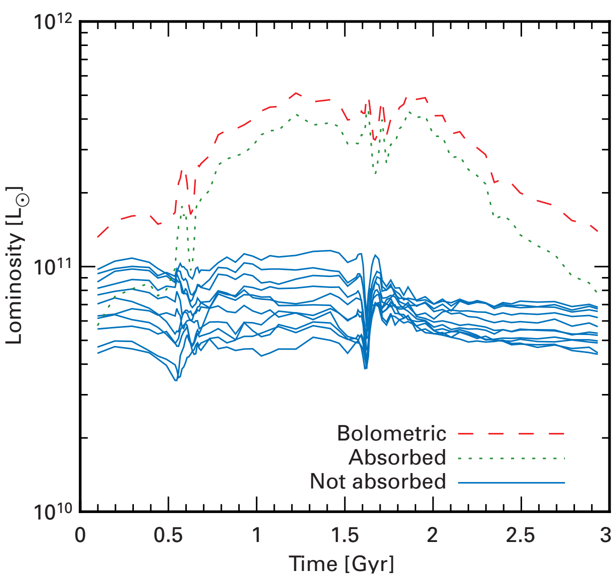
This new work uses a full radiative transfer model within detailed hydrodynamic simulations, so that for the first time astronomers can study the detailed appearance of merging galaxies at many wavelengths, including the effect of dust scattering, absorption, and re-emission. Another improvement in these simulations is a better treatment of the feedback of energy into the gas from supernovae with respect to previous work. The simulations assume an empirical relationship between the gas density and the resulting star formation rate. In addition, the simulations track the production of heavy elements (»metals«) produced by supernovae. The goal of this work was to study the fraction of light absorbed by dust as a function of physical properties of the galaxy such as mass, gas fraction, metallicity, and star formation rate.

The starting point of the simulations is models of individual galaxies with properties chosen to match spiral galaxies in the nearby universe. They span a range of properties such as mass, gas fraction, and metallicity. These galaxies are then set up on a parabolic orbit and allowed to collide with one another. A large number of simulations was performed in order to explore variations due to the galaxy orientation and orbit.

During the interaction, the distribution of stars, gas, and dust was determined at 50 different points in time and used as input to the detailed radiative-transfer calculations. This procedure produced images of the galaxies at 22 wavelengths between 21 nm and 5 µm and from eleven different viewpoints. The radiative transfer code is based on a »ray tracing« method, in which »photon packets« emitted by stars are followed as they are scattered or absorbed by dust grains, and then re-radiated at longer wavelength.

Figure II.8.2 shows an example of the evolution of the star formation rate during the merger of two gas-rich spiral galaxies viewed perpendicular to the orbital plane. The small figures illustrate the distribution of the gas at various stages. Tidal forces compress the gas, inducing a high star formation rate during the first close passage. These forces become weaker as the galaxies separate,

Fig. II.8.3: Time evolution of the bolometric luminosity and the fraction of it attenuated by dust (*upper curves*). The variation of the UV and blue-band fraction is smaller for each of the eleven viewing angles (*lower curves*) considered.



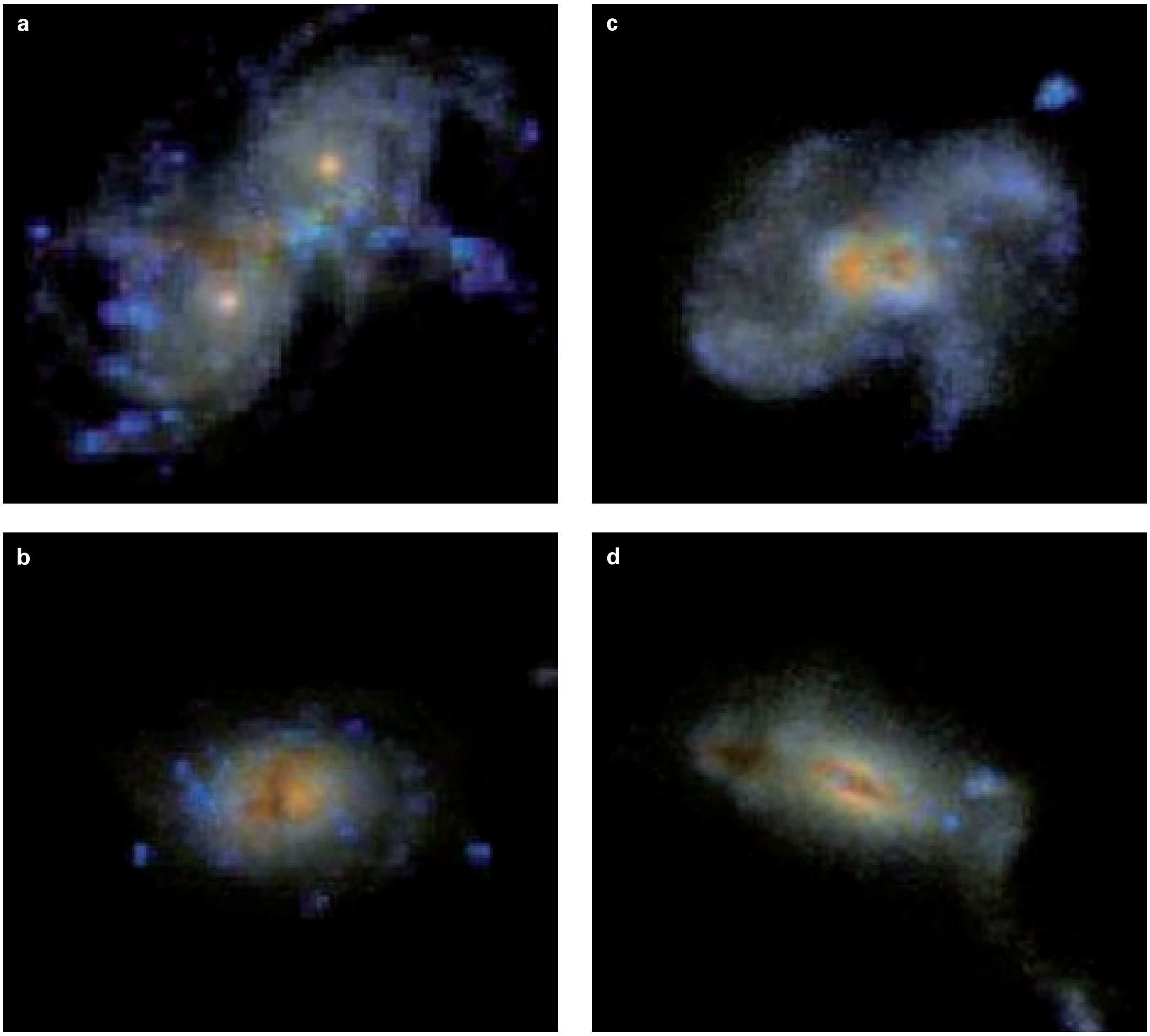
and we see a temporary decline in the star formation rate. But the galaxies then turn around, and during the final coalescence a powerful burst of star formation occurs. After the final merger, the star formation gradually tails off as the gas is consumed.

These simulations predict that the total period of enhanced star formation lasts for about two billion years. During this time the bolometric luminosity increases by almost one order of magnitude. However, the surprising result shown by this work is that the observed UV and blue-band luminosity stays almost constant because the dust density also increases, leading to increased attenuation of the light emitted by the young stars (Fig. II.8.3). This radiation escapes preferentially when the galaxy is viewed perpendicular to the disk plane so that the galaxy appears up to twice as bright when viewed face-on rather than at an oblique viewing angle. After the merger of two disk galaxies a spheroidal or elliptical remnant is left, whose luminosity in the UV and blue band no longer depends strongly on the viewing angle.

As mentioned above, the luminosity was calculated for 22 wavelengths. Therefore from the 25 simulation runs with 7 different galaxy types and 50 different points in time a total of more than 100000 images and 10000 spectra were obtained. These images and spectra will prove valuable for comparing with multi-wavelength observations of real galaxies. Fig. II.8.4 shows the appearance of the spiral-spiral merger at several different times during the simulation. Fig. II.8.5 illustrates the effect of the dust attenuation on the galaxy spectrum.

Based on the results of this large set of simulations, the team developed a simple analytic formula describing the fraction of light absorbed by dust as a function of the galaxy's luminosity, mass, and metallicity. Fig. II.8.6 shows the attenuation predicted by the analytic formula compared to the results obtained in the simulations. This

Fig. II.8.4: Simulated images of two merging Sbc galaxies at a) 0.6, b) 1.6, c) 1.7, and d) 2 billion years into the simulation.



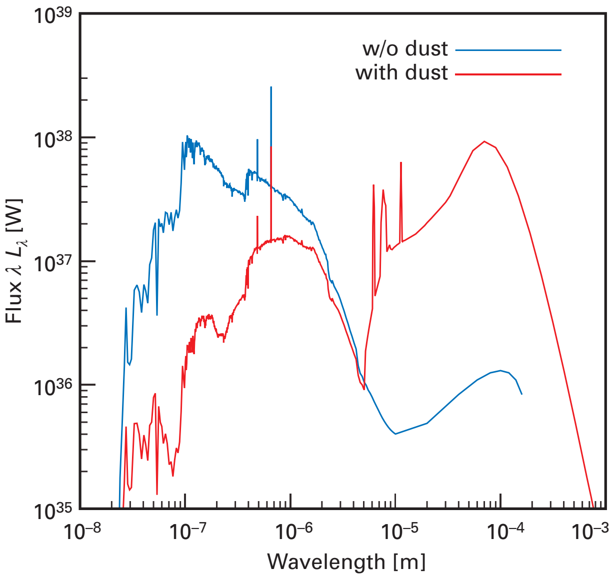


Fig. II.8.5: Spectral energy distribution at the stage of the second image in Fig. II.8.4. The two lines illustrate the effect of dust attenuation.

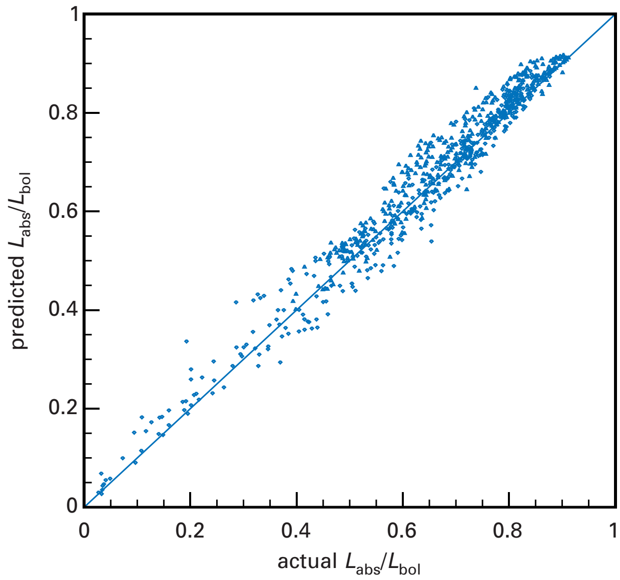


Fig. II.8.6: The attenuation predicted by an analytic approximation compared with the results obtained in the simulation.

figure shows that the formula describes the attenuation reasonably well. However, there is a large scatter in the attenuation depending on the viewing angle. [Averaged over all directions the mean uncertainty is 4 percent. Along a particular line of sight it varies, depending on wavelength, between 6 and 12 percent.] The derived relation seems to be valid not only for interacting but also for isolated galaxies. The analytic formula can be used to predict the dust attenuation in cosmological models of galaxy formation and evolution.

These results are an important step towards realistic modeling of the observed appearance of interacting galaxies. In particular, these simulations will help provide the basis for the determination of the actual merger rate of galaxies. In order to measure this rate based on flux-limited samples, one needs to account for the brightening of the galaxies due to the starburst, as well as the possible dimming and reddening due to the dust extinction. The simulations can also be used to calibrate statistics used to identify interacting galaxies in real observations.

However, the team hopes to improve the simulations in the near future. While the large-scale structure of the dust distribution in the galaxies is determined by the hydrodynamic simulations, structures on the scale of individual star-forming regions are still below the computational resolution. Moreover, gas outflows from the galaxies should be included, which, e.g., could eject some of the heavy elements produced by supernovae. Finally, the effects of an active galactic nucleus containing a supermassive black hole should also be taken into account.

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In collaboration with the
University of California, Santa Cruz,
and the Space Telescope Science Institute, Baltimore)

III. Selected Research Areas

III.1 Star Formation in the Magellanic Clouds

The Magellanic Clouds, two of the closest galaxies to our own, provide a unique opportunity to study the recent star formation process on full-galaxy scales. Although they are much smaller than the Milky Way Galaxy, both the Small and the Large Magellanic Cloud exhibit extraordinary star formation activity, which is demonstrated by super-giant expanding shells of interstellar medium, active star-forming regions associated with ionized hydrogen and a large variety of young systems of stars, such as stellar clusters and associations. Young stellar systems are excellent targets for probing the star formation processes on various scales in a galaxy.

Young stellar associations in the Magellanic Clouds form a complete sample of targets with a variety of characteristics suitable for investigating questions concerning the clustered formation of stars. The information that has been provided from ground-based observations so far concerns the massive young stars in associations of the Magellanic Clouds and the distribution of their masses, which is called the Initial Mass Function. There is a lack of information, though, on the low-mass stellar content of these systems, which is currently being filled in with results from observations with the Hubble Space Telescope. The combination of studies for both the high- and low-mass stellar content of young associations in the Magellanic Clouds provides a complete picture of recent clustered star formation in an environment quite different from our Milky Way.

Introduction

The Large and Small Magellanic Cloud (LMC, SMC) are two dwarf galaxies which are satellites of our own Galaxy, orbiting it about every 1.5 billion years. They are conspicuous objects in the southern hemisphere, and they can be seen by the naked eye like separated pieces of the Milky Way. They are named after the Portuguese maritime explorer, Ferdinand Magellan, who made them known to Europe during his first circumnavigation of the Earth in 1519. The Large Magellanic Cloud (LMC), at its distance of 179 000 light years, is the largest and nearest external, still undisrupted galaxy. The Small Magellanic Cloud (SMC) orbits our Milky Way galaxy at about 210 000 light years distance, which makes it the second most nearby external galaxy known. Both Magellanic Clouds (MCs) are irregular dwarf galaxies and they are close enough to be resolved into individual stars. Deep photographs reveal them to be highly complex systems with large numbers of interesting objects, including diffuse bright nebulae and dust clouds, globular and open clusters, supernova remnants and planetary nebulae apparently scattered at random across the face of the galaxies (Fig. III.1.1). Consequently, they are ideal laboratories for studying different stellar populations. The very low interstellar absorption from our Galaxy toward their direction certainly offers a great advantage for these studies, because the light from the MCs is not reduced by the foreground dusty disk of the Milky Way. In addition, their depth seems to be very small and so, all observed stars are located more or less at the same distance with very small foreground contamination by Milky Way stars. Both the MCs, having lower abundances in elements heavier than hydrogen (metals) than the Milky Way, also have low intrinsic absorption from the interstellar medium (ISM).

The MCs provide a unique laboratory for the study of star formation in an environment different from that of the Milky Way. Various investigations have provided valuable information on them due to their proximity to the Earth. For example, the metal abundance (content of elements heavier than hydrogen) in the LMC is almost 4 times lower than that of the Galaxy, while its star formation rate (newly-formed stellar mass as a function of time) is high, almost on par with the Galaxy's (Westerlund 1997, The Magellanic Clouds, Cambridge Univ. Press). This results in a large number of early-type stars establishing intense radiation fields, causing the star formation in the LMC to be different than that in the Milky Way.

The MCs show very active star formation with the impressive star-burst region of the Tarantula nebula (30 Doradus) in the LMC, giant and super-giant shells of atomic hydrogen (HI shells) and regions of ionized-emitting hydrogen (HII regions). The glowing gas of the ISM in the latter is the breeding ground for the formation of new stars (Fig. III.1.2). All these features are linked to recent star formation, while most of them are related to newly-formed young stellar systems. Specifically, both the MCs are characterized by a unique sample of HII regions, HI shells, molecular CO and H_2 clouds and young star clusters and stellar associations located in regions of recent star formation.

The concept of stellar associations was originally introduced by Ambartsumian in 1947, who showed that they are star-forming regions of our Galaxy. Extragalactic

Fig. III.1.1: This two-colour image shows an overview of the full Small Magellanic Cloud and was composed from two images from the Digitized Sky Survey 2 (DSS2). The field of view is slightly larger than 3°.5. Credit: ESA/HUBBLE, Digitized Sky Survey 2, and Davide De Martin.

associations are easily outlined by their massive stars of »early spectral type«, while the stellar members of the associations in the Milky Way are confused with fore- and background stars of the spiral arms of the Galactic disk, where they are located. In general, stellar associations are considered to be single, loose concentrations of early type luminous stars, which are embedded in the most recent star-formating regions in a galaxy (Kontizas et al. 1999). Their dimensions range from those of ordinary galactic clusters with diameters of a few parsecs to several tens of parsecs, and the stellar mass density in these systems is defined to be less than one tenth of a solar mass per cubic parsec. Photometric and spectroscopic investigations of young stellar associations in the MCs have previously been based on ground-based observations, which are appropriate for the study of their massive stellar content only down to about 2 times the solar mass ($M_\odot$). The upper mass limit of the massive stars of these systems is found to be of the order of 100 $M_\odot$. The latter stars are characteristic of very recent star formation, due to their very short lifetime. Their existence clearly suggests that stellar associations of the MCs are very young, with estimated ages between 1 and 30 million years. The

Fig. III.1.2: Mosaic image of the glowing gas of the interstellar medium of the Large Magellanic Cloud taken for the Magellanic Cloud Emission Line Survey (MCELS). This image, which covers the central 8 by 8 degrees of the LMC, is a color composite of observations taken in five wavelength bands: emission lines of hydrogen (H_α), doubly-ionized oxygen ([O III]), singly-ionized sulfur ([S II]), and red and green continuum bands. Over 1.500 individual images have been combined for the mosaic. Credit: C. Smith, S. Points, the MCELS Team and NOAO/AURA/NSF.

emission from the HII regions at the loci of associations is related to these massive stars, since they affect the ISM of their environment through their strong stellar winds and ionizing radiation, which can be observed in the ultraviolet wavelengths.

The Initial Mass Function

The star formation process is determined by the conversion of gas to stars with the outcome of stars with a range of masses. It is of great significance to quantify the relative numbers of stars in different mass ranges and to identify systematic variations of the stellar mass distribution with different star-forming conditions, which will allow us to understand the physics involved in assembling each of the mass ranges. The distribution of stellar masses in a given volume of space in a stellar system at the time of their formation is known as the stellar Initial Mass Function (IMF). Together with the time modulation of the star formation rate, the IMF characterizes the stellar content of a galaxy as a whole (Kroupa 2002, Science, 295, 82). The IMF may be characterized by the logarithmic derivative Γ (Scalo 1986, Fundam. Cosmic Phys. 11, 1):

$$\Gamma = \frac{\mathrm{d} \log \xi(\log m)}{\mathrm{d} \lg m} .$$

Here, $\xi(\log m)$ is the IMF, which is constructed by counting stellar masses in equal logarithmic intervals, and Γ is its slope, which can be derived from the linear regression between $\log \xi(\log m)$ and $\log m$. A reference value for the IMF slope Γ, as found by Salpeter (1955, ApJ, 121, 161) for the solar neighborhood and stars with masses between 0.4 and 10 $M_\odot$, is $\Gamma = -1.35$.

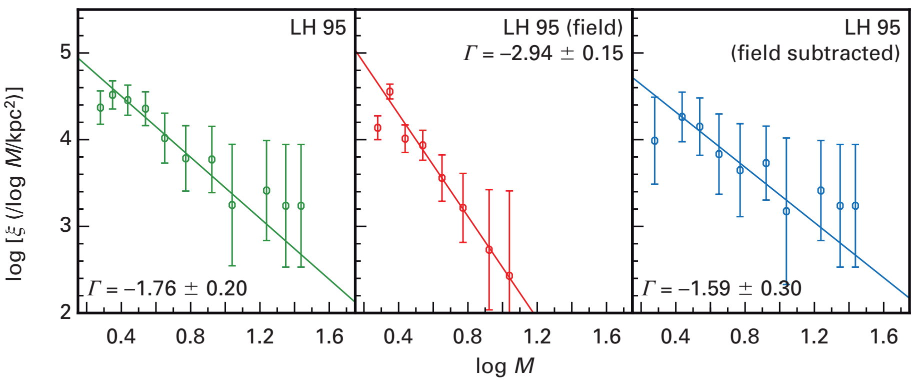
The Massive Initial Mass Function

Ground-based investigations of a large sample of associations in the MCs led to the conclusion that for massive stars, the IMF in these systems is more or less the same, and it has a slope which varies around a value of $\Gamma \approx -1.5 \pm 0.1$ (Massey et al. 1995, ApJ, 454, 151). This value is not very different from the IMF slopes of typical young compact LMC clusters for the same mass range (e.g. Gouliermis et al. 2004, A&A, 416, 137). Thus, the IMF of massive stars in young stellar systems appears more or less to be universal, with a typical slope, which does not differ significantly from the reference value found by Salpeter. On the other hand, the IMF of massive stars in the field away from any stellar system in both the LMC and SMC appears to be steep with slope $\Gamma \sim -4$, the same value as for the Milky Way field. In general, the IMF for massive stars shows variations from one region of the galaxy to the other, which clearly suggest that environmental conditions most likey significantly affect the IMF in the high-mass regime. A characteristic example is the case of the LMC association LH 95 (Gouliermis et al. 2002, A&A, 381, 862), where a gradient of the IMF slope was observed in the sense that the IMF of stars with masses between 3 and 10 $M_\odot$ becomes steeper outwards from the center of the system (Fig. III.1.3). This suggests that there is a clear distinction between the population of the system, its surrounding field and the general field of the LMC. In addition, there are stellar associations which exhibit slopes of the massive IMF quite different from each other with values varying between $\Gamma = -1$ and -2 (Parker et al. 1998, AJ, 116, 180).This variability presumably originates in the differences in the star formation process from one region to the other.

The IMF Toward the Low-Mass Regime

The picture of the stellar content of stellar associations in the MCs from ground-based observations is limited above 2 $M_\odot$. Information on the low-mass stellar membership and the corresponding IMF in these systems is still incomplete. Considering that the MCs, being very close, are the only extra-galactic targets where stars of sub-solar masses can be observed with the advanced instruments available today, this gap has only recently started to be filled with our research based on observations with the HUBBLE Space Telescope (HST). Our results open up a new debate by addressing important questions such as: (1) Are there any low-mass stars in stellar associations and, if yes, then what is the low-mass slope of the IMF in these systems? (2) What would be the lowest mass that can be observed? Is there any specific low-mass cutoff in the IMF of associations in the MCs? (3) What is the functional form of the low-mass IMF in the MCs? Is there a flattening of the IMF for sub-solar masses? and therefore (4) Has the IMF got a constant slope or not through the whole mass range detected? and finally (5) What is the low-mass slope of the IMF in the general field and what are the differences to those of young stellar systems? Is there any dependence/relation of the IMF slope on/to the environment, in which star formation does it take place? Data from space observations of the MCs is available in

Fig. III.1.3: The Mass Function of all main-sequence stars located in the region of the association LH 95. The mass function for all the stars within the association (distance less than 1.2 arc minutes from its center) is shown in the left plot. The field population is included. The corresponding mass function of stars in the surrounding field is shown in the central plot. The lack of stars more massive than 10 $M_\odot$ in the latter makes the mass function steeper. This exemplifies the radial dependence of the mass function slope, which becomes steeper outwards. The plot on the right shows the IMF of the main sequence stars in the association, after the contribution of stars, which belong to the field has been subtracted. This IMF is comparable to a typical Salpeter IMF. Adapted from Gouliermis et al. (2002).

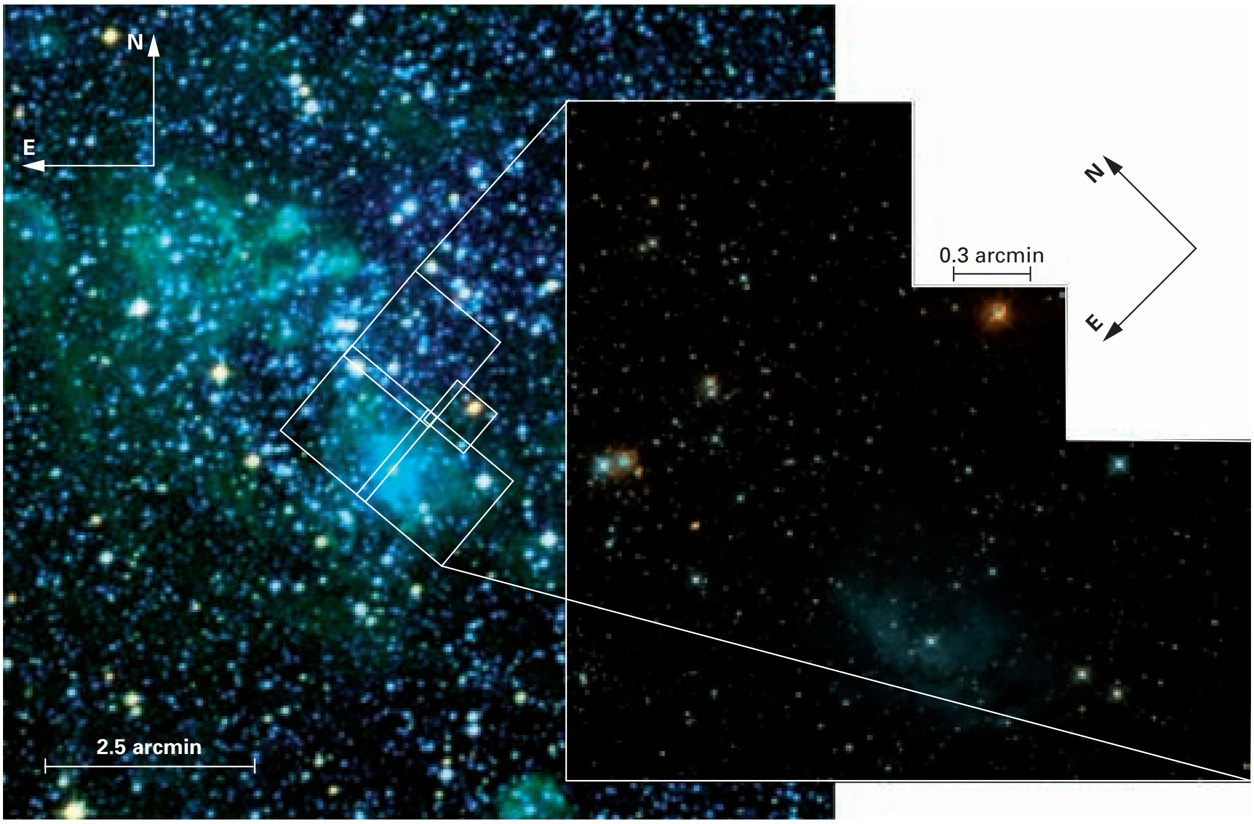


the Data Archive of HST. We examined such observations of the LMC and we found that, indeed, low-mass stars are located within the vicinity of associations in the MCs. This enabled us to construct the IMF for stars with masses down to 1 solar mass.

Stellar Associations in the Large Magellanic Cloud with HST Observations

The MCs have been extensively observed with HST throughout its productive career. These observations were mainly done with one of the most successful instruments on-board HST, the Wide-Field Planetary Camera 2 (WFPC2), which is a two-dimensional UV-visible imaging photometer. Installed in HST in 1993, it is located at the center of the HST focal plane and covers the wavelength range 1150 to 10 500 Angstroms (Å). The most popular MCs targets for WFPC2 were young star clusters, the general field of the galaxies and the star-burst of 30 Doradus in the LMC. Although stellar associations of the MCs are among the best targets for the search of extragalactic low-mass stars, they were not observed sufficiently with WFPC2, and only very few observed fields covered some parts of associations in the LMC. Our analysis of WFPC2 observations of two stellar fields located on the boundaries of the super-giant shell LMC 4 showed that HST observations can provide unique information on the faint stellar populations of stellar associations in the MCs (Gouliermis, Brandner & Henning 2005, ApJ, 623, 846). The first field covers the southwestern part of the large association LH 52, and it provides a representative sample of the stellar population of a LMC association (Fig. III.1.4). The second field is located in the empty area between two smaller associations (LH 54 and LH 55), and it accounts for the stellar population of the general background field of the LMC. We refer to it as LH 55 Field. These observations reach a detection limit almost 6 magnitudes deeper than the ones previously taken from the ground, and they cover a large number of faint stars down to sub-solar masses. Specifically, in the WFPC2 field of LH 52 Area, more than 4000 stars were found, while in the same field only about 220 of the brightest stars could be detected using modest ground-based CCD imaging (Hill et al. 1995, ApJ, 446, 622).

Fig. III.1.4: A composite picture from digitized photographic observations of the general area of the stellar association LH 52 (NGC 1948) in the Large Magellanic Cloud. The outlined region shows the field observed with the Wide Field Planetary Camera 2 (WFPC2) on the Hubble Space Telescope, shown in detail on the right. The data were obtained from the HST Data Archive. This area covers more than 4000 stars detected with the HST, in comparison to no more than 220 stars previously found with ground-based CCD imaging. This exemplifies the advance in crowded stellar photometry toward LMC gained through the Hubble Space Telescope.



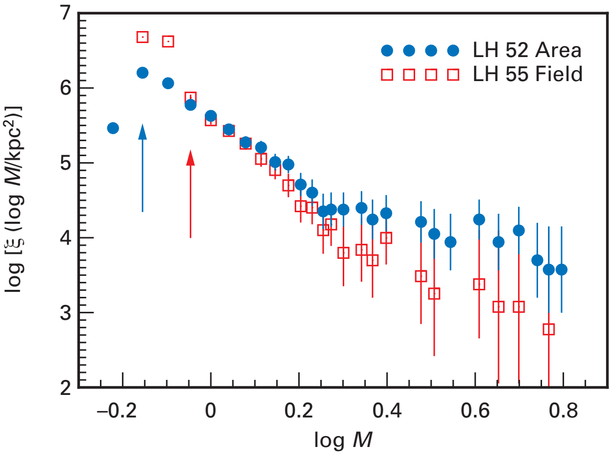


Fig. III.1.5: Mass Function of the main sequence stars of the LH 52 area and the LH 55 Field from observations with HST/WFPC2. The mass function is constructed by using the mass-luminosity relation provided by the theoretical stellar evolution models. The stars were counted in logarithmic (base 10) mass intervals. The numbers were corrected for incompleteness and normalized to a surface of one square kiloparsec. The errors reflect the statistical uncertainties. The arrows indicate the level of 50 % success in the detection of stars in the LH 52 area (*blue arrow*) and the LH 55 Field (*red arrow*). The mass function was found to change shape for stars with masses lower than 2 $M_\odot$.

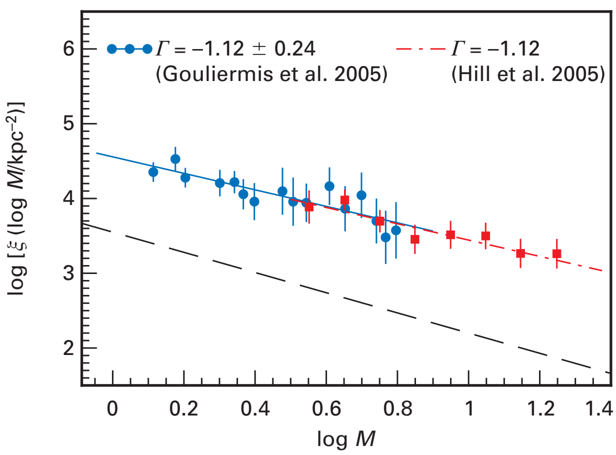


Fig. III.1.6: The Initial Mass Function of the association LH 52 down to about 1 $M_\odot$ from observations with HST/WFPC2. Results from studies on both high- (Hill et al. 1995) and low-mass (Gouliermis et al. 2005) stellar populations combined for the first time for the construction of the IMF through the whole observed mass range of a young stellar system in the Magellanic Clouds for stars with masses up to 18 solar masses. The IMF of the association is found to be constant through the whole mass range and it has a slope comparable, but a bit more shallow than a typical Salpeter mass function (plotted with the dashed line for reference).

The large majority of the observed low-mass stars with masses between 1 and 2 $M_\odot$ in both fields seems to be a feature of the general field population of the LMC. The mass function of these stars closely resembles their IMF, since low-mass stars evolve very slowly and no evolutionary effects are expected to have taken place, changing their original mass and forcing them to leave the main sequence within the life-span of the LMC general field. This time-scale is revealed from the corresponding Color-Magnitude Diagrams (CMDs) of the LH 52 Area and of LH 55 field. In this investigation, it could be shown for the first time that the Present-Day Mass Function (PDMF) of the main-sequence stars with low and intermediate masses in the LMC is not a single power-law, but that it is steeper for masses lower than about 2 $M_\odot$ with slopes between −4 and −6, while for stars with masses greater than about 2 $M_\odot$ the mass function slope is more shallow, between −1 and −2 (Fig. III.1.5). This implies that the contribution of the low-mass stars in the main sequence to the mass function of a system is higher than expected, when assuming that the mass function follows the same slope for masses smaller than about 2 $M_\odot$. The mass function of the stars found in the general background field of the LMC is used for correcting the contribution of the background field to the stars found in the observed area of the association LH 52. Applying this correction, the field-subtracted mass function of the main-sequence stars found with WFPC2 in LH 52 is constructed. This PDMF covers only the stars which are members of the association and therefore is the IMF of the system, since it is considered to be very young. Its reconstruction was possible for masses down to about 1 $M_\odot$, due to observational limitations in the LH 55 Field.

The slope of this IMF is found to be comparable, maybe somewhat shallower than a typical Salpeter IMF ($\Gamma \approx -1.12 \pm 0.24$) in the mass range between 1 and 9 $M_\odot$. Previous, modest, ground-based CCD imaging by Hill et al. (1995, ApJ, 446, 622) led to the construction of the IMF of the same association for stars of intermediate and high masses (between 3 and 18 $M_\odot$). The combination of our results on the low-mass regime of the IMF based on HST observations with the ones on its high-mass end from ground-based imaging enabled us to construct the IMF of a young LMC association throughout its full observed mass range of 1 to 18 $M_\odot$ (Fig. III.1.6) for the first time. Its slope is found to be constant for the whole mass range, providing clear indication of a »top-heavy« IMF, which is well represented by a single-power law with slope $\Gamma \approx -1.1$. Conclusively, the Present-Day Mass Function slope of the field of the Large Magellanic Clouds is found to be determined by the low-mass population, while the Initial Mass Function of the association LH 52 by its more massive members. This clearly suggests the local star formation conditions in LMC associations may favor the formation of higher-mass stars. No evidence for flattening of the IMF toward the low-mass regime was detected in our data, neither was a lower mass cutoff in the IMF down to the observed limit of about 1 $M_\odot$.

The Field of the Large Magellanic Cloud with HST Observations

We were recently able to present the first evidence for flattening of the IMF toward the low-mass regime in the field of the LMC (Gouliermis, Brandner & Henning 2006, ApJ, 641, 838). In this study, a large amount of archived HST/WFPC2 photometric data of an area located to the west of the Bar of the LMC, was used. This area accounts for the general background stellar field of the inner disk of the LMC and the data cover six overlapping WFPC2 fields, reaching magnitudes as faint as $V=25$ mag, and providing a large sample of more than 80 000 stars. This data enabled us to determine the PDMF of the main-sequence stars in the field of LMC in detail down to about 0.7 $M_\odot$. This mass function is identical to the Initial Mass Function (IMF) for stars with masses lower than about 1 $M_\odot$, since no evolutionary effects had time to take place and alter the initial masses of these stars, or remove them from the main sequence.

The highest mass found in the data is about 2 solar masses, and the PDMF of main sequence stars up to this limit in the LMC field is found not to have a uniform slope throughout the observed mass range, meaning that the PDMF slope of the LMC field does not follow a single power law. This complies with what we found for the general background population in the case of the LH 55 field and LH 52 Area. We established that a multi-power law can represent the field PDMF, the slope of which changes at about 1 $M_\odot$ to become shallower for stars with smaller masses down to the lowest observed mass of about 0.7 $M_\odot$, and show clear indications of flattening for even smaller masses. We statistically verified that the IMF has a slope Γ of roughly -2 for stars with masses lower than 1 $M_\odot$, with a Salpeter-like slope $\Gamma \approx -1.4$ for stars in the mass range between 0.7 and 0.9 $M_\odot$, while for more massive stars the main sequence PDMF becomes much steeper with $\Gamma \approx -5$. The main-sequence luminosity function (LF) of the observed field closely matches the previously found Galactic LF. Taking several assumptions concerning evolutionary effects into account, which should have changed the stellar content of the observed field through time, we qualitatively reconstructed its IMF for the whole observed mass range (0.7–2.3 $M_\odot$). We found that the number of observed evolved stars is not large enough to have significantly affected the form of the IMF, which is almost identical to the observed PDMF (Fig. III.1.7). Deeper observations would certainly provide a better statistical stellar sample with lower masses to verify this result.

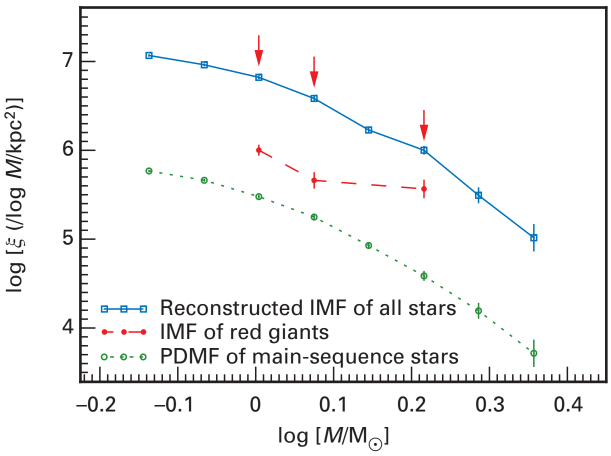


Fig. III.1.7: The Mass Function of the stars in the general field of the Large Magellanic Cloud to the west of its bar, observed with HST/WFPC2. The Present-Day Mass Function (PDMF) of the main-sequence stars was plotted with the green dotted line. Several assumptions concerning the star formation history of the LMC were taken into account for the reconstruction of the Initial Mass Function of these stars. The IMF of the Red Giant Branch stars (RGB) was constructed after taking the evolutionary effects of these stars into account and was plotted with the red dashed line. The small number of RGB stars in the area and their narrow mass range introduce only small changes to three specific mass intervals (*red arrows*), showing a trend of the IMF to become slightly more shallow toward the limit of about 1.6 $M_\odot$. The IMF of all stars (both red giants and main sequence stars) was plotted with the blue solid line. It was reconstructed by the combination of the IMF of main sequence and RGB stars. All mass functions shown were shifted to avoid overlapping.

The Pre-Main Sequence Population of Associations in the Magellanic Clouds

Low-mass stars (with masses lower than 1 $M_\odot$) are very important for addressing some of the most fundamental problems in star formation, as they provide a snapshot of the fossil star formation record of giant molecular cloud complexes. Large scale surveys have identified hundreds of low-mass members of nearby OB associations in the Milky Way, and revealed that low-mass stars exist wherever high-mass stars have recently formed (Briceño et al. 2006, in Protostars & Planets V). The low-mass stellar populations of Galactic OB associations are considered to be a key to investigating fundamental issues in the formation and early evolution of stars. The shape of the low-mass IMF is still a debated issue, and whether OB associations have low-mass populations according to the field IMF of the Galaxy, or if their IMF is truncated. Infrared studies have provided strong/convincing evidence of primordial accretion disks around low-mass stars, which dissipate on various timescales of 1 to 20 or even 30 million years. These are infant stars which are not yet on the main sequence and therefore named pre-main- sequence (PMS) stars. Do such stars exist in associations of the MCs? An answer to this question is only possible with observations from instruments equipped with high resolving power.

Our study using HST observations of the association LH 52 revealed a low-mass stellar population which is considered to be the PMS population of the association (Gouliermis, Brandner and Henning 2006, ApJL, 636, L133). This is the first time such stars were found in the vicinity of an extra-galactic association. The candidate PMS stars form a secondary red sequence, running almost parallel to the lower main sequence from the turnoff down to the detection limit, as it is seen in the CMD of LH 52 from the WFPC2 observations (Fig. III.1.8). Almost 500 candidate PMS stars were selected. PMS evolutionary models of ages between 1.5 and 15 million years (Siess et al. 2000, A&A, 358, 593) trace the location of these stars in the CMD very well, providing the first evidence that these stars are of a PMS nature. Comparisons of the CMD of stars with high statistical significance in the area of LH 52 to the ones in different areas of the field of the LMC showed that these stars are merely part of the association and they are not a common general feature of the LMC. This indicates that the suggestion/theory that the secondary red sequence represents PMS stars in the association and not low-mass stars on its main sequence. Furthermore, the location of the candidate PMS stars in the CMD almost perfectly matches the loci of low-mass PMS stars recently discovered in the Galactic association Orion OB1 (Sherry et al. 2004, AJ, 128, 2316; Briceño et al. 2005, AJ, 129, 907). The latter stars are identified as T Tauri stars with masses

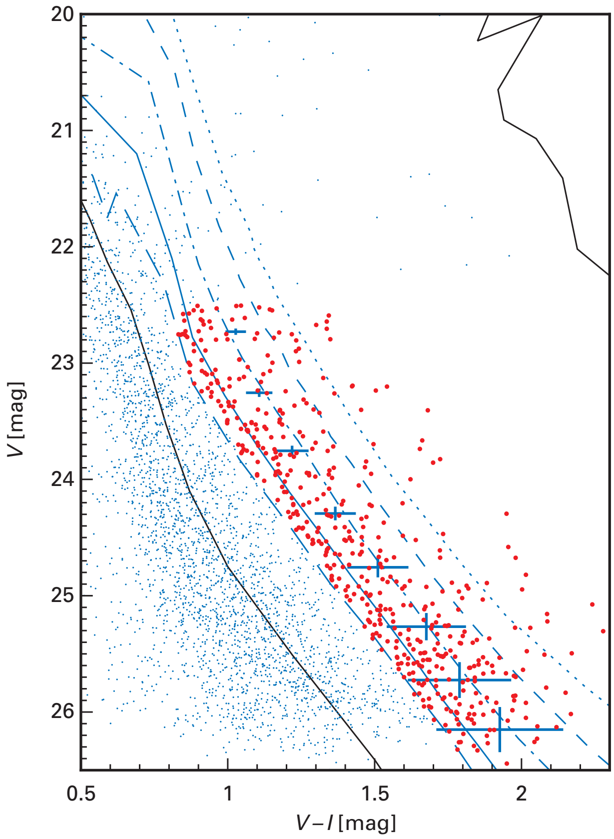
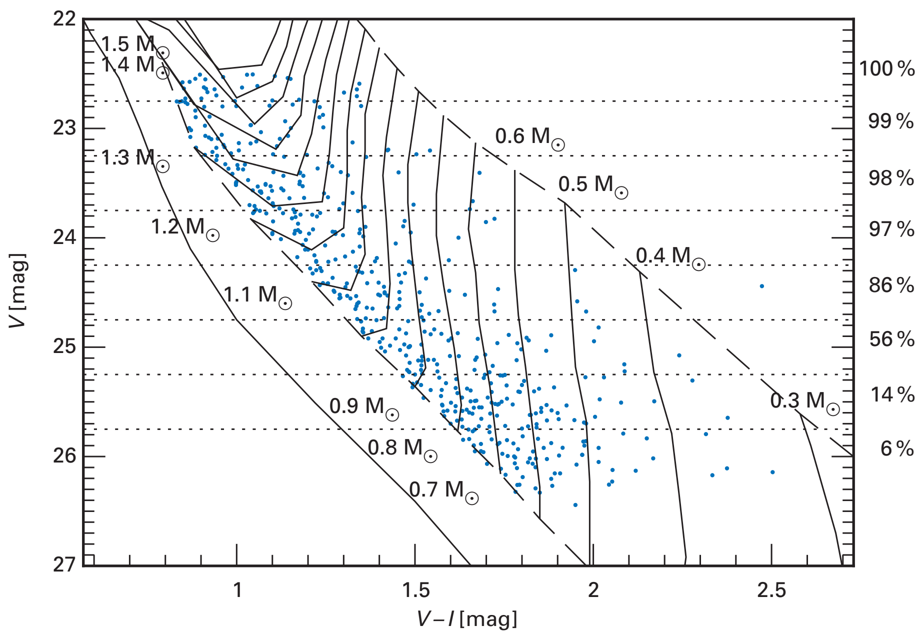


Fig. III.1.8: *top right and bottom:* Color-Magnitude Diagram of the low-main sequence stars in the observed WFPC2 field of the association LH 52. In the upper plot, Pre-Main Sequence isochrone models for ages 1.5, 2.5, 5, 10, and 15 million years and for the metal abundance of the LMC are plotted with blue dashed-dotted lines. They track the discovered secondary faint red sequence well, which does not seem to coincide with either a binary sequence or main-sequence broadening due to photometric errors. The candidate low-mass PMS stars are represented with thick red dots. The models of Zero Age Main Sequence and birth line are plotted with thick black lines. The horizontal blue lines on the right indicate typical mean photometric errors in color. In the lower plot, PMS evolutionary tracks for masses down to 0.3 solar masses are overplotted on the diagram of the candidate PMS stars. These tracks are indicative of the corresponding mass of each star and they are used for the construction of the IMF of these stars. The corresponding mass is indicated next to each track. On the right, the detection efficiency (in %) in each brightness range (completeness) is also provided.



lower than 2 solar masses. This coincidence of the loci of low-mass PMS stars in the CMD of a galactic association with the observed sequence of PMS candidates seen in our CMD of LH 52 provides additional evidence that this sequence accounts for the PMS population of the association. In addition, it shows that the LMC PMS stars in stellar associations have a Galactic counterpart, most likely because they are of the same nature as PMS stars in Galactic associations.

We constructed the distribution of the candidate PMS stars in LH 52 according to their masses as they are defined by limits provided by theoretical evolutionary tracks on the CMD (Fig. III.1.8). This distribution accounts for the IMF of these stars. Due to limitations in the detection of stars with very low masses (percentage of detection efficiency per magnitude range is given in Fig. III.1.8), the IMF can efficiently constructed for stars with masses down to about 0.8 $M_{\odot}$. In addition, since we strictly selected the brightest limit of the PMS stars to be well below the turnoff, the numbers of counted stars in the higher mass ranges are also incomplete. The upper useful mass limit is thus defined at about 1.4 $M_{\odot}$. The IMF for the mass range between 0.8 and 1.4 $M_{\odot}$ has a slope of $\Gamma \sim -1.26$, which is very close to a typical Salpeter IMF. More complete data for PMS stars in MCs associations over a wider mass range will certainly provide a more complete picture of the IMF of the whole mass range of such objects.

Future Prospects

Our studies with HST/WFPC2 observations explored the scientific gain that would be achieved using very high spatial resolution 2D photometry on the basis of the newest instrument on-board HST, the Advanced Camera for Surveys. The Advanced Camera for Surveys (ACS), which was installed in HST in March 2002, increases the discovery efficiency of the HST by a factor of ten. It consists of three electronic cameras and a complement of filters that detect light from the ultraviolet to the near infrared (1200 – 10 000 Å). Deep observations with HST ACS of associations in the MCs will certainly enrich our knowledge on recent star formation in their environment. Although stellar associations in the MCs are characterized by their loose structure, so their photometry does not suffer from significant confusion in identifying individual bright stars (crowding effects), high spatial resolution is required for the study of the fainter ones. The high resolving power of ACS is required so that crowding effects are avoided for stars down to about half a solar mass (corresponding to brightness $V \approx 27$ mag). In addition stellar associations are of the order of several tens parsec across, and thus, wide field imaging, which can also be provided by ACS, is required to observe a stellar association as a whole and its surrounding field.

Taking these arguments and our results with WFPC2 into account, we proposed and were granted observations with HST/ACS of the LMC association LH 95 in HST Cycle 14. There are a number of facts that make this system a bona fide target for the investigation of the IMF and recent star formation in the LMC. Our program hosts a collaborative project on recent star formation in the MCs with colleagues from Leiden Observatory and ESO. Similar observations with HST/ACS of NGC 346, which is the brightest star forming association in the SMC have recently revealed a rich population of low mass PMS stars in the area (Nota et al. 2006, ApJL, 640, L29). These stars are likely the product of a single star formation 3 to 5 million years ago and they have masses between 0.6 and 3 solar masses. They appear mostly concentrated in the main part of the association, but they are also spread over a region across around 45 parsecs (Fig. III.1.9). The data of these observations, which are available in the HST Data Archive, include a large sample of high- and low-mass stars, covering an area about 5 arc minutes wide.

The contribution of the field low-mass stars to the IMF of an association is so important that the field subtraction provides one of the major uncertainties in the determination of the IMF. Therefore, observations of the general LMC field are as necessary as those of the system itself. Consequently, within our HST program (No. 10566) two fields, one centered on LH 95 and one on the general field, about 75 parsec west of the first, were observed within 10 orbits with ACS in wide-field mode in the V- and I-equivalent ACS filters (F555W and F814W). Parallel observations with NICMOS will help us to characterize any PMS population in the area.

Several 10 000 low-mass main-sequence and pre-main-sequence stars are expected to be detected, giving a very clear picture of the sub-solar IMF in a star-forming association of the LMC. We will take advantage of the wide-field high-resolution ability of ACS with the use of the archived data on NGC 346, as well as of our own data on LH 95, which were recently collected (Fig. III.1.10), to study the low-mass IMF and recent star formation in associations of both the LMC and the SMC. It is almost certain that such deep observations will reveal the PMS population of these systems and, coordinated

Fig. III.1.9: This HUBBLE Space Telescope image taken with the Advanced Camera for Surveys shows one of the most dynamic and intricately detailed star-forming regions in the Small Magellanic Cloud. It is a composite of observations taken with the Wide-Field Channel of ACS in three wavelengths: V, I and H_{α}. At the center of the region is the brilliant stellar association NGC 346. A structure of arched, ragged filaments with a distinct ridge, which is found to host infant PMS stars, surrounds the association. Such high-resolution observations of the Magellanic Clouds will considerably advance our knowledge on their recent star formation processes. Credits: NASA, ESA and A. Nota (ESA/STScI).


17.4 Lightyears
20 arcsec

Fig. III.1.10: The Hubble Space Telescope photo presented at the 2006 General Assembly of the International Astronomical Union in Prague, showing observations of the star forming association LH 95 in the Large Magellanic Cloud with the Advanced Camera for Surveys. This sharp image reveals a large number of low-mass infant stars coexisting with young massive stars, changing dramatically the picture that we had for stellar associations in the Magellanic Clouds. Credits: Nasa, Esa, and D. A. Gouliermis (MPIA).

with high-resolution ground-based observations with the most advanced near-infrared detectors, will allow the characterization of the PMS stars and other stellar objects under formation, and the study of their IMF. This would open a complete new field of study for the Magellanic Clouds.

(Dimitrios A. Gouliermis,
Wolfgang Brandner,
Thomas Henning)

III.2 Radiative Transfer – Link between Simulation and Observation

Almost all information about the objects in the Universe is obtained through the analysis of the radiation we receive from them. One therefore might expect that the calculation of the transfer of radiation within an object and in the interstellar medium is an astrophysical problem that has been solved long ago. Surprisingly the reverse is true: Among the numerous processes important in astrophysics, radiative transfer is one of the most difficult problems.

The MPIA is among the few institutes worldwide where programs are used that are able to trace the radiation even in complex three-dimensional structures. This is particularly important for objects surrounded by gas and dust envelopes – such as forming and young stars or debris disks around main-sequence stars where planets are possibly forming, as well as the central black holes in active galactic nuclei.

The Seven Dimensions of Radiative Transfer

According to current notion, star formation starts with the gravitational collapse of the cores of cold molecular clouds. Due to the conservation of angular momentum, the gas and dust distribution around the forming protostar flattens, creating a circumstellar disk in later stages. In order to follow the evolution from a molecular cloud core to a completed star sophisticated simulations are required where the motion of the gas and dust is being traced using magnetohydrodynamical calculations. Here, radiative transfer is playing an important double role: On the one hand, the radiation carries energy through the structure, contributing to its heating or cooling; on the other hand, the appearance of the structure at a certain wavelength can only be determined from the calculation of radiative transfer.

Yet radiative transfer was still neglected or calculated in a much simplified way in simulations so far. The reason for this is the high dimensionality of the problem: The radiation field is not only a function of space and time but also of direction and wavelength. Compared to other physical quantities like density or magnetic field it thus has three additional dimensions. Accordingly, a simulation calculating the magnetohydrodynamics and the radiative transfer equally correctly would use almost all the computing time for the radiative transfer.

In approximative radiative transfer calculations, at least the transfer of the mean energy through the system is calculated correctly. Within the »flux limited diffusion«, e.g., the radiation field is calculated correctly in the optically very thin or very thick case, which suffices for many applications. However, as soon as spectral energy distributions or spatially resolved images of the objects have to be calculated, a correct radiative transfer is required. This is due to the fact that the appearance of the object at a certain wavelength is dominated by the radiation originating from the spatial region where the optical depths equal unity. But exactly in this region, the approximations break down – which is why it is also the numerically most demanding region.

Radiative Hydrodynamics: Diffusion plus Ray-tracing

Thus, the numerical calculation of the hydrodynamic evolution of accretion disks under simultaneous consideration of radiative transfer is still a great challenge. Realistic thermodynamics of the disk, however, cannot be done without radiative transfer. Flux limited diffusion so far has been the method of choice in this field since correct radiative transfer without approximations would consume too much computing time to be able to follow the dynamical evolution of the optically thick disk. Concerning the incoming radiation of the central star the diffusion approximation can be used only under certain circumstances. But if the simple local diffusion approximation with an assumed local black-body radiation is replaced by a wavelength dependent diffusion approach, as has been done by colleagues in Pasadena, even with modern computers the numerical effort is so high again that the time evolution of a disk can no longer be simulated in all three spatial dimensions. Therefore, in collaboration with Willy Kley (Tübingen), we have extended the simple diffusion approach by a ray-tracer. This ray-tracer allows to calculate precisely the absorption of the stellar radiation in the accretion disk. The radiation energy absorbed is then added to the diffusion approach as a source term.

The test results are encouraging, showing that the »diffusion plus ray-tracing« approach and an exact continuum radiative transfer are providing quantitatively comparable results (Fig. III.2.1). Although the errors are too large for a reliable determination of the spectral energy distribution or an intensity map of the disk they allow to determine locally a sufficiently accurate sound velocity, which is just the quantity needed for hydrodynamics. This new algorithm is being applied first to protoplanetary accretion disks around luminous young stars and young planets embedded in their parent disk.

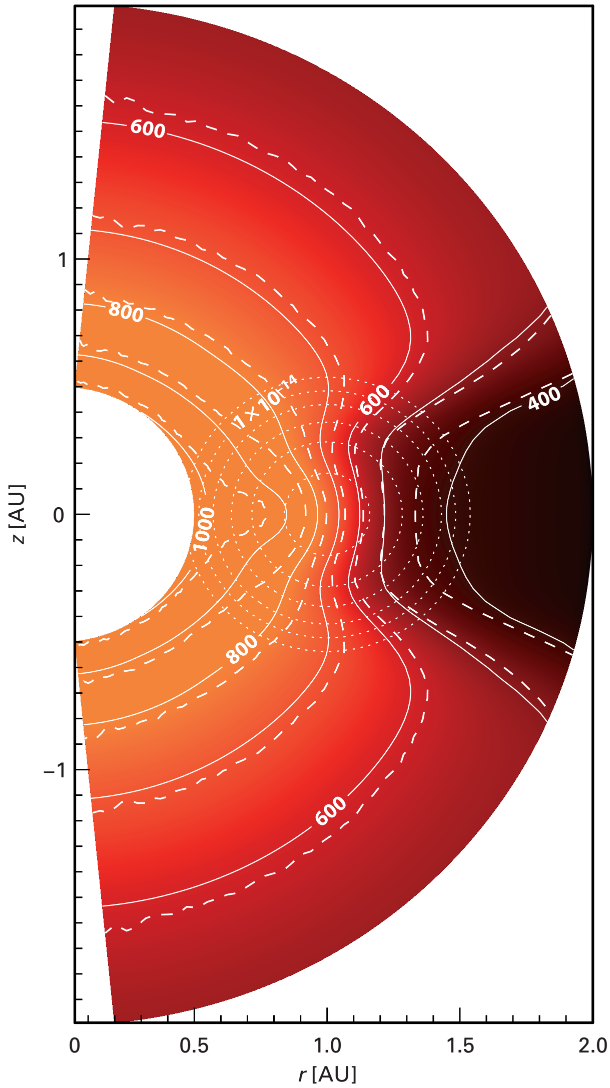


Fig. III.2.1: A dust torus is illuminated by a central source. The dotted lines indicate the density distribution of the dust. The colors illustrate the temperature distribution (bright = hot) determined with the »diffusion plus ray-tracing« algorithm. The corresponding lines of constant temperature are drawn as solid lines. For comparison, the dashed line shows the result from the more accurate continuum radiative transfer. The local error of the sound velocity in this test was always below 5 %.

A Bit Closer to the Ideal Case: Inverse 3D Radiative Transfer

When images of an object are available it would be desirable for the interpretation of the observational results to directly calculate a density and temperature distribution from the telescope images. However, the calculation of the radiation field for a given distribution is so complex that an inversion is possible only for very simply structured objects. For modeling telescope images one therefore has to rely on multiple iterations, varying the density and temperature distribution. A glance at the spatially resolved dust distributions around young stars suffices to realize that filamentary or ellipsoidal distributions have to be assumed in almost all cases. And for these, modeling is virtually out of question because it takes too long to calculate a configuration.

Scientists at MPIA, together with colleagues from Bordeaux and Potsdam, succeeded in calculating the first 3D-model of a condensation in the molecular cloud near rho Ophiuchi. This starless core is a good example of the initial stage of star formation where a protostar is forming by gravitational collapse of the core. For the core ISOCAM maps at 7 and 15 μm wavelength were available, where it is visible in absorption against the infrared radiation of the background region as a complex structure divided in two main clumps. In a map obtained with the IRAM-30-m-telescope in the long-wavelength mm-region, however, the core was detectable by emission of cold dust. The complex geometry of the distribution precluded a simple modeling with a 1D- or 2D-model. So 30 clumps with a three-dimensional Gaussian density distribution were used that were variable in their position, their axial ratio and their overall density. With the help of the optimizing algorithm »simulated annealing« the clumps were shifted and deformed in such a way that the measured absorption in the mid-infrared range at a given background radiation was exactly reproduced. However, the distribution of the clumps along the line of sight and their shapes could not be obtained by this alone. But since the dust emission in the mm-range is sensitive to the particular shape of the core it could be used to infer the missing 3D-information. For the calculation of the mm-emission the scientists made use of the fact that the temperature witin the core mainly depends on the mean optical depth of the radiation entering from the outside. This dependence varied with the translation and distortion of the clumps by less than 1 K in temperature and could be calculated before the actual modeling within the so-called T-tau method by using a 3D-program for the transfer of continuum radiation.

The density distribution determined this way shows many local maxima, with a compact southern absolute maximum. Comparison with hydrodynamic simulations, which also allow for turbulent motions, shows that such maxima can be of transient nature and may disappear on the dynamical timescale of the turbulence. But because of the high density and compactness of the southern maximum it can be expected not to dissolve and even to collapse.

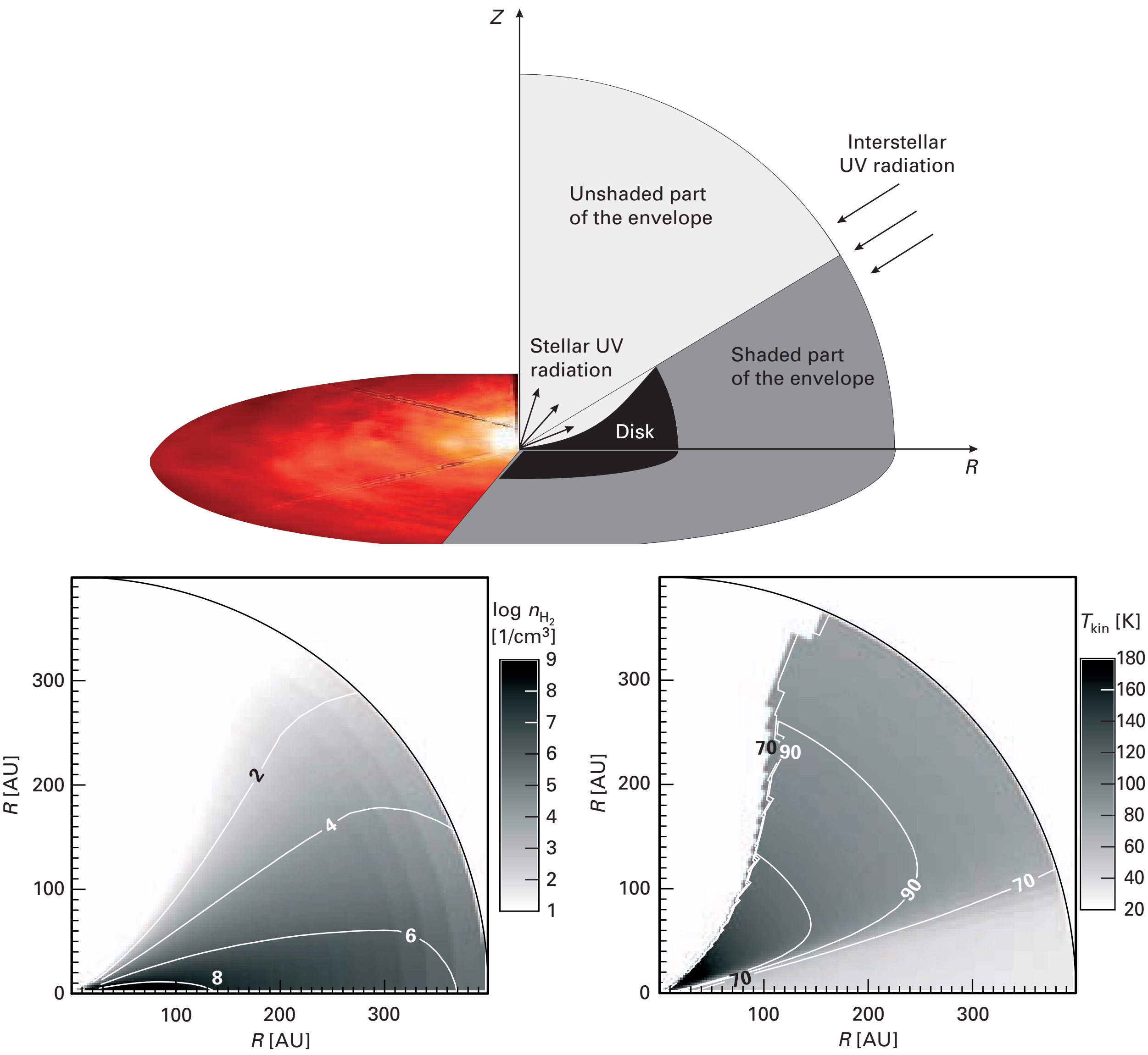
Complex structures as often found in star formation regions have many free parameters which have to be determined by comparison with observations. The new inverse 3D-radiative-transport-method, however, is based on a simultaneous modeling of several maps containing several thousand pixels and is therefore well-defined. The development of three-dimensional models is also a natural consequence of the fact that many observations show a clearly resolved three-dimensional structure where conventional one-and two-dimensional models fail.

An important aspect of the modeling are the properties of the absorbing and emitting dust particles, which are assumed to be constant. Especially in cool molecular clouds, however, the particles could grow by coagulation thereby changing their optical properties. Besides the shape, the chemical composition of the dust grains (the thickness of possible ice mantles, e.g.) has still to be determined and is subject of current research. Future models will have to take into account such a differentiation.

What Do Molecular Lines Tell Us about Star Formation?

The common feature of the prestellar cores and disks is that they are well shielded from ionizing interstellar or stellar radiation, leading to low internal temperatures. Under such conditions many complex molecular species can be formed and survive, most notably CO, CS, N_2H^+. Each molecule rotates and emits radiation at certain radio frequencies. The energy state of the rotation can be changed by collisions with other species, like H_2, or by interactions with photons. The radio emission of a hundred molecules has been detected in space so far. Using an antenna or antenna array with a good spectral and spatial resolution, we can image these objects in various molecular lines in detail. Molecular line observations allow physical condition and chemical composition of prestellar cores and circumstellar disks to be constrained. The major difficulty here is that the main component of the medium, H_2, which constitutes about 80 percent of the mass, is not easily observable. Therefore, we have to rely on other indirect methods to determine the physical structure of prestellar objects and disks, namely, using observations of molecular lines and thermal continuum dust emission. The

Fig. III.2.2: Sketch of the AB Aur system (*top*) and the model distributions of the density (*left bottom*) and temperature (*right bottom*) in the disk.



line observations have an important advantage since they also carry information about kinematics of the gas in these objects, which is however well hidden in the line profiles.

The use of molecular line observations as a tool of investigations is faced with two severe difficulties. First, the chemical structure of the prestellar objects is not uniform, so different species trace different regions of the source. Second, molecular emission lines are often excited in non-steady conditions that vary through the object. Both this facts make it challenging to extract a wealth of information about the source structure directly from the line data. This necessitates the use of sophisticated, coupled chemo-dynamical and radiative transfer models. By iteratively comparing the modeling results with observed quantities, the best fit and thus the basic parameters of the object can be found.

At the MPIA, we are involved in the development of all necessary tools for the interpretation and modeling of molecular emission lines from the disks and clouds, including multi-dimensional chemo-dynamical models and numerical codes for radiative transfer simulations.

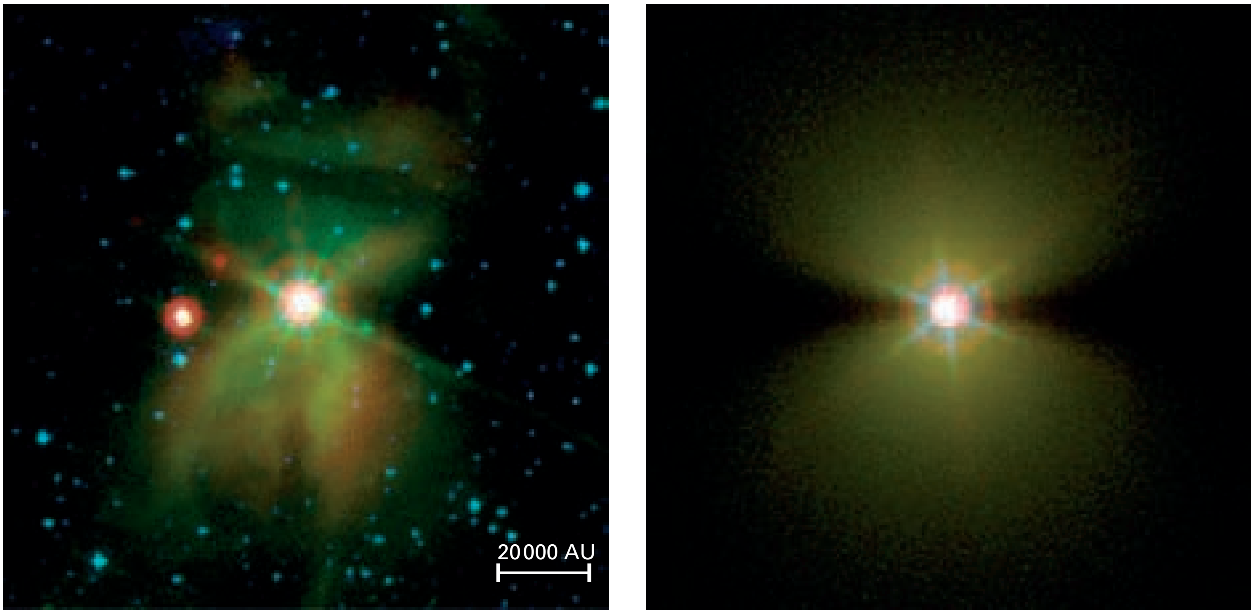
Here we present an application of these tools to millimeter observations of AB Aur. This system is one of the best studied circumstellar disks around young Herbig Ae stars. It was intensively investigated within the entire spectral range from UV to millimeter wavelengths, including molecular lines. The main aim of our study was to determine the orientation and properties of the AB Aur system using a combination of line observations and advanced theoretical modeling. The sketch of the system is shown in Fig III.2.2 (left), together with density and temperature structure of the adopted disk model (right). The AB Aur system consists of a flaring disk surrounded by an extended envelope. The disk shades off a torus-like region in the envelope from stellar UV flux, allowing many complex molecules to form there. We used a coherent step-by-step modeling of the AB Aur disk, its envelope physical structure, and its chemical evolution, using radiative transfer in several molecular lines.

With the best-fit model we could explain most of the features in the molecular line profiles on the observed map of the disk and derive its basic parameters, like mass, size, chemical structure, and orientation. However, the lack of spatial resolution in our observations did not allow us to reveal all details of the AB Aur disk structure. Future radio-interferometers, like ALMA, will provide us with more detailed information regarding chemical composition and structure of protoplanetary disks and prestellar cores.

A Small Disk Acting Big

The circumstellar dust- and gas disks in which planets form are often too small and too distant to be spatially resolved. This is particularly true for the SPITZER Space Telescope: it is the most sensitive infrared telescope now available, but has only limited spatial resolution. Many stars with disks, however, reside in giant molecular clouds. Some of these disks happen to lie nearly edge-on (i.e. we look at the outer edge of the disk). Pictured in the left panel of Fig. III.2.3 is the environment around the bright star VV Serpentis imaged with the SPITZER Space Telescope in false color: blue represents emission at a

Fig. III.2.3: *Left* – Environment around the star VV Serpentis imaged with the SPITZER Space Telescope. Blue represents emission at a wavelength of 4.5 µm, green represents 8.0 µm and red represents 24.0 µm emission. The bright star in the center is VV Ser. *Right:* Model image for VV Ser. The disk is so small that it resides entirely within the central bright dot. The dark wedge is the shadow cast by the small disk.



wavelength of 4.5 μm, green represents 8.0 μm and red represents 24.0 μm. The bright red star to the left is probably unrelated to VV Ser. The nebulosity surrounding VV Ser is glow from polycyclic aromatic hydrocarbons (PAHs), i.e. very small dust grains in the vicinity of the star which radiate due to quantum-excitation by ultraviolet (UV) photons originating from VV Ser. The dark wedge is *not* the circumstellar disk, as one may suspect, because such disks are ten to hundred times smaller than that. Instead, using multi-dimensional modeling with radiative transfer codes, K. Pontoppidan and C.P. Dullemond show that a much smaller disk casts a shadow *into* the environment. PAH grains residing in this shadow cannot see the UV photons by the star since their line of sight is blocked by the circumstellar disk, while PAH grains elsewhere get excited by the stellar UV photons.

A model (Fig. III.2.3, right panel) shows that this explanation works. In this figure the disk is so small that it resides entirely within the central bright dot (the size of the dot is the resolution of the telescope). The dark wedge is the shadow cast by the small disk. In this way the disk is magnified about a hundred times. The opening angle of the dark wedge is equal to the opening angle (i.e. thickness) of the unresolved disk in the center of the image. The authors compared the same model also to Spitzer Space Telescope infrared spectra, and showed that the model can also explain those. Moreover, the disk structure inferred from the above image and the fitting of the spectra was used to explain a peculiar kind of variability in the optical light from the star (called UX Orionis-type variability), and they could explain near-infrared interferometric observations of this object. In this way, the disk around VV Ser has become one of the most comprehensively modeled disks around a young star. The model has given insight into the structure of the disk and in the size-distribution of the dust particles residing in this disk. Both are very important for theories of planet formation.

Signatures of Planets in Spatially Unresolved Debris Disks

Main-sequence stars are commonly surrounded by debris disks, composed of cold dust continuously replenished by a reservoir of undetected dust-producing planetesimals. In a planetary system with a belt of planetesimals (like the solar system's Kuiper Belt) and one or more interior giant planets, the trapping of dust particles in the mean motion resonances with the planets can create structure in the dust disk, as the particles accumulate at certain semimajor axes. Sufficiently massive planets may also scatter and eject dust particles out of a planetary system, creating a dust-depleted region inside the orbit of the planet. In anticipation of future observations of spatially unresolved debris disks with the Spitzer Space Telescope, we are studying how the structure carved by planets affects the shape of the disk's spectral energy distribution (SED) and consequently whether the SED can be used to infer the presence of planets. We numerically calculate the equilibrium spatial density distributions and SEDs of dust disks originated by a belt of planetesimals in the presence of interior giant planets in different planetary configurations and for a representative sample of chemical compositions. The dynamical models are necessary to estimate the enhancement of particles near the mean motion resonances with the planets and to determine how many particles drift inside the planet's orbit. On the basis of the SEDs and predicted Spitzer colors we discuss what types of planetary systems can be distinguished and the main parameter degeneracies in the model SEDs.

For the simulation of the debris disk SEDs we use a radiative transfer tool which is optimized for optically thin dust configurations with an embedded radiative source. The density distribution, radiative source, and dust parameters can be selected either from an internal database or defined by the user. Furthermore, this tool is optimized for studying circumstellar debris disks where large grains (with radii ≥ 1 μm) are expected to determine the far-infrared through millimeter dust reemission spectral energy distribution. The tool is available at http://aida28.mpia-hd.mpg.de/~swolf/dds.

In Figure III.2.4 we compare the emission arising from the different compositions (keeping the particle size approximately constant). These simulations demonstrates the dependence of a debris disk SED on the dust grain properties (chemical composition, density, and size distribution) and the mass and location of the perturbing planet. The SED of a debris disk with interior giant planets is fundamentally different from that of a disk without planets; the former shows a significant decrease of the Nir and Mir flux due to the clearing of dust inside the planet's orbit. The SED is particularly sensitive to the location of the planet, i.e., to the area interior to the planet's orbit that is depleted in dust.

However, some degeneracies can complicate the interpretation of the spectral energy distribution in terms of planet location. For example, the SED of a dust disk dominated by Fe-poor silicate grains has its minimum at wavelengths longer than those of a disk dominated by carbonaceous and Fe-rich silicate grains. Because the SED minimum also shifts to longer wavelengths when the gap radius increases (because of a decrease in the mean temperature of the disk), we note that there might be a degeneracy between the dust grain chemical composition and the semimajor axis of the planet clearing the gap. For example, note the similarities in the shape of the SEDs arising from a dust disk with a 3 M_J planet at 1AU that is dominated by $MgSiO_3$ grains and that arising from a disk with a 3 M_J planet at 30 AU that is dominated by $MgFeSiO_4$ grains (see Fig. III.2.5). This illustrates the importance of obtaining spectroscopic observations able to constrain the grain chemical composition, and/or high-resolution images, able to spatially resolve the disk.

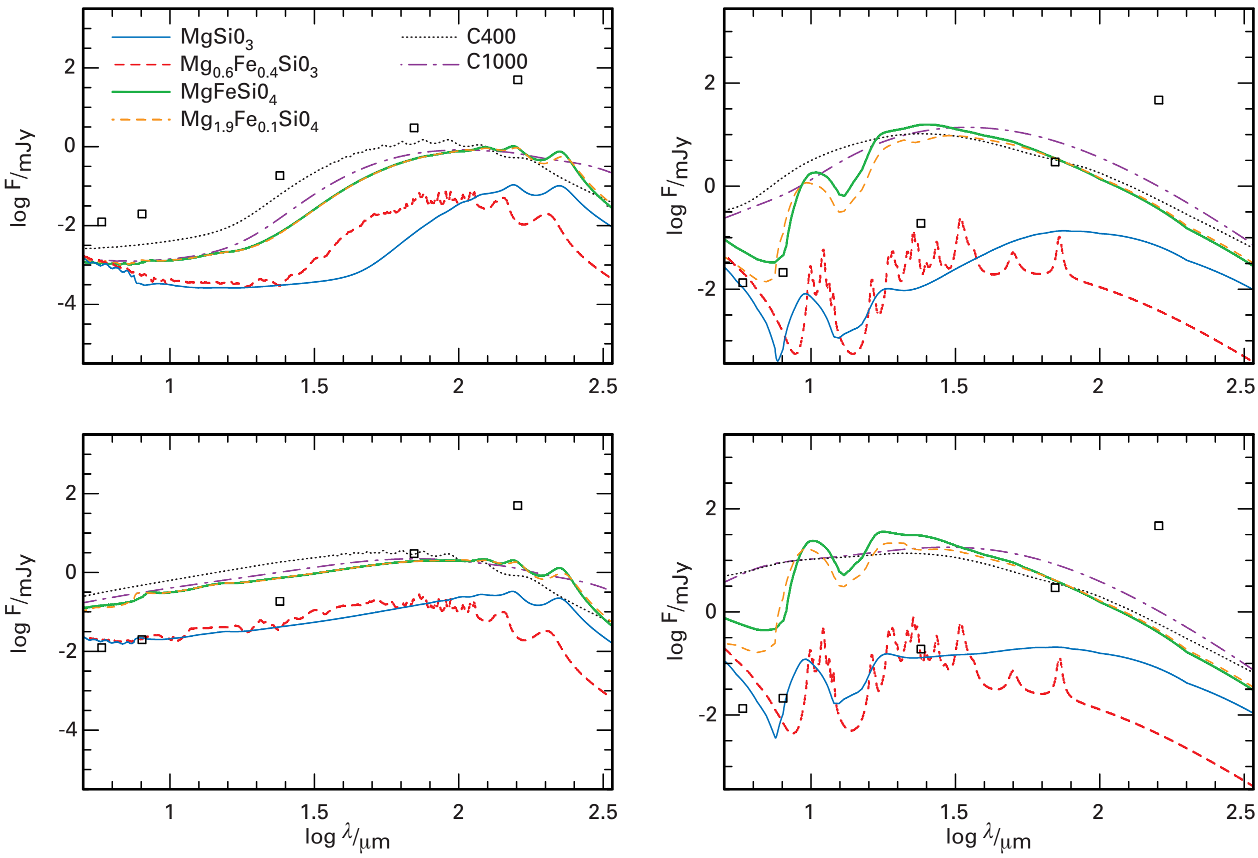


Fig. III.2.4: Spectral energy distributions (SEDs) of disks composed of 1 and 40 µm grains with different grain chemical compositions, for a model resembling the solar system (i.e., the planets, excluding Mercury and Pluto, and the Kuiper belt as the source of dust). *Top left:* Single grain size (40 µm) disk with planets; *Top right:* Single grain size (1 µm) disk with planets; *Bottom left:* Single grain size (40 µm) disk without planets; *Bottom right:* Single grain size (1 µm) disk without planets.

Once interesting debris disks have been identified by Spitzer, the next step will be to obtain high-sensitivity and high-spatial resolution images in scattered light and/or thermal emission (using, e.g., LBT, JWST, Sofia, Alma, or Safir). Of particular interest are the longer wavelengths, at which observations can constrain the amount of material farther away from the planet and at which the emission of the larger dust particles, the ones that show more prominent structure, dominate. If one could spatially resolve the disk, the dynamical models could allow us to locate the perturbing planet. Then we could compare the information derived from the SED alone with that derived from the resolved image. This is important to understand the limitations of the characterization of planetary architectures on the basis of spatially unresolved debris disks only. In addition, by obtaining resolved images in one or more wavelengths we can break the degeneracy expected from the analysis of the disk SED. In anticipation of these spatially resolved observations, we have started working on the modeling of the brightness density distributions arising from debris disks in the presence of different planetary configurations (see Fig III.2.6).

Radiative Transfer Simulations in the Context of Matisse Science Case Studies

Matisse is foreseen as a mid-infrared spectro-interferometer combining the beams of up to four UTs/Ats of the Very Large Telescope Interferometer (VLTI). Matisse will measure closure phase relations and thus offer an efficient capability for image reconstruction. In addition to the ability to reconstruct images with interferometric resolution, Matisse will open three new observing windows at the VLTI: the L, M, and Q band which all belong to the mid-infrared domain. Furthermore, the instrument will offer the possibility to perform simultaneous observations in separate bands.

Matisse will also provide several spectroscopic modes. In summary, Matisse can be seen as a successor of Midi by providing imaging capabilities in the entire mid-infrared accessible from the ground. The extension of Matisse down to 2.7 µm as well as its generalisation of the use of closure phases make it also a successor of Amber. Thus, in many respects Matisse will combine and extend the experience acquired with two first generation VLTI instruments – Midi and Amber.

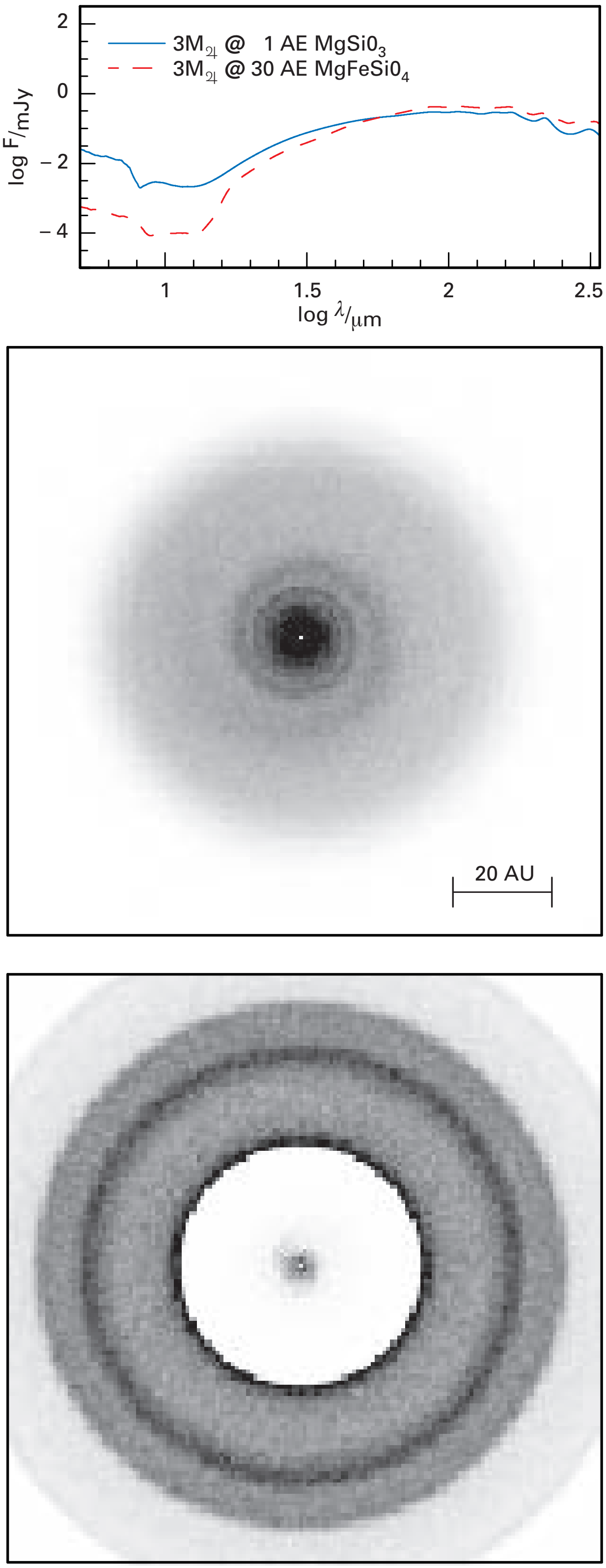


Fig. III.2.5: *Top* – Possible degeneracy between the grain chemical composition and the location of a planet clearing the gap: SED of a dust disk composed of $MgSiO_3$ grains with a $3\,M_J$ planet at 1 AU (solid line) and a dust disk composed of $MgFeSiO_4$ grains with a $3\ M_J$ planet at 30 AU (dashed line). *Middle* – Brightness density distributions at 70 µm (assuming graybody emission from 12 µm grains) expected from a disk with a $3\ M_J$ planet at 1 AU (shown in arbitrary units). *Bottom:* Same as middle, but for 30 AU. High resolution images are needed to resolve the degeneracy.

Matisse will extend the astrophysical potential of the VLTI by overcoming the ambiguities often existing in the interpretation of simple visibility measurements. It will be an instrument with unique performance. This is partly related to the existence of the four large apertures of the VLT (UTs) that permits to push the sensitivity limits up to values required by selected astrophysical programs such as the study of Active Galactic Nuclei and extrasolar planets.

Moreover, the evaluated performance of Matisse is linked to the existence of ATs which are relocatable in position in about 30 different stations allowing the exploration of the Fourier plane with up to 200 meters baseline length. Key science programs using 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.

Matisse will offer to the European community high angular resolution imaging and spectroscopic capabilities in the mid-infrared wavelength domain covering the L, M, N, and Q band. This wavelength range, in between the near-infrared domain to which instruments like Amber are sensitive, and the (sub)millimeter domain for which high angular resolution is foreseen with Alma, is of fundamental scientific interest. In terms of image capability Matisse can be seen as a ground precursor of the future space interferometer Darwin which is presently studied as an instrument sensitive to the 6 to 18 µm range.

Radiative transfer simulations are of vital importance for the identification and analysis of science cases for Matisse, and thus for the definition of the instrument specifications during the Matisse design phase. For example, the study of the capability of Matisse to reconstruct images is based on model images of selected astrophysical objects resulting from radiative transfer simulations.

One of the major goals of Matisse will be the investigation of the planet formation process. Planets are expected to form in circumstellar disks, which are considered as the natural outcome of the protostellar evolution, at least in the case of low and medium mass stars. While a detailed picture of the evolution of the circumstellar environment, in particular of circumstellar disks, has been developed already, the planet formation process is mostly still under discussion. The dominant observable quantity originating from the inner disk region ($r < 10$ to 20 AU) is the emission of mid-infrared continuum radiation by hot dust. Given the typical distance of nearby star-forming regions of about 140 to 200 pc and the spatial resolution achievable with the Very Large Telescope Interferometer (VLTI) in the mid-infrared atmospheric windows (L, M, N, Q band) of up to 3 milliarcseconds (depending on the observing wavelength and AT/UT configuration), MATISSE will be the ideal instrument to study the planet-forming region in circumstellar disks.

Two exemplary questions which MATISSE will be able to address are the following: [1] Is the inner disk structure modified by early stages of planet formation? – The inner region of circumstellar disks is expected (but not yet proven) to show large-scale (sub-AU to AU sized) density fluctuations and inhomogenities. The most prominent examples are predicted long-lived anti-cyclonic vortices in which an increased density of dust grains may undergo an accelerated growth process – the first step towards planet formation (Klahr and Bodenheimer 2003). Locally increased densities and the resulting locally increased disk scale height have direct impact on the heating of the disk by the central star and are expected to show up as local brightness variations (due to increased absorption or shadowing effects) in the mid-infrared images (for illustration, see Fig. III.2.7).

[2] What is the status of disk clearing within the inner few AU? – According to the temperature and luminosity of the central star, the sublimation radius for dust grains is in the order of 0.1 – 1 AU (T-Tauri and Herbig Ae/Be stars). This can be approximately spatially resolved with MATISSE in the L band in the case of nearby YSOs. However, in contrast to these values, an even significantly larger inner dust disk radius of about 4 AU has been deduced from SED modelling in the 10 Myr old protoplanetary disk around TW Hydrae (Calvet et al. 2002).

Other examples are the object CoKu Tau/4 with an evacuated inner zone of radius ~10 AU (D'Alessio et al. 2005, Quillen et al. 2004) and GM Aur with a significant decrease of the dust reemission inside about 4 AU around the central star (Rice et al. 2003). This gap is characterized by a depletion of at least the population of small dust grains which are responsible for the near- to mid-infrared flux. The confirmation of these indirectly determined gaps,

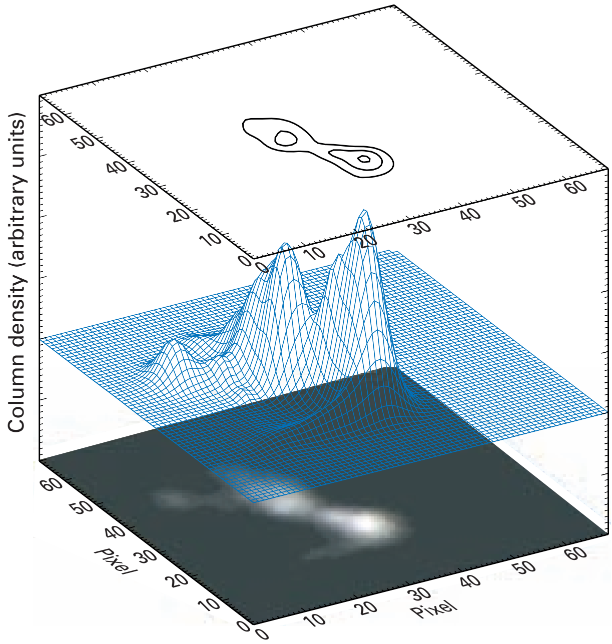
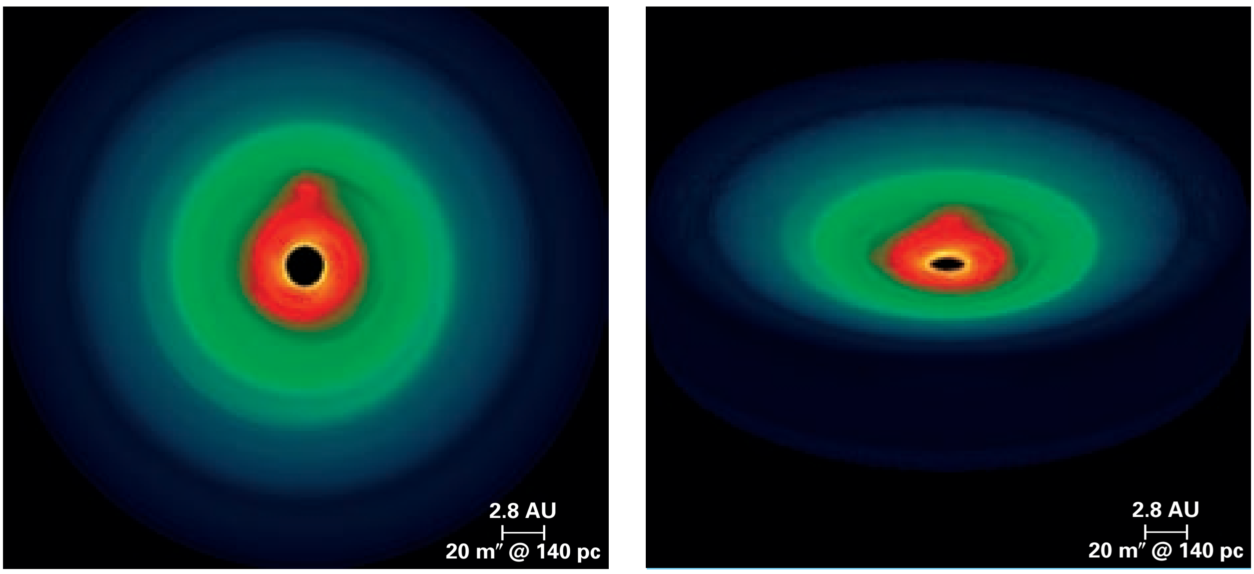


Fig. III.2.6: Simulated scattered light image of a debris disk with an embedded planet (Jupiter-mass planet; orbital radius: 54 AU; dust grain radius: 9 μm).

Fig. III.2.7: Simulated 10 μm images of the inner region (radius 20 AU) of a circumstellar T-Tauri disk, with an embedded Jupiter-mass planet at a distance of 5.2 AU from the central star (Wolf and Klahr 2005). The left image shows the disk under an inclination of 0°, the right under 60°. For both inclinations, the hot region around the planet above the center of the disk, indicated as bright areas in these reemission images, is clearly visible. Assuming a distance of 140 pc, the corresponding 20 mas scale is indicated in the lower right edge of both images.



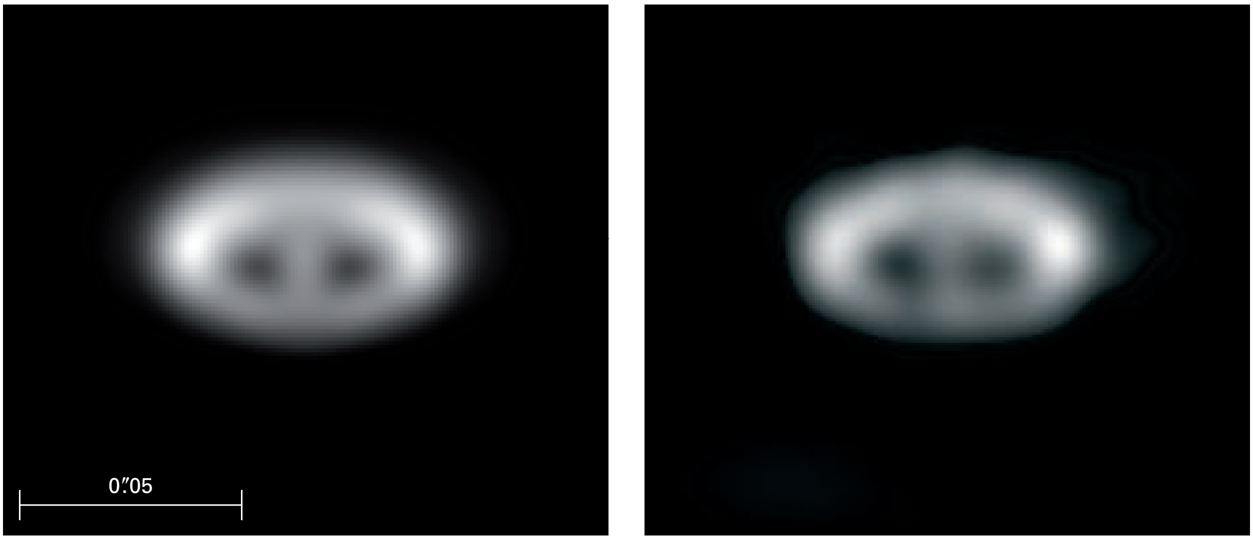


Fig. III.2.8: Simulated 10 µm image of the inner region of a T-Tauri circumstellar disk with a cleared inner region, seen under an inclination of 60° (assumed distance: 140 pc). *Left:* original image, convolved with a PSF corresponding to a 202 m aperture. *Right:* Reconstructed image. Configuration: seven nights of observing time with three axilliary telescopes (ATs) on Paranal. (MATISSE Science case study)

as well as the test of other disks for the existence of similar gaps will provide valuable constraints on the evolution of the planet-forming region and thus on the process of planet formation itself (see Fig. III.2.8 for an illustration of the feasibility to detect a large inner gap with MATISSE).

The radiative transfer simulations which Figures III.2.7 and III.2.8 have been performed with the radiative transfer code MC3D, a 3D continuum radiative transfer code which combines the most recent Monte Carlo radiative transfer concepts for both the self-consistent radiative transfer, i.e., the estimation of spatial dust temperature distributions, and pure scattering applications, taking into account the polarization state of the radiation field (Wolf 2003). The code is available for download at www.mpia.de/homes/swolf/mc3d-public/mc3d-public.html.

Future Prospects

The perspective of applying the inverse 3D radiative transfer method to other cores is promising. Every additional image observed at other wavelengths will introduce new constraints for the unknown parameter, and will thus increase the accuracy of the determined density structure. The ultimate goal of applying the method to well-observed cores, however, will be to address the key question of early star formation, namely if the considered cores have in-falling material. The current line observations provide the molecular line emission flux integrated over all moving gas cells along the line of sight.

In the general case, gas motion and emissivity of the cells can not be disentangled, and the 1D approximation or shearing layers are assumed to unfold it. Without unfolding it, infall motion can be mixed up with rotational motion leaving it undecided if the core shows any sign for the onset of star formation. This is changed if the core has been investigated with the new method. Knowing the full 3D structure in dust density and temperature, the line of sight-integral can be inverted providing the complete kinematical information if the considered line is optically thin and a model for the depletion of the considered molecules is used. This direct verification of infall motion would also allow to answer the question if the infall occurs spherically or through a first phase accretion disk.

(Jürgen Steinacker, Sebastian Wolf, Hubert Klahr, Cornelis Dullemond, Yaroslav Pavlyuchenkov, Thomas Henning, Manfred Stickel, In collaboration with colleagues from Observatoire de Bordeaux, Astrophysikalisches Institut Potsdam, Institut für Astronomie und Astrophysik der Universität Tübingen, Steward Observatory of the University of Arizona, Department of Planetary Sciences of the University of Arizona and California Institute of Technology)

III.3 The Galaxy-Dark Matter Connection

Halo occupation statistics, which describe the statistical link between galaxies and their dark matter haloes, play a crucial role in modern astrophysics. They provide insights into the complicated physical processes associated with galaxy formation, and they allow us to use the observed distribution of galaxies to put tight constraints on cosmological parameters. A new Nachwuchsgruppe at the MPIA is involved in developing new methods to constrain these occupation statistics, and to use them to constrain both cosmology and galaxy formation.

Understanding the origin and evolution of galaxies is one of the most fascinating unsolved problems in astrophysics. It involves physical processes from the scale of the Universe itself (i.e., cosmology) down to the micro-physics that describe the formation of individual stars. Currently popular cosmologies consider a Universe that consists of baryonic matter, cold dark matter and some form of vacuum energy. Shortly after the Big-Bang, quantum processes are thought to have created small perturbations in the matter distribution (both the dark and baryonic matter), which act as the seeds for structure formation. Since an overdense region exerts a larger than average gravitational force on its surroundings, there will be a net infall of material into the overdense region. This causes the overdense region to become more overdense, and thus to grow in amplitude. At some point, the overdensity reaches a critical level at which the perturbation starts to collapse. The associated dark matter experiences what is called violent relaxation, which results in the formation of a virialized dark matter halo. At the same time, the baryonic material is shock heated to high temperature while it settles in hydrostatic equilibrium in the potential well of the dark matter halo. Subsequently, atomic processes cause the gas to cool, thereby radiating away its kinetic energy. As a result, the gas falls to the center of the dark matter halo and collapses into a dense condensation of gas, which ultimately experiences star formation, and forms a galaxy. This picture, however, is not complete, as dark matter haloes don't evolve as isolated systems. Instead, their formation is hierarchical, in that small haloes continuously merge together to build ever larger haloes. The galaxies in these haloes either merge together into a larger galaxy, or they survive as satellite galaxies, orbiting in the background potential provided by the dark matter.

Although this standard picture has been around for almost three decades, we are still far from a proper understanding of the intricate processes involved in transforming the hot gas of the early Universe into the stars that comprise the luminous galaxies of today. This is largely due to the fact that many of the physical processes involved are still poorly understood, in particular the »micro-physics« associated with star formation and its associated feedback on the interstellar medium.

In principle, we could learn a great deal about galaxy formation if we could somehow determine the average relation between halo mass and galaxy properties: e.g., how many galaxies are there, on average, per halo, and how does this scale with halo mass? How are galaxy properties such as luminosity, star formation history or morphology related to the mass of the halo in which they reside? These halo occupation statistics describe the galaxy-dark matter connection, which reflect the direct imprint of the various physical processes associated with galaxy formation. Constraining the statistical link between galaxies and dark matter haloes therefore constrains the physics of galaxy formation.

The halo occupation statistics are also of crucial importance if we ever want to use the distribution of galaxies in order to constrain cosmological parameters. An important goal of modern day cosmology is to determine the distribution of matter in the universe, which is strongly cosmology dependent. Unfortunately, the majority of the matter is dark matter, which is invisible. However, according to the galaxy formation paradigm described above, galaxies reside inside dark matter haloes, and we can thus use the light of galaxies as a tracer of the dark matter mass distribution.

Unfortunately, galaxies are not a fair, unbiased tracer of the mass distribution; if a certain region contains twice as much light (from galaxies) than another region of the same volume, this does not necessarily mean that it also contains twice as much mass. This non-linear relation between light and mass is called »galaxy bias«. It arises in part from the fact that dark matter haloes themselves are a biased tracer of the dark matter mass distribution. This is easy to understand from the fact that dark matter haloes form out of overdensities in the initial matter field. Haloes therefore only trace overdense regions, not the underdense ones. Fortunately, this halo bias is well understood, and for a given cosmology we know fairly accurately how haloes of a given mass are biased. The only missing ingredient for specifying galaxy bias is therefore the link between galaxies and dark matter haloes, which brings us back to the halo occupation statistics.

In summary, a detailed description of the galaxy-dark matter connection, in terms of the halo occupation statistics, can provide useful constraints on both galaxy formation and cosmology. In the following we describe some highlights of our work that aims at establishing a self-consistent, coherent picture of the statistical link between galaxies and their dark matter haloes.

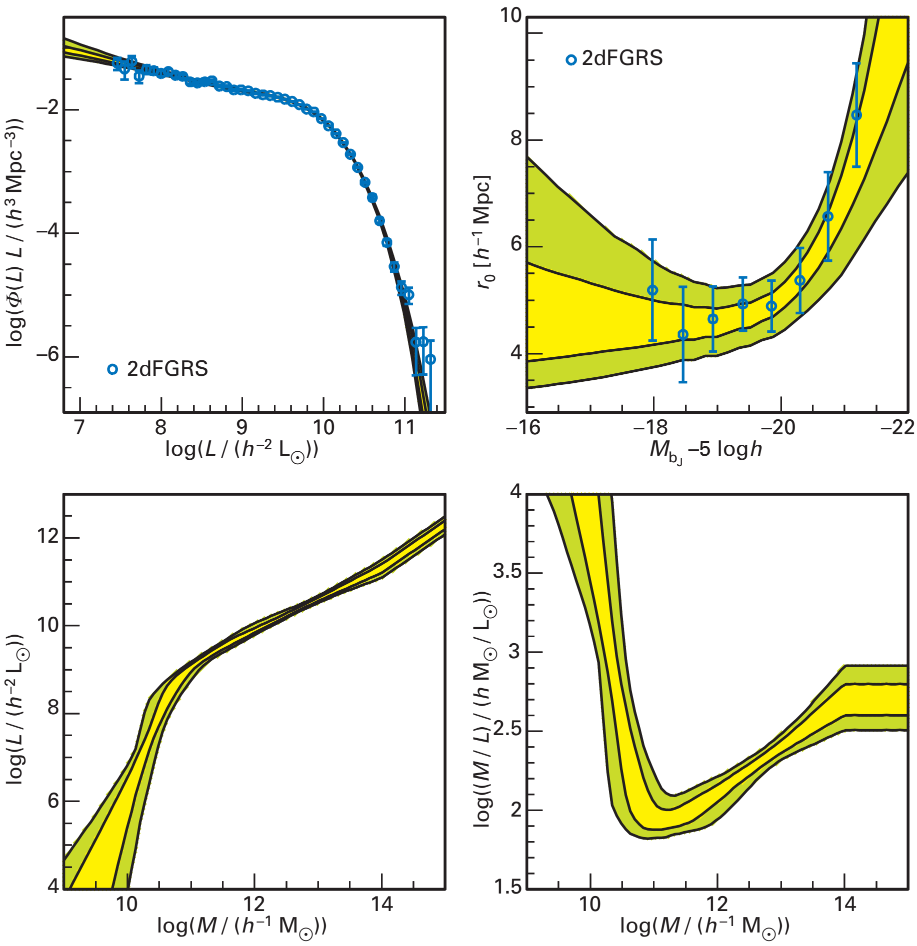
The Conditional Luminosity Function

As discussed above, gravity causes hierarchical growth of structures in the Universe. As a consequence, the matter distribution in the present day Universe is strongly clustered. Since galaxies reside in dark matter haloes, it therefore should not come as a surprise that the distribution of galaxies is also strongly clustered, as is indeed confirmed by large galaxy redshift surveys. A more detailed analysis shows that more luminous galaxies are more strongly clustered. This luminosity dependence of the clustering strength provides the information required to establish a statistical description of the galaxy-dark matter connection. The reason that this approach works is that more massive haloes are more strongly clustered: in terms of the halo bias mentioned above, more massive haloes are more strongly biased. Consequently, the clustering strength of galaxies of a give luminosity is a direct measure of the mass of the haloes in which these galaxies reside: since more luminous galaxies are more strongly clustered than less luminous galaxies, and more massive haloes are more strongly clustered than less massive haloes, more luminous galaxies have to reside in more massive haloes.

At the MPIA, the research group of Frank van den Bosch, in collaboration with Xiaohu Yang (Shanghai Observatory) and Houjun Mo (University of Massachusetts), has developed a novel statistical technique based on this principle. The technique aims at describing the halo occupation statistics via the so-called conditional luminosity function (hereafter CLF), which expresses the average number of galaxies of luminosity L that reside in a halo of mass M. This CLF completely specifies the bias of galaxies as a function of their luminosity and it allows one to compute the total, average luminosity of all galaxies that reside in a halo of a given mass. In other words, the CLF completely specifies the average relation between light and mass in the Universe.

Using the luminosity function, which expresses the abundance of galaxies as function of their luminosity, and the luminosity dependence of the clustering strength obtained from the 2dFGRS, one of the largest galaxy

Fig. III.3.1: Comparison of the observed present-epoch galaxy luminousity function and (spatial) correlation function and the matched CLF models. In each panel the contours show the 68 and 95 percent confidence limits from our CLF model. *Upper left:* The galaxy luminosity function. *Upper right:* the correlation lengths as function of luminosity. *Lower left:* the relation between light and mass implied by the LCF models matched to the data (upper panels). *Lower right:* the implied average mass-to-light ratio as function of halo mass.



redshift surveys constructed to date, we have been able to put strong constraints on the conditional luminosity function and thus on the average relation between light and mass. Fig. III.3.1 shows confidence levels on various quantities computed from the CLF obtained for a typical ΛCDM concordance cosmology. The open circles with errorbars in the upper two panels indicate the 2dF GRS data used to constrain the models: the galaxy luminosity function (upper left panel) and the correlation length, which is a measure of the clustering strength, as function of luminosity (upper right panel). The shaded areas indicate the 68 and 95 percent confidence levels obtained from our model. Note the good agreement with the data, indicating that the CLF can accurately match the observed abundances and clustering properties of galaxies in the 2dFGRS. In other words, we have quantified how galaxies of different luminosities are distributed within haloes of different masses.

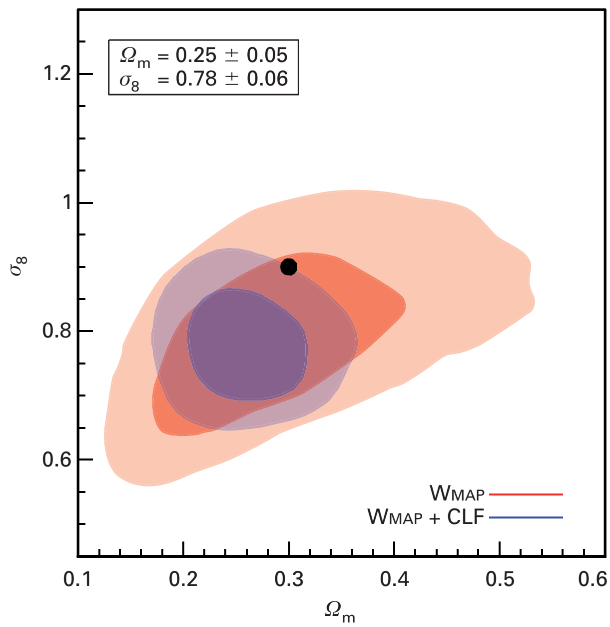
The lower left-hand panel of Fig. III.3.1 plots the relation between halo mass *M* and the total luminosity *L*, the expectation value of which follows from the CLF. Note that the confidence levels are extremely tight, especially for the more massive haloes: apparently there is not much freedom in how one can distribute light over haloes of different masses while remaining consistent with the data. Note that the average relation between light and mass reveals a dramatic break at around $M \approx 7 \times 10^{10}$ h^{-1} $M_\odot$. This characteristic scale is not an artefact of the model, but is actually required by the data. It tells us that this scale is somehow picked out by the physics of galaxy formation.

The lower right-hand panel of Fig. III.3.1 plots the corresponding mass-to-light ratios as function of halo mass. The characteristic break in the average relation between light and mass now translates into a pronounced minimum in mass-to-light ratios. The characteristic scale therefore marks the mass scale at which galaxy formation is most efficient, i.e., at which there is the largest amount of light per unit mass. For less massive haloes, the mass-to-light ratio increases drastically with decreasing halo mass. It indicates that galaxy formation needs to become extremely inefficient in haloes with $M < 5 \times 10^{10}$ h^{-1} $M_\odot$. One physical explanation that has been proposed for this decreased efficiency in small mass halos is feedback from supernovae. These stellar explosions produce enormous amounts of energy, which can expel large fractions of the baryonic mass from low mass haloes, which have relatively low escape velocities. The results shown here indicate how the efficiency of this process needs to scale with halo mass, if the model is to successfully reproduce the observed abundances and clustering properties of galaxies. At the massive end, the average mass-to-light ratio also increases. Numerical simulations of galaxy formation have long been unable to reproduce such a trend, which has become known as the overcooling problem. Currently, many research groups are investigating the role of feedback from Active Galactic Nuclei (AGN) in preventing gas from cooling in massive haloes. Once again, the statistical results obtained from our CLF analysis put tight constraints on how the efficiency of this so-called AGN feedback has to scale with halo mass.

Cosmological Parameters

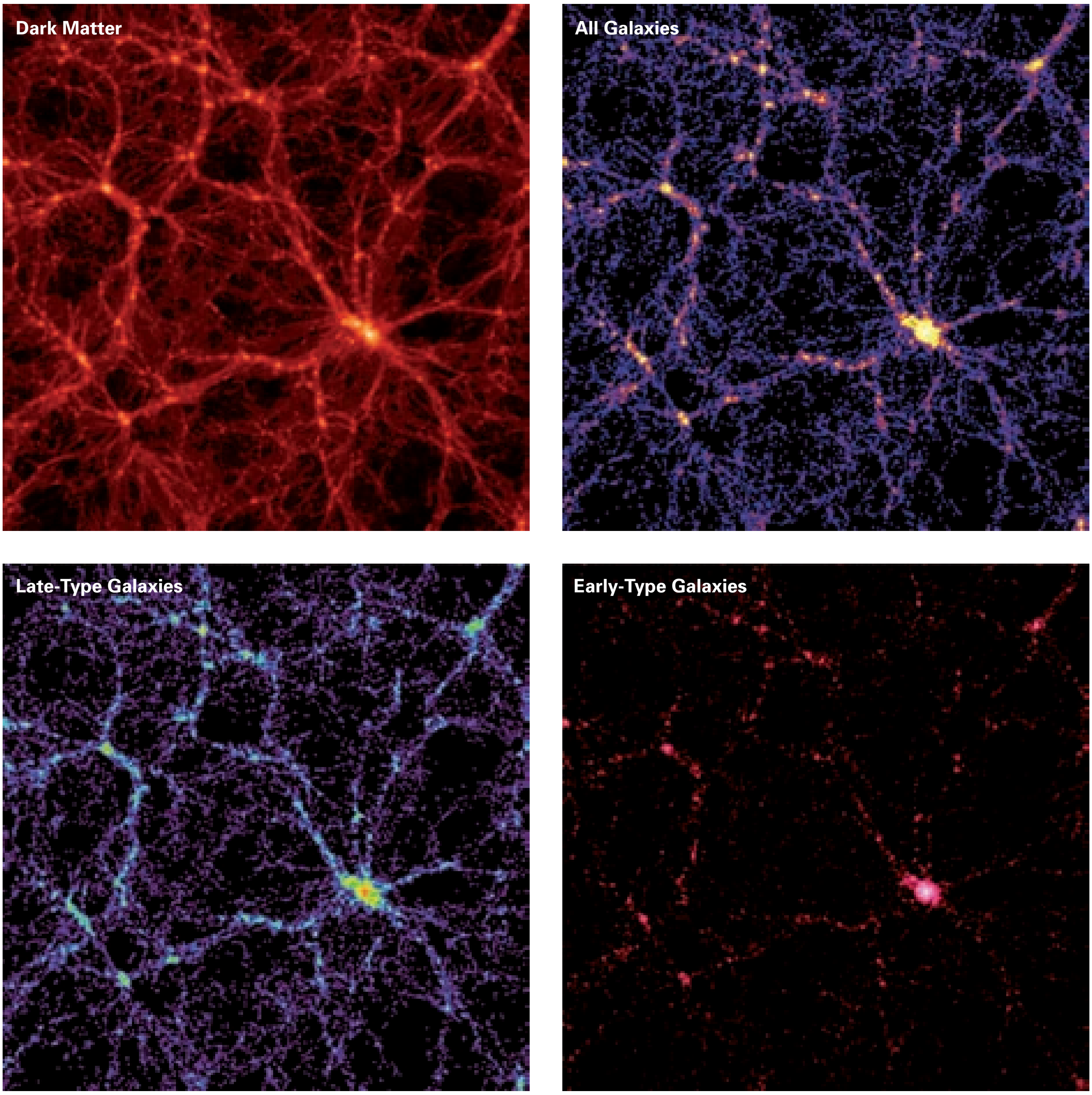
Two of the most important cosmological parameters are the average matter density, and the normalization of the strength of the initial density perturbations. These are typically parameterized via the matter density parameter and the so-called power-spectrum normalization parameter σ_8. Typically, increasing either of these parameters will result in a larger abundance of massive haloes and a stronger overall clustering strength of dark matter haloes. A different cosmology therefore requires a different galaxy-dark matter relationship (i.e., a different CLF) to be consistent with the observed abundance and clustering properties of the galaxies. For example, if one increases the normalization of the matter power spectrum, the dark matter haloes becomes more strongly clustered. In order to match the observed clustering strength, galaxies therefore have to be less strongly biased. This can be accomplished by distributing galaxies over lower mass haloes, which are less strongly clustered than massive haloes. However, if one removes more and more galaxies from cluster sized haloes to

Fig. III.3.2: Constraining cosmological parameters: The 68 and 95 percent confidence levels on the matter density Ω_m and the power spectrum normalization parameter σ_8 obtained from the cosmic microwave background by the WMAP satellite (*red contours*) and from the combination of WMAP data and our CLF analysis of the large scale structure of the Universe (*blue contours*).



redistribute them over lower mass haloes, this increases the overall mass-to-light ratio of clusters. Using independent constraints on the average mass-to-light ratio of clusters, we were able to use our CLF formalism to put tight constraints on cosmological parameters. The results are shown in Fig. III.3.2, where the blue contours indicate the 68 and 95 percent confidence levels on the matter density parameter Ω_m and the power spectrum normalization parameter σ_8. For comparison, the red contours indicate the constraints from the first year data release from the WMAP satellite. Our results clearly prefer a cosmology with a lower matter density and a lower normalization parameter than typically assumed for the so-called concordance cosmology (indicated by the black dot). In March 2006, the WMAP science team confirmed our findings, and showed that the improved measurements of the anisotropies and polarization of the cosmic microwave background suggest a cosmology with parameters that are extremely close to those favored by our CLF analysis. This clearly demonstrates that the CLF formalism provides an accurate description of galaxy bias, thereby allowing us to use the distribution of galaxies to constrain cosmological parameters.

Fig. III.3.3: Projected dark matter/galaxy distribution of a $100 \times 100 \times 10\ h^{-1}$ Mpc slice in a »mock Universe«. The panels show (clockwise from top-left) the dark matter particles, all galaxies, early-type galaxies, and late-type galaxies. Galaxies are weighted by their luminosities.



Mocking the Universe

Another powerful application of the CLF is the construction of mock galaxy redshift surveys (hereafter MGRSs), which are extremely useful tools for the interpretation of large redshift surveys. As with any dataset, several observational biases hamper a straightforward interpretation of such surveys. The CLF is ideally suited for building up virtual Universes from which mock galaxy redshift surveys can be constructed using the same biases and incompleteness effects as in the real data. All that is required is a numerical simulation of the dark matter distribution in the Universe. After identifying the dark matter haloes in such a simulation, the CLF can be used to populate each of these haloes with galaxies of different luminosities. Note that, by construction, the abundance and clustering properties of these galaxies will automatically match those of the data. After introducing a virtual observer in the simulated volume, one can construct MGRSs, which can be compared to real redshift surveys, such as the 2dFGRS and the Sloan Digital Sky Survey (SDSS) on a one-to-one basis.

Fig. III.3.3 shows a slice through one of our virtual Universes. Clockwise, from the upper left panel, we plot the distribution of dark matter, of all galaxies, of early-type galaxies, and of late-type galaxies. Note that, at first sight, the galaxies seem to accurately trace the dark matter mass distribution. However, a more detailed analysis would reveal that the actual spatial distributions of galaxies of different types and different luminosities are statistically different from each other, and from that of the dark matter. This reflects the complicated dependence of the galaxy bias on scale, type, and luminosity, which is nevertheless completely specified by the CLF.

Satellite Kinematics

As discussed above, and as shown in Fig. III.3.1, the observed clustering of galaxies as function of luminosity puts tight constraints on how galaxies of different luminosities occupy haloes of different masses. In order to test the inferred relation between light and mass shown in the lower left panel of Fig. III.3.1, we have used the kinematics of satellite galaxies. Satellite galaxies are those galaxies in a dark matter halo that do not reside at the center of the halo (which are called central galaxies), but which instead orbit within the halo at relatively large halo-centric radii. Consequently, these satellites probe the potential well out to the outer edges of their haloes, and are therefore ideally suited to measure the total halo masses. In particular, the typical velocity with which satellites orbit their corresponding central galaxy is a direct, dynamical indicator of the mass of the associated halo. A downside of this method, however, is that the number of detectable satellites in individual systems is generally much too small to obtain a reliable mass estimate. However, one can stack the data on many central-satellite pairs to obtain statistical estimates of the halo masses associated with central galaxies of a given luminosity. The crucial problem is how to decide which galaxy is a central galaxy, and which galaxy a satellite.

Using the MGRSs describes above, we optimized the central-satellite selection criteria to yield large numbers

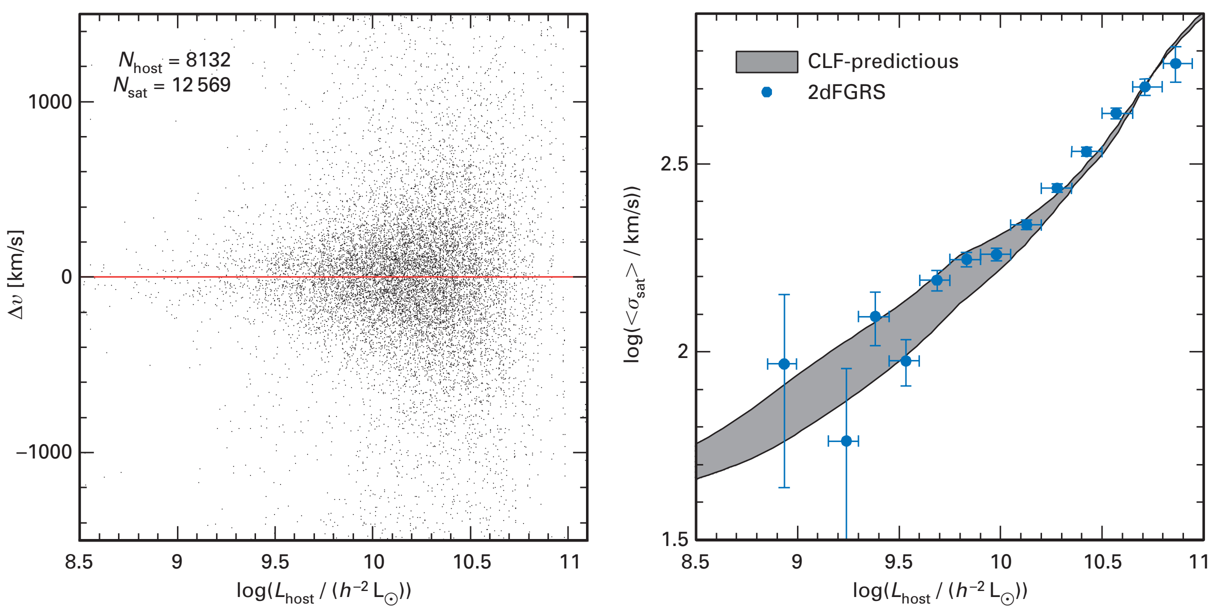


Fig. III.3.4: *Left:* The observed velocity differences ΔV between host and satellite galaxies in the 2dFGRS as function of the luminosity of the host galaxy. *Right:* The satellite velocity dispersion as function of host luminosity. Solid dots with errorbars correspond to the 2dFGRS results shown in the left panel, while the gray area indicates the expectation values obtained from the CLF.

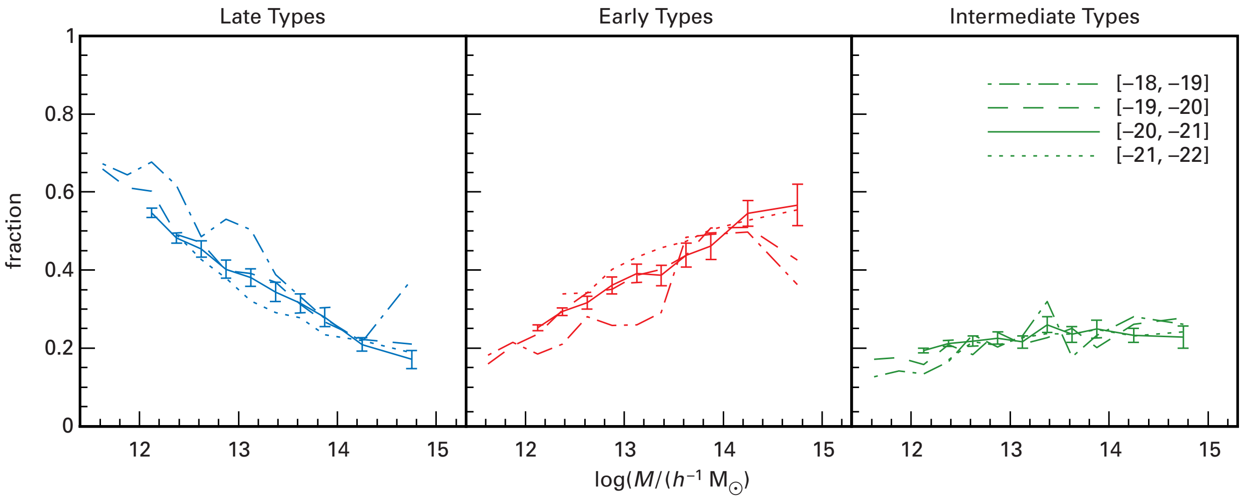


Fig. III.3.5: The fractions of late-type, early-type and intermediate type galaxies as function of halo mass. Results as shown for galaxies in four luminosity bins. The values is square brackets indicate the ranges of $0.1M_r - 5 \log h$ used.

of centrals and satellites, and small fractions of interlopers (satellites not physically associated with the halo of the host galaxy). Applying these optimized selection criteria to the 2dFGRS yields a total of 8132 central galaxies and 12569 satellite galaxies, which is an order of magnitude larger than any previous study. The left-hand panel of Fig. III.3.4 plots the velocity difference, ΔV, between central and satellite galaxies as function of the luminosity of the central galaxy. Note that the variance in ΔV increases strongly with this central luminosity, indicating that more luminous galaxies live in more massive haloes. This is emphasized in the right-hand panel of Fig. III.3.4 where we plot the velocity dispersion of the satellites as function of the luminosity of the central galaxy (solid dots with errorbars) The gray area indicates the expectation values obtained from our CLF. Clearly, the satellite kinematics obtained from the 2dFGRS are in excellent agreement with these predictions. This provides a dynamical confirmation of the average relation between mass and light inferred solely from the clustering properties.

Galaxy Groups

The CLF formalism uses the clustering properties of galaxies to infer, in a statistical sense, the halo occupation statistics of galaxies of different luminosities. In principle, these occupation statistics can also be inferred from galaxy group catalogues: if one can somehow determine which galaxies belong to the same dark matter haloes (i.e., belong to the same »group«), and one can somehow obtain an accurate estimate of the mass of that halo, then one can directly infer the halo occupation statistics. Clearly, this method is much more direct than the statistical method based on the clustering properties. In particular, rather than providing only average occupation numbers, it will yield the full probability distributions.

The problem is how to find a reliable algorithm that allows the identification of those galaxies that belong to the same dark matter halo. Using the MGRSs described above as a testbed, we have developed a new group finder that can successfully assign galaxies into groups according to their common haloes. Detailed tests have shown that this group finder is significantly more reliable in terms of completeness and interloper fractions than previous group finding algorithms that have been used extensively in the past.

We have applied this new group finder to the SDSS, and used the resulting galaxy group catalogue to investigate how various galaxy properties (in addition to luminosity) correlate with halo mass. In particular, we have investigated the dependence of colour and star formation rate on halo mass. We first subdivide the galaxy population in three types according to their colour (obtained from the SDSS photometry) and their specific star formation rate (obtained from the SDSS spectroscopy): late type galaxies are defined as being blue and with relatively active ongoing star formation. Early type galaxies, on the other hand, are defined to be red and with relatively passive star formation. Finally, we identified a class of intermediate type galaxies, which are red but yet have relatively active star formation. Fig. III.3.5 shows the fractions of early, late and intermediate type galaxies as function of group (i.e. halo) mass. Results are shown for different magnitude bins, indicated by different line styles. Not surprisingly, we find that the late type fraction decreases with increasing halo mass. Correspondingly, the fraction of early-type galaxies increases with halo mass. This basically reflects the well known environment dependence of galaxies, but now expressed in terms of the mass of the halo in which the galaxies reside. A new result, however, is that at a given halo mass, the type-fractions do not significantly depend on luminosity. This indicates that the colour and star formation rate of a galaxy depend much more strongly on halo mass than on luminosity. The well-known fact that more luminous galaxies consist of a larger fraction of early types therefore merely reflects that more luminous galaxies, on average, reside in more massive haloes. Note also that the fraction of intermediate type galaxies is independent of halo mass and independent of luminosity. This argues against these intermediates being edge-on disk galaxies, since if this were the case their occupation statistics would mimic those of the late-types.

Conclusions and Future Prospects

With the Sloan Digital Sky Survey nearing its completion, and various high-redshift galaxy surveys well underway, the future is bright. Our research group will continue to explore the galaxy-dark matter connection using the various approaches discussed above, but now applied to these new observational surveys. Our ultimate goal is to obtain a detailed picture of how galaxies with different properties are distributed over halos of different masses at different redshifts. We will also investigate whether galaxy properties depend on other halo properties, such as their large scale environment. All this information holds important clues regarding galaxy formation, and we will strive to combine our methodology with galaxy formation models in order to further our understanding of the various physical processes involved. Last but not least, as discussed, our CLF formalism allows a detailed and accurate description of galaxy bias, thus allowing us to use the observed galaxy distribution to constrain cosmological parameters.

(Frank C. van den Bosch, in collaboration with colleagues from the Partner Group of the MPA at Shanghai Astronomical Observatory, the University of Massachussets, and the University of Zürich)

III.4 The Interstellar Medium in Nearby Galaxies

The interstellar medium (ISM) in nearby galaxies is an active area of research at the MPIA. Detailed studies of the ISM in galaxies are a key to understanding the processes leading to star formation in a galaxy and for investigating how/if the star formation properties change as a function of galaxy type and environment. The HI Nearby Galaxy Survey (THINGS), the largest program ever undertaken at the VLA to perform high-quality observations of the 21 cm line of atomic hydrogen (HI) in nearby galaxies, is based at the MPIA.

The goal of THINGS is to investigate key characteristics related to galaxy morphology, star formation and mass distribution across the HUBBLE sequence. A sample of 34 objects at distances of $3 < D < 10$ Mpc are targeted in THINGS, covering a wide range of star formation rates, total masses, absolute luminosities, evolutionary stages, and metallicities. Researchers at the MPIA also contribute to SINGS, the SPITZER Infrared Nearby Galaxies Survey (PI: R. Kennicutt, University of Cambridge, UK). In combination with SINGS, high-quality observations from the X-ray through the radio are available at comparable resolution for a carefully selected sample of nearby galaxies. Data from THINGS can be used to investigate issues such as the small-scale and three-dimensional structure of the ISM, the (dark) matter distribution, and the processes leading to star formation. Furthermore, the data also enables studies of the variation of each of these properties as a function of galaxy environment. Another focus is the study of the global properties of the ISM in galaxies, by using multi-wavelength data from the radio to the X-ray regime.

Studies of the molecular gas distribution in the central kiloparsecs of galaxies at the MPIA were the subject of an article in the last annual report (»Fueling the Central Kiloparsec, or: How to Make Galactic Centers Active«, by Eva Schinnerer et al.).

The Interstellar Medium

The interstellar medium (hereafter: ISM) is nowadays recognized as one of the main components of a galaxy. It refers to the (non-dark) material which is distributed between the stellar components (ed) of a galaxy. From a historical perspective, Hartmann was one of the first to propose the presence of such material in our Galaxy in 1904: he studied absorption lines of a few nearby stars and concluded that the medium between the Earth and a particular star (δ Ori) contains gas in which calcium is present. Subsequently, due to the achievements of atomic physics and quantum mechanics, more and more absorption lines in stellar spectra were attributed to interstellar gas along the line of sight between a star and Earth, confirming the presence of some kind of ISM.

In addition, early star counts of photographic plates already showed that dark clouds are probably responsible for dark patches which interrupt the rather diffuse distributed light of the Galaxy. The argument of extinction was soundly confirmed(ed) by Trümpler in 1930, who linked a discrepancy in the spectrostropic vs. photometric distance determination of star clusters in the plane of the Milky Way to interstellar extinction. He concluded that stellar light seems to be attenuated by an ISM. Around this time, Karl Jansky was the first to pick up radio signals from space, which he later linked to radio emission coming from the Galactic center. A few years later (in 1937), Reber found radio continuum emission coming from almost all parts of the Galaxy and suspected the source to be thermal free-free radiation from interstellar gas with a temperature of $T = 10^4$ K and an electron density of $n_e = 1/\mathrm{cm}^3$.

The Discovery of Neutral Hydrogen (HI)

All these observations led to a first picture of the interstellar medium of the Galaxy containing heavy elements and dust. Intuitively, however, it was already clear at the times (around 1940), that hydrogen, the most common element in the universe, is probably the main constituent of the ISM. However, a possible emission mechanism of neutral hydrogen was unknown at that time. It was not until 1945 that van de Hulst predicted that atomic hydrogen might emit »forbidden« emission due to a hyperfine structure transition at 21 cm which might be detected in the radio regime. It took 8 years, using antennas and radar techniques left over from the Second World War, before three independent groups (in Australia, the Netherlands, and the USA) were able to pick up the 21 cm emission. This discovery was a major breakthrough for studies of the ISM, and a first map of our Galaxy in the 21 cm line of neutral hydrogen was just published one year later.

These observations revolutionized galactic astronomy because HI was abundantly detected, is not attenuated by interstellar dust, and its Doppler-shift provides information about the velocity of the emitting gas. This obviously contains important information about the physical properties of the interstellar gas. Furthermore, the 21 cm emission is (under most circumstances) optically thin; this means that the total amount of HI-column density observed is a direct measure for the total mass of neutral hydrogen in a system.

The Different Phases of the ISM

With the first emission and absorption measurements of neutral hydrogen, it became clear that atomic hydrogen can be in two different phases: cold and warm. This led to the first models of the structure of the ISM. A first attempt to explain the different absorption and emission features of the ISM was made by Clark in 1965, who introduced the »raisin pudding« model. A few years later, Field, Goldsmith and Habing extended and formalized this idea in their two-phase model for the ISM, which consists of a cold and a warm phase in static equilibrium. Later, in the mid-seventies, Cox and Smith recognized that the hot interiors of old SN shells should persist in the ISM on time scales $> 10^6$ years, long enough for the hot interiors to interconnect to form a »tunnel« system of hot coronal gas ($T > 10^6$ K, named after the Sun's corona) in the ISM, leading to a morphology resembling Swiss cheese. Thus the idea of a new phase, the hot interstellar medium (HIM), was born. McKee and Ostriker incorporated this idea into their famous three-phase model in which cool, warm and hot phases of the ISM are in global pressure equilibrium.

The Multi-Wavelength Approach

Coming back to observations, subsequently, numerous other atoms and molecules were also detected in the ISM. In the early seventies, UV-spectroscopy obtained with satellites revealed the presence of hundreds of absorption lines and enabled the derivation of abundances for heavy metals in the ISM. These UV-absorption studies also showed that molecular hydrogen, H_2, as expected, is probably the most abundant interstellar molecule. Around the same time, satellites operating in the far infrared (FIR) part of the spectrum were able to directly observe emission from warm dust; early missions include the IRAS satellite, which observed the full sky in the FIR. This was later followed by the ISO satellite, and today, NASA's powerful SPITZER Space Telescope is revolutionizing our view of the dusty ISM

Fig. III.4.1: The Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO), located near Socorro, New Mexico, USA. The VLA is a radio interferometer which consists of 27 individual telescopes. It is the most powerful radio telescope for studies of the 21 cm line of atomic hydrogen (HI). About 500 hours of VLA time went into the HI maps shown in Figure III.4.2. (Image courtesy of NRAO/AUI)

in galaxies. Hot ($T \approx 10^{6-7}$ K) X-ray emitting gas was detected by the first orbiting X-ray missions. Among other discoveries, the advent of X-ray and UV satellites provided observational evidence for the predicted hot phase of the ISM with the detection of diffuse X-ray emission and of OVI ($\lambda\lambda$ 1032Å – 1037Å) UV absorption lines. These observations dramatically changed the qualitative understanding of the ISM. This illustrates that a multi-wavelength approach (from the radio to the X-ray regime) is needed to shed light on the different ingredients and various phases of the ISM.

The Composition of the ISM

In brief, interstellar matter can be decomposed into the following ingredients:

- *Hydrogen* (H_2, HI, HII, e^-) is the dominant constituent of the ISM in galaxies and accounts for about 90 % by number of all interstellar matter in either its molecular, neutral or ionized form.
- *Helium* (He) as well as hydrogen, was mainly produced during Big Bang nucleosynthesis and is therefore usually assumed to be uniformly mixed with hydrogen. About 9 % of the ISM by number is helium, corresponding to about 28 % by mass.
- *Other atoms and molecules:* heavier elements, mainly produced by massive stars, make up only a minor fraction, e.g. C, N, O, Ne, Fe contribute about 10^{-3} to 10^{-4} by number. All other atoms and molecules are trace elements. However, since efficient cooling requires heavy elements, they are important for the energy balance of the ISM. Heavy elements are also valuable for probing the physical conditions (such as pressure and temperature) of the ISM.
- *Dust particles* and grains contribute a few percent of order to the mass in a typical interstellar environment.
- *Cosmic ray particles and magnetic fields:* the ISM is permeated by a magnetic field of order a few Microgauss, which constrains the motion of cosmic ray particles, mainly protons.

Observations of the Neutral ISM

HI observations using radio telescopes form a cornerstone in current studies of the ISM. After the first HI mapping of the Galaxy, rapid technical improvements occurred, achieving higher resolution as larger radio telescopes became available. For example, the single-dish Galaxy surveys conducted in the mid-seventies showed that the ISM of our Galaxy is not uniformly distributed, but shows a high degree of structure and complexity (mostly in the form of large HI holes, arcs, loops and shells). This situation has been subsequently referred to as the »cosmic bubble bath«, the »Swiss cheese« or the »violent interstellar medium«. The advent of powerful radio synthesis telescopes such as the Very Large Array (VLA), the Australia Telescope Compact Array (ATCA) and the Westerbork Synthesis Radio Telescope (WSRT) made it clear that the ISM in nearby galaxies is shaped in a similar way.

THINGS: The HI nearby Galaxy Survey

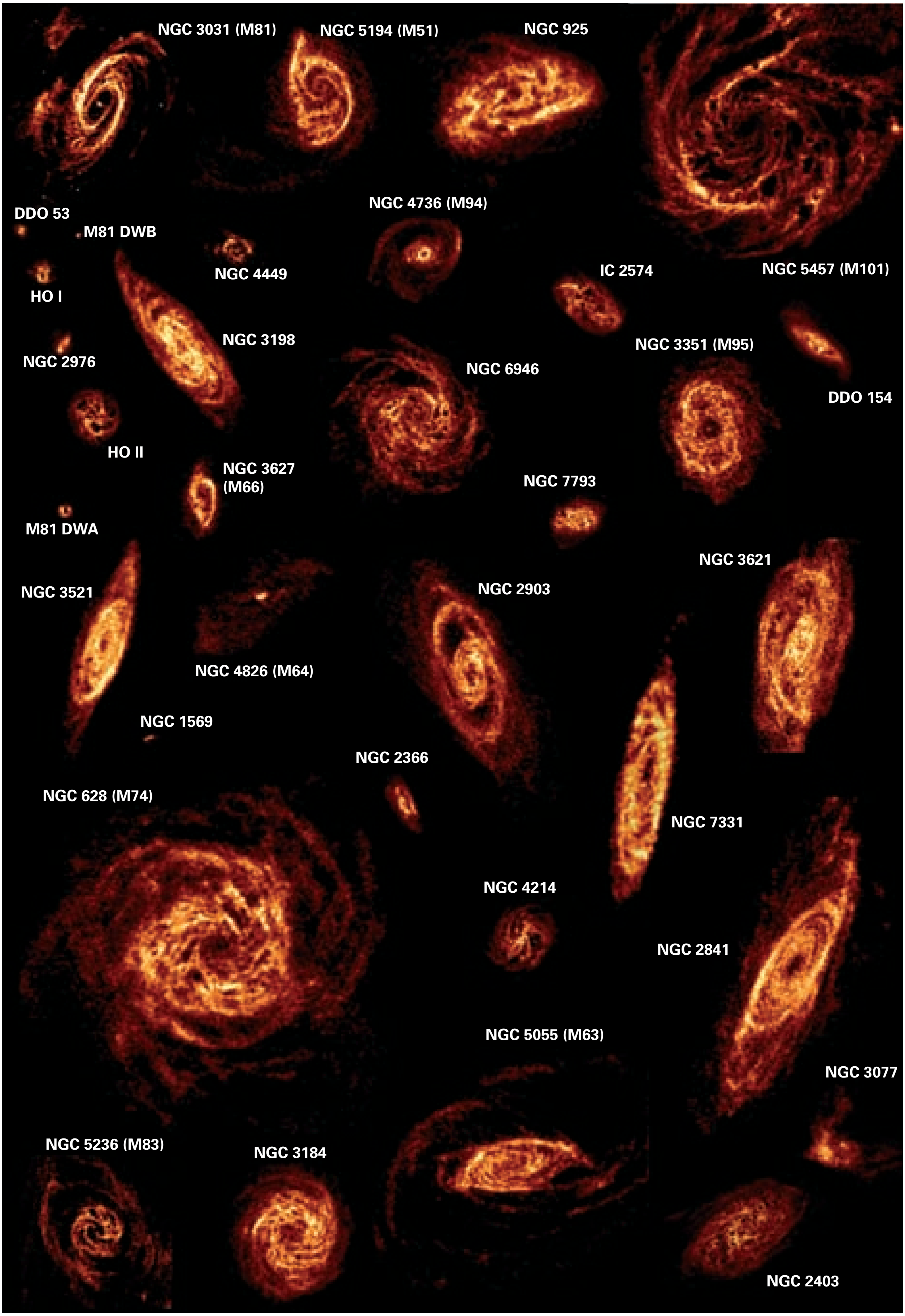
Studies of the atomic interstellar medium (ISM), through observations of the 21 cm line of atomic hydrogen (HI), are critical for our understanding of the processes leading to star formation, the dynamics and structure of the ISM, and the (dark) matter distribution, thereby touching on major issues related to galaxy evolution. In 2003, »The HI Nearby Galaxy Survey« (THINGS) was started at the Very Large Array (Fig. III.4.1) of the National Radio Astronomy Observatory (NRAO). The goal of THINGS was to obtain high-quality observations of the atomic ISM of a substantial sample of nearby galaxies, covering a wide range of HUBBLE types, star formation rates, absolute luminosities, evolutionary stages, and metallicities. This database has homogeneous sensitivity and the spatial and velocity resolution is at the limit of what can be achieved with the NRAO Very Large Array.

Most of the galaxies in THINGS are part of the SPITZER Infrared Nearby Galaxy Survey (SINGS) Legacy Project (led by R. Kennicutt at the Cambridge University), a multi-wavelength project designed to study the properties of the ISM in nearby galaxies. SINGS will provide an infrared imaging and spectroscopic survey of five nearby galaxies. The products of THINGS will thus complement the SINGS data.

In Figure III.4.2 we show a composite of the atomic hydrogen maps for all THINGS galaxies. In this figure, all galaxies are shown at the same physical scale (i.e. 1 cm corresponds to the same physical length). The resolution of all maps presented in this figure is 10″, which corresponds to linear sizes of 100 – 300 pc (depending on the distance of the target). It is obvious from this composite that there is a stunning variety of morphologies in the sample galaxies, from the dwarf galaxies shown towards the bottom left, to the more massive and bigger spiral galaxies. In the majority of all cases, the HI distribution is dominated by the presence of HI shells and bubbles.

In addition to the high spatial resolution, THINGS observations also reveal the kinematics of the systems as the strength of the Doppler-shift of the HI line yields the

Fig. III.4.2: Velocity-Integrated HI maps of the THINGS galaxies. All galaxies are shown to scale (i.e. 1 cm corresponds to the same physical length). This composite shows the stunning variety of morphologies from the dwarf galaxies shown towards the bottom left, to the larger and more massive spiral galaxies. In the majority of all cases, the HI distribution is dominated by the presence of so-called HI shells and bubbles.


NGC 3031 (M81)
NGC 5194 (M51)
NGC 925
DDO 53
M81 DWB
NGC 4736 (M94)
NGC 4449
HO I
IC 2574
NGC 5457 (M101)
NGC 3198
NGC 2976
NGC 3351 (M95)
NGC 6946
DDO 154
HO II
NGC 3627 (M66)
NGC 7793
M81 DWA
NGC 3621
NGC 3521
NGC 2903
NGC 4826 (M64)
NGC 1569
NGC 2366
NGC 628 (M74)
NGC 7331
NGC 4214
NGC 2841
NGC 5055 (M63)
NGC 3077
NGC 5236 (M83)
NGC 3184
NGC 2403

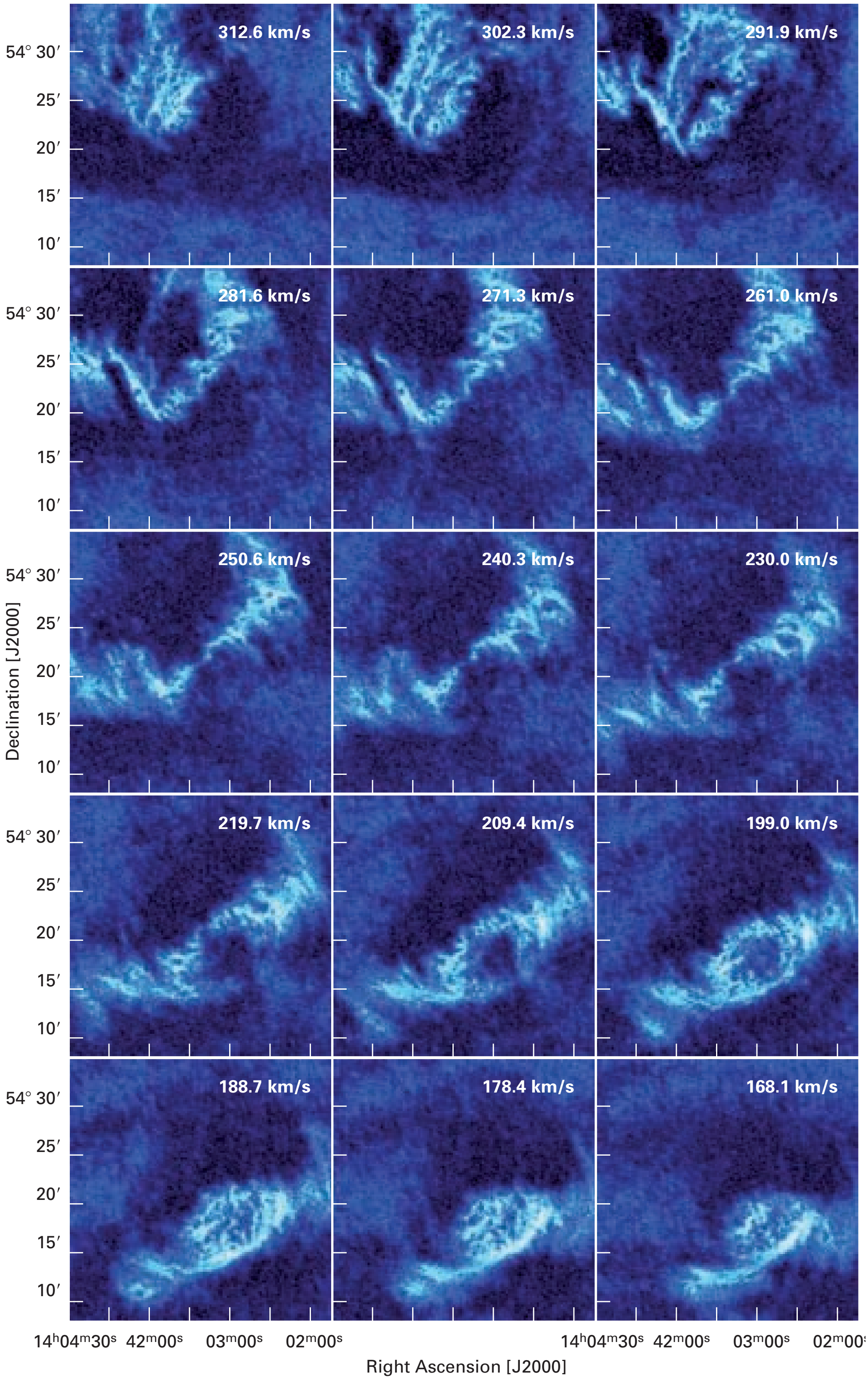


Fig. III.4.3: »Channel maps« for one of the THINGS galaxies (M 101). Each panel shows HI emission at a given velocity (velocities are shown in the upper right of each panel). This velocity information can be used to create maps of the average velocity per pixel (so-called »velocity fields«) or of the velocity dispersion per pixel (see Fig. III.4.4). Note the rich degree of fine structure in the ISM in the individual channel maps.

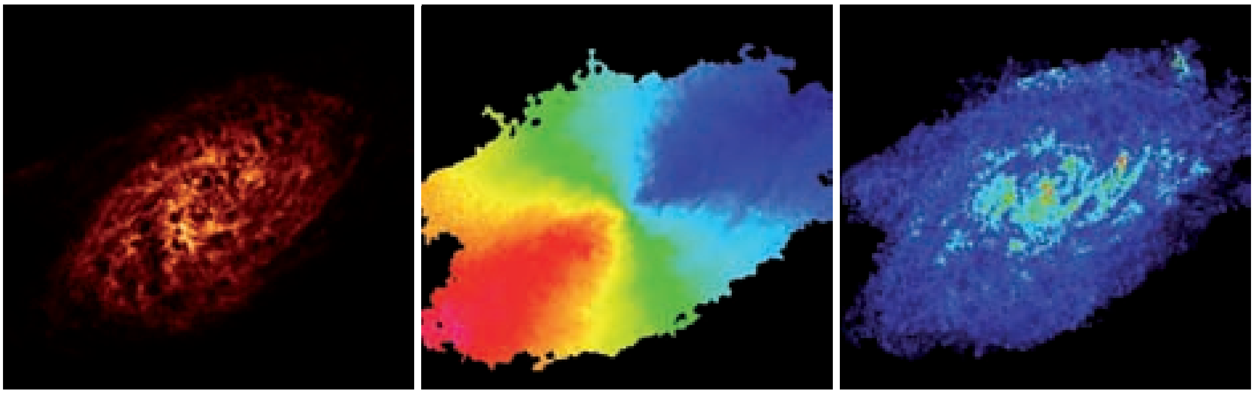


Fig. III.4.4: The spiral galaxy NGC 2403 as an example. *Left:* integrated HI column density map (similar to the map shown in Fig. III.4.2). *Middle:* velocity field of NGC 2403 – the different colors indicate different velocities: Red colors indicate emission moving away from the Earth, blue colors represent approaching material (relative to the center of mass). This information can be used to derive rotation curves and to study the fine-scale kinematics in galaxies. *Right:* the velocity dispersion map of NGC 2403. Red colors indicate high dispersion in the atomic ISM; blue colors indicate more quiescent regions. Such maps are used to study the energy input of star formation into to the ISM.

velocity at which the gas is moving. This is illustrated in Fig. III.4.3, where we show so-called channel maps for one of THINGS targets (M 101). In each panel, only HI emission measured at a given velocity (as labeled in the upper right in each panel) is shown. This clearly demonstrates that the different parts of the galaxy have different velocities – the »movement« from the upper left to the lower right (with increasing channel number) is due to the rotation of the galaxy (the receding side is seen in the first channels, the approaching side is in the last channels, and the systemic velocity of the galaxy is at around 240 km/s). In addition to this global rotation, the channel maps also reveal a rich degree of fine structure in the ISM.

For each of the THINGS galaxies, these channel maps are then used to create 1) the integrated HI maps (by simply adding the channels seen in the channel maps), 2) a map of the average velocity for each pixel (so-called velocity fields) and 3) a velocity dispersion map. As an example, we present these three maps for the galaxy NGC 2403 in Fig. III.4.4. The left hand panel shows the

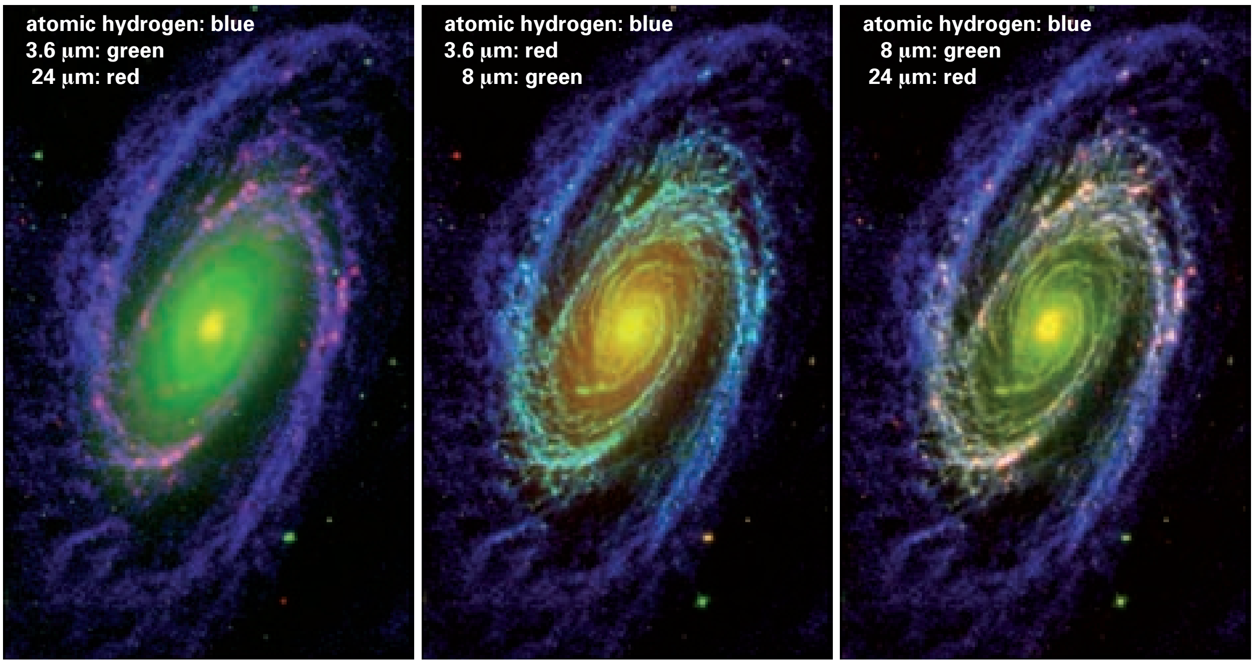


Fig. III.4.5: The spiral galaxy M 81 in different wavebands: The distribution of atomic hydrogen from the THINGS project is shown in blue in all panels. The other wavebands were observed with SPITZER and the colors are explained in each panel. The 3.6 micron emission is dominated by the contribution of old stars in the bulge, the 8 micron map contains emission from stars, hot dust and so-called PAH emission features. Such comparisons provide important clues about the processes leading to star formation in galaxies of the THINGS sample.

Fig. III.4.6: Three-color composite of the nearby spiral galaxy M 101. The distribution of atomic hydrogen from THINGS is shown in green. Blue indicates emission seen by GALEX, a UV satellite, which traces current and recent star formation. Red indicates emission seen at 24 microns with the SPITZER space telescope, which is dominated by warm dust emission powered by young starforming regions (image credits: Karl Gordon, Steward Observatory.

integrated HI map which reveals the presence of many holes and shells in the ISM. The middle panel shows the velocity field: red colors indicate emission receding from Earth, blue colors indicate approaching gas (the global rotation of this galaxy is evident from this plot). The velocity dispersion (right panel) seems to be higher in the regions where spiral arms and star formation are present, which may be explained by the mechanical feedback of the stars in the spiral arms. Typical resolutions for THINGS observations are a spatial resolution of 7″ and a velocity resolution of 2.5 – 5 km/s.

Scientific Rationale of THINGS

Interplay between the ISM and Star Formation. THINGS allows astronomers to study the interplay between star formation (as traced by Hα, Far UV, IR, and X-ray emission) and the ambient ISM at 100 – 300 pc resolution over a range of different HUBBLE types. The location and energy input of regions of recent star formation and the impact they have on the structure and dynamics of the HI can be investigated on these small scales. With THINGS, a census of supergiant shells as a function of HUBBLE type will be possible (see Fig. III.4.2). THINGS data products permit studies of how these structures form and how they, in turn, might trigger secondary star formation. In combination with the multi-wavelength data from SINGS, a complete energy budget of the ISM can be derived. As an example, we show a multi-wavelength comparison of the spiral galaxy M 81 in Fig. III.4.5. In this figure, the distribution of atomic hydrogen is shown in blue in all panels. The other wavebands have been observed with SPITZER and the colors are explained in each panel. The 3.6 micron emission is dominated by the contribution of old stars in the bulge; the 8 micron map contains emission from stars, hot dust and so-called PAH emission features. Such comparisons provide important clues about the processes leading to star formation for the THINGS /SINGS galaxies. Another example is shown in Fig. III.4.6, where we show a three-color composite of the nearby spiral galaxy M 101. The distribution of atomic hydrogen from THINGS is shown in green. Blue indicates emission seen by GALEX, a UV satellite, which traces current and recent star formation. Red indicates emission seen at 24 microns observed with the SPITZER space telescope, which is dominated by warm dust emission powered by young star-forming regions.

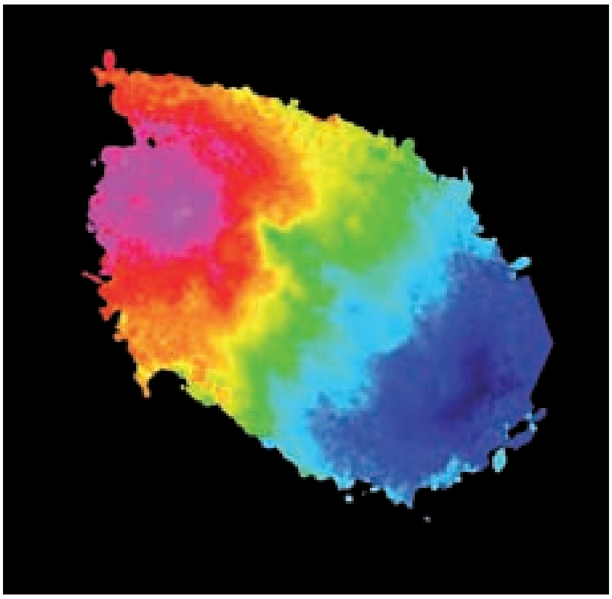
Global Mass Distribution. Another topical subject that can be addressed by THINGS is the apparent failure of cold dark matter (CDM) models to explain the distribution of dark matter in galaxies. Numerical CDM simulations find concentrated »cuspy« halos, whereas observations seem to suggest halos with a constant-density core. The latter result, posing a potentially severe problem for CDM cosmology, is still subject to observational uncertainties such as the possible dominance of non-circular motions. These effects can be studied directly using the data products of THINGS, e.g., using two-dimensional, high-resolution velocity fields to derive accurate rotation curves and to constrain the dark matter distribution. High spatial resolution (100–300 pc) data near the center is especially important, as the discrepancies show themselves most clearly in the central regions. As an example, we show the rotation curve for the dwarf irregular galaxy IC 2574 (member of the M 81 group of galaxies) in Fig. III.4.7. The left panel shows the velocity field of IC 2574 (see Fig. III.4.2 for an integrated HI map of this galaxy). This velocity field (and other similar ones at different resolutions) is used to derive the circular velocities of this galaxy – such a rotation curve is shown in the right hand panel (the different colors indicate the derived rotation speed for different resolutions). In the case of IC 2574, the rotation curve rises almost linearly, indicating that the galaxy is rotating almost like a solid body out to large galactocentric distances. This is in sharp contrast to the rotation curves of more massive spiral galaxies, where the rotation curves typically rise sharply and then stay flat for most of a galaxy's disk. Rotation curves for all THINGS galaxies will be used to derive the detailed dynamics and dark matter content of each galaxy.

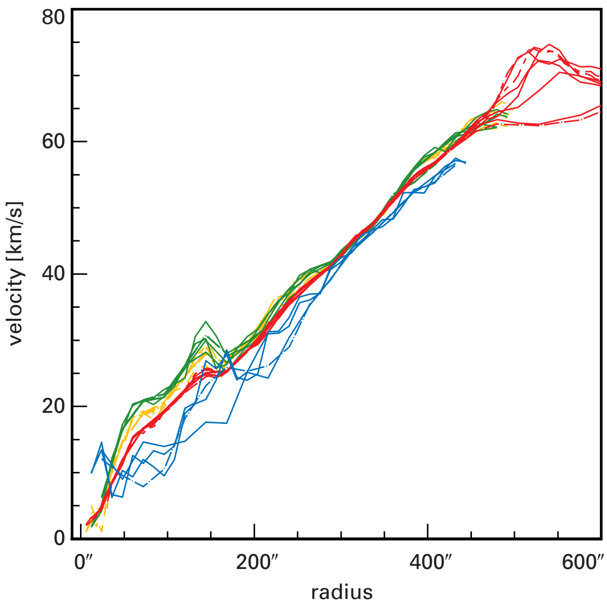
Summary

The HI Nearby Galaxy Survey (THINGS) based at the MPIA is the largest program ever undertaken at the VLA to perform 21 cm HI observations of the highest quality (7″, 5 km/s resolution) of nearby galaxies. THINGS includes archival observations and totals about 500 hours of VLA time. Dedicated observations for THINGS started in September 2003 and were completed in summer of 2005. A sample of 34 objects at distances between 3 and 10 Mpc were targeted in THINGS, covering a wide range of star formation rates, total masses, absolute luminosities, evolutionary stages, and metallicities. Data from THINGS complements SINGS, the SPITZER Infrared Nearby Galaxies Survey; hence high-quality observations from the X-ray through the radio range are available at comparable resolution for each galaxy. At the MPIA, data from THINGS is being used to investigate issues such as the small-scale and three-dimensional structure of the ISM, the (dark) matter distribution, and the processes leading to star formation. Furthermore, THINGS enables studies of the variation of each of these properties as a function of galaxy environment. A major leap forward in the studies of the atomic interstellar medium of galaxies will only be possible with the advent of the next generation of radio telescopes, such as the Square Kilometer Array (SKA).

(People involved at the MPIA with the THINGS / SINGS projects are: Fabian Walter, John Cannon, Frank Bigiel, Hélène Roussel and Domenico Tamburro)

Fig. III.4.7: Dynamical analysis of one of the THINGS galaxies: the dwarf galaxy IC 2574. *Left:* the velocity field of IC 2574 (cf. Figs. III.4.2 and III.4.4). *Right:* the rotation curve for IC 2574 derived from the velocity fields similar to the one shown to the left (the different colors refer to different resolutions to extract the rotation curve). For each radius, the circular rotation velocity of IC 2574 is plotted, the linear rise in rotation indicates that this dwarf galaxy is rotating like a solid body.





IV. Instrumental Development

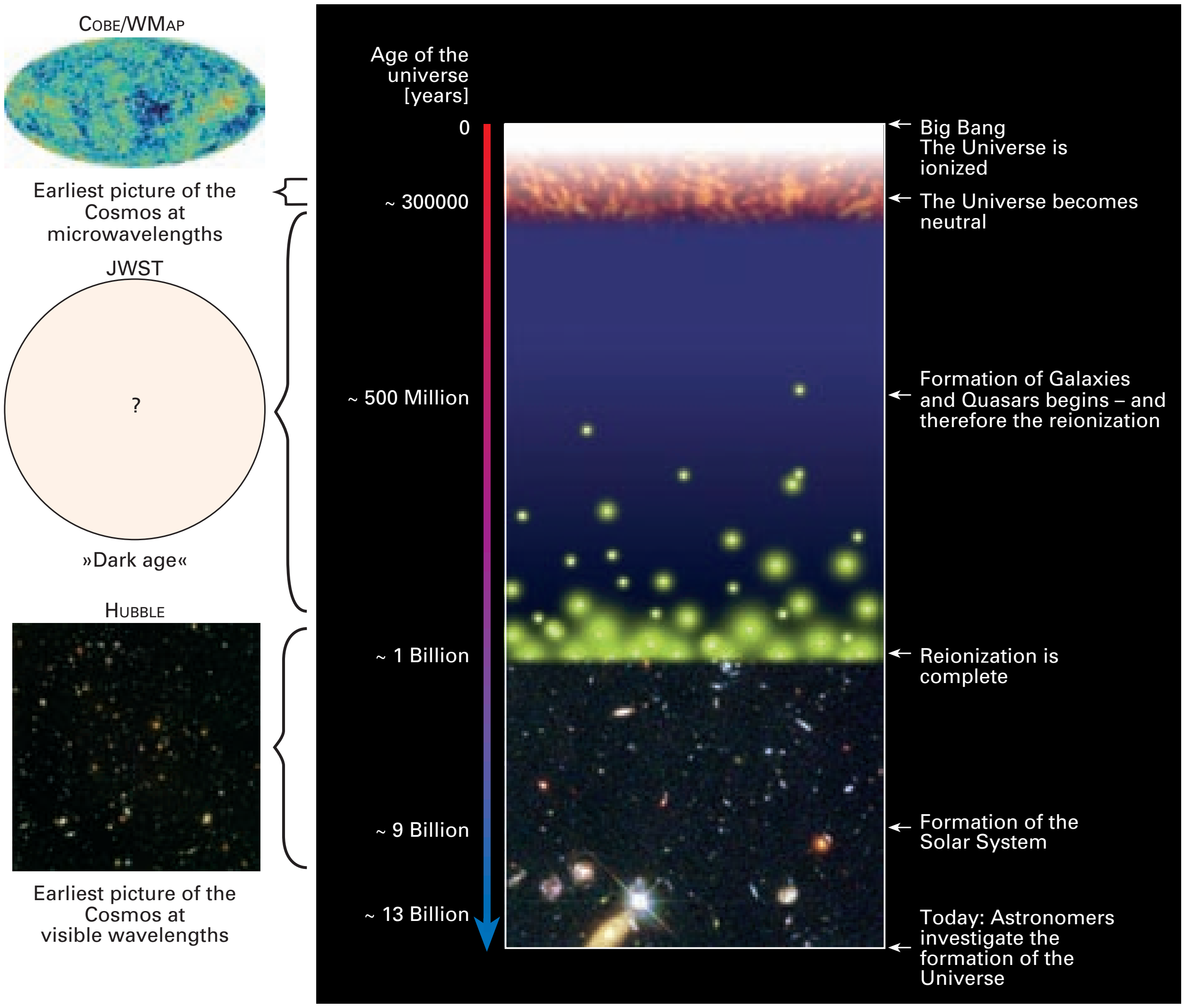
IV.1 Instruments for the James Webb Space Telescope

The launch of JWST, the successor of the HST, is foreseen for the year 2013. The 6.5 m telescope will be operated about 1.5 million kilometers away from the Earth and perform observations in the infrared. The MPIA is engaged in developing the moving parts for the instruments NIRCAM, NIRSPEC, and MIRI.

HUBBLE needs a successor

Space telescopes get older too: over the course of time solar cells provide less power, the gyroscopes – controlling the orientation of the spacecraft – successively fail, electronic components can be damaged by high-energy cosmic rays, and mechanisms start to fail. Furthermore, space telescopes also become outdated. Space telescopes are designed years before launch. Because of the rapid progress in electronic cameras, in computers and memory, in control engineering and in materials, a space telescope that has been in operation for some years can contain technologies a decade or more out of date.

Fig. IV.1.1: Evolution of the universe from the big bang (*top*) until the present day (*bottom*). All-sky surveys of microwave radiation allow exploration of the distribution of cosmic matter from when the universe was only ~300 000 years old (COBE/WMAP). The last ~12 billion years are accessible to large ground-based telescopes and the HUBBLE Space Telescope. In between lie the »dark ages« of the universe in which the first stars formed. JWST is expected to fill this gap.



All this is foreseeable. So only a few years after the launch of the HUBBLE Space Telescope (HST) the planning of its successor, the »Next Generation Space Telescope« (NGST), was started. This new instrument should by far excel the achievements of its famous predecessor. It is an experience frequently confirmed during the last century; once the performance of an astronomical instrument is increased by about a factor of ten, new discoveries follow. With HUBBLE, sensitivity and spatial resolution were increased each by this order of magnitude compared to earth-bound telescopes. A huge number of discoveries were made; e.g., imaging of the youngest stars with their dusty disks in the Orion Nebula and the most distant galaxies at redshifts up to $z \sim 6$, when the Universe was less than a billion years old.

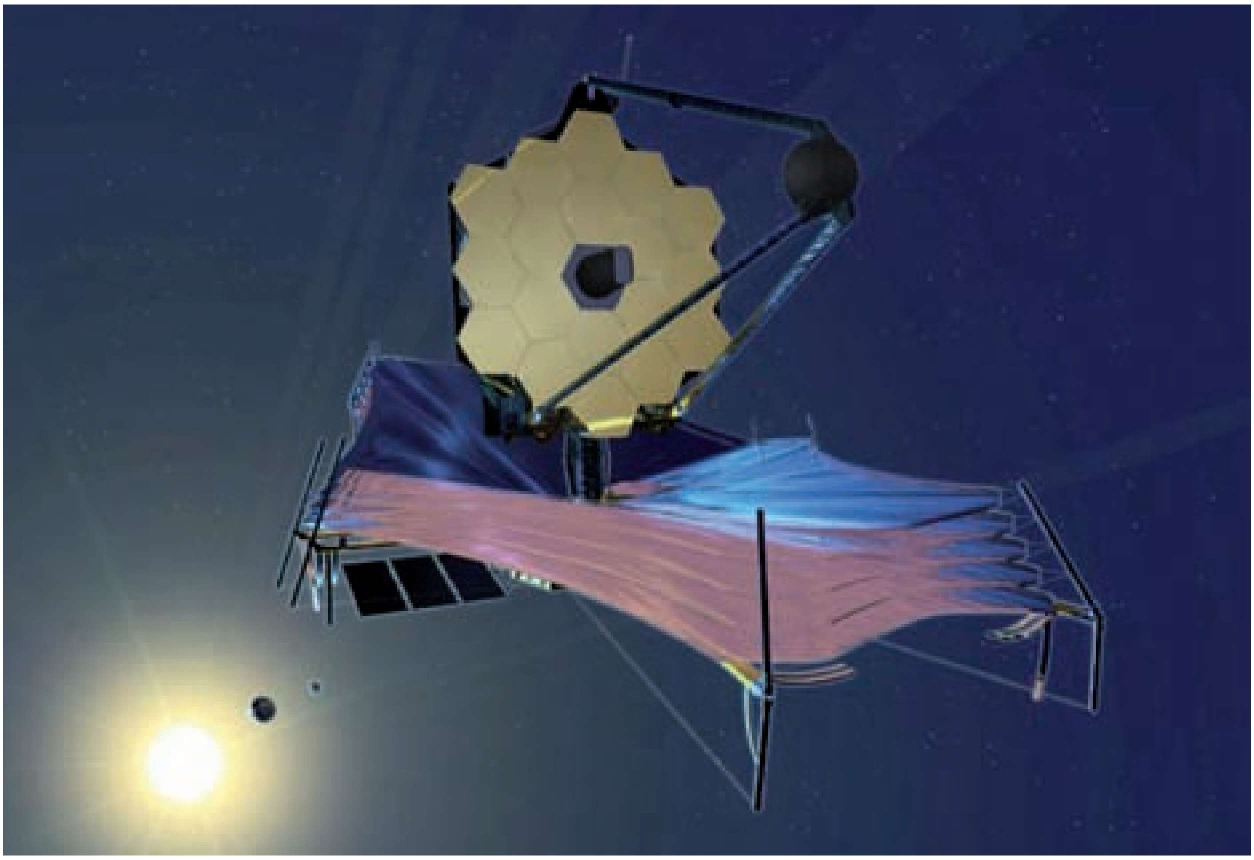
First light as a goal

Although the hope for many unforeseeable discoveries had been a driving force behind the development of NGST, its performance specifications were determined by a number of clearly defined scientific goals. The most important one is the observation of the »first light« in the universe – of the first stars and/or galaxies. Between the earliest image of the universe at an age of 300 000 years after the big bang (at a redshift of $z \sim 1000$) and the HUBBLE Ultra Deep Field with high-redshift galaxies at $z \sim 6$, i.e. at a cosmic age of one billion years, lie the hitherto unobserved »dark ages« of the universe (Fig. IV.1.1).

During that time the first stars must have formed from the cooling fireball of the universe. Yet, these stars were not like stars we see today: these consisted only of hydrogen and helium and were likely hot ($T > 50\,000$ K) and massive (≥ 100 solar masses). Owing to their high luminosity the first stars lived very short lives. Many of them exploded as supernovae, thereby enriching the early universe with heavy elements (»metals« – as all elements heavier than helium are called by astronomers) formed within their interiors. Furthermore, since the first stars were very hot, they were able to ionize the neutral gas.

With the most sensitive (or »deepest«) images of the universe we have an overview of the last 12 billion years of its evolution. The most distant and therefore youngest galaxies that currently can be observed out to a redshift of $z \sim 6$ are already very massive, as is demonstrated very impressively by the HUBBLE Ultra Deep Field. Therefore the first galaxies/quasars/stars must have formed much earlier, at $z \sim 8 \ldots 20$, i.e. a few hundred million years after the big bang; this is also predicted, in general terms,

Fig. IV.1.2: The 6.5 m-mirror of the JWST consists of 18 adjustable individual mirrors. The radiation shield has the size of a tennis court. JWST orbits the Lagrangian Point L2; the Earth and its moon can be seen in the background at a distance of 1.5 million km. Another 150 million km further away is the Sun.



by galaxy formation theory. As the universe expanded, the wavelengths of the light emitted originally in the ultraviolet and visible spectral range became longer, shifting into the near- (1 to 5 μm) and mid-infrared (5 to 30 μm) regions. Because of the finite speed of light we now observe the first cosmic objects in the infrared as they looked almost 13 billion years ago in the ultraviolet range.

From the visible to the infrared

For this reason the Next Generation Space Telescope was planned from the beginning – in 1995 – as an infrared space telescope. In 1997, the inspiring memorandum »Visiting a time when galaxies were young« was published. Here the scientific and technical feasibility of the mission was demonstrated convincingly.

Four topics are the guiding principle for the development of JWST and its instruments: (1) First light and re-ionization, (2) formation and evolution of galaxies, (3) birth of stars and protoplanetary systems, and (4) planetary systems and the origins of life. These topics have been translated into a long list of detailed scientific requirements, such as: »measurement of the spatial density of galaxies with a detection limit of 1×10^{-34} Wm^{-2} Hz^{-1} at a wavelength of 2 μm by imaging in the wavelength range from 1.7 to 27 μm and determination of the density variation as a function of age and evolutionary stage (L1-1)«; or »measurement of spectra of at least 2500 galaxies with a spectral resolution of 100 (0.6 to 5 μm) and 1000 (1 to 5 μm) with a detection limit of the emission-line flux at 2 μm of 5.2×10^{-22} Wm^{-2} and determination of their redshifts, metallicities, star formation rates as well as the degree of ionization of the interstellar medium (L1-2)« … . This list of 40 detailed scientific requirements determined the exact design of the three scientific instruments, the telescope and the planning of the mission.

NIRCAM, NIRSPEC and MIRI – the three large scientific instruments

The detector of the near-infrared camera (NIRCAM) has 40 megapixels and is suitable for the range from 0.6 to 5 μm. The camera can image fields of 4.4×2.2 arcminutes in several broad- and narrow-band filters, and can be used as a coronagraph. At the same time it serves as a wavefront sensor for the observatory, measuring the alignment of the 18 mirror pieces of the 6-m-primary mirror. Marcia Rieke of the University of Arizona, Tucson, is in charge of the development of the instrument, which is built by Lockheed-Martin. The targets to be detected include the earliest galaxies and quasars, the most distant supernovae and objects within the Kuiper belt around the Sun. The 6 m-mirror of the JWST will allow acquisition of images of star forming regions and protoplanetary disks – in the dust-penetrating infrared – that will be as sharp as those taken by the smaller HUBBLE-mirror in the optical range (Fig. IV.1.3).

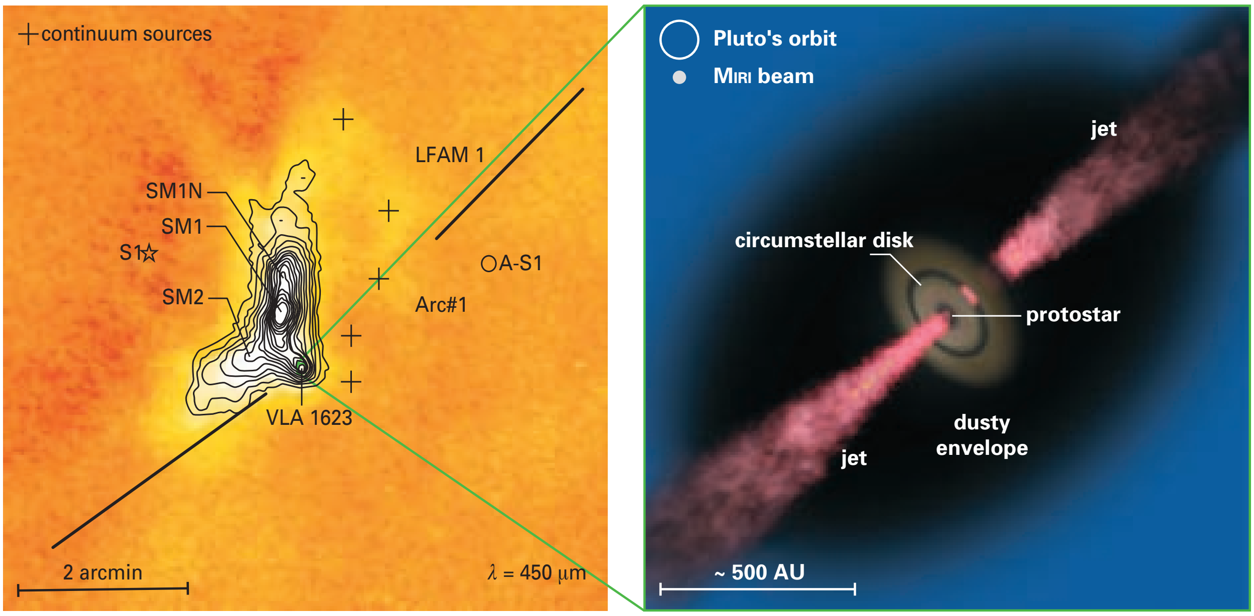


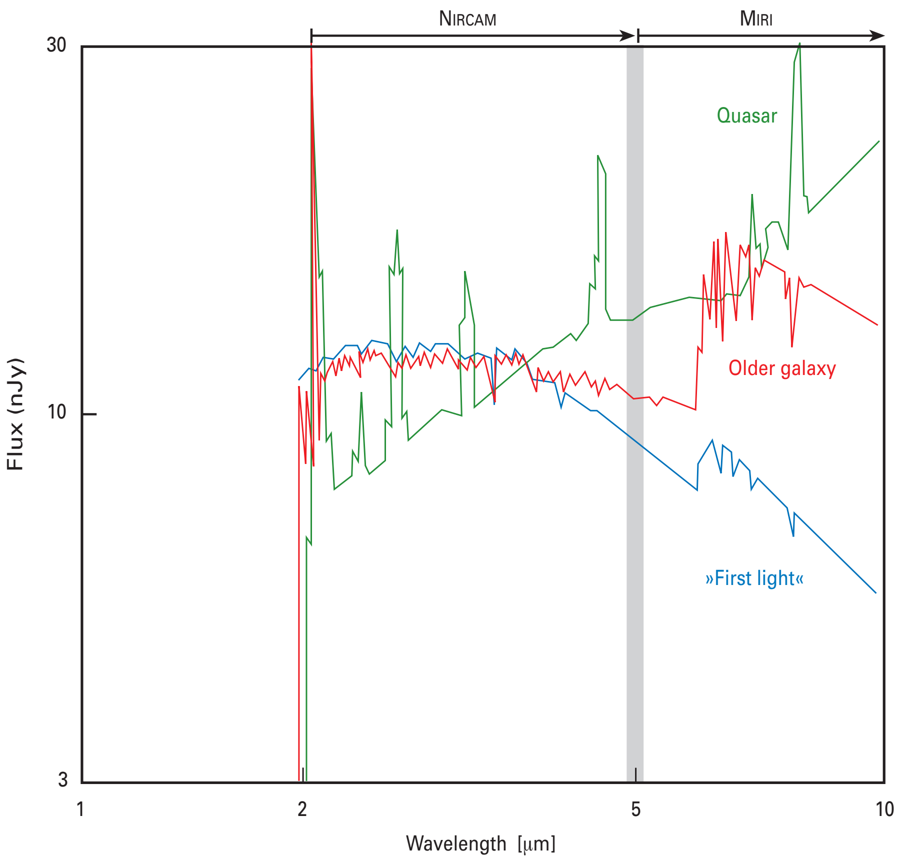
Fig. IV.1.3: A glimpse into the interiors of the star-forming clouds detected in the far-infrared and sub-millimeter range. The high resolution and sensitivity of MIRI will allow study of the warm protostars residing within the cold clouds. In the source VLA 1635, e.g., details like dusty disks and beginning planet formation as well as polar flows will become visible. The picture to the right shows our expectations based on current theoretical models together with the resolving power of MIRI (*beam*) and the orbit of Pluto for comparison.

NIRSPEC is a spectrometer for the near-infrared range with a resolution of $\lambda/\Delta\lambda \sim 100$ and 1000. It allows simultaneous spectroscopy of more than 100 objects within its field of 3×3 arcminutes. For the selection of the objects of interest a silicon shutter array with small electrically-controlled micro-shutters (similar to an Advent calendar) is currently being developed. Only those shutters which are open will admit the light from the galaxies of interest. This multi-object spectrograph is developed by ESA and built by ASTRIUM, Germany. The MPIA is making contributions to this instrument. This instrument will allow study of, among other things, the redshifts, element abundances, excitation conditions, and spatial velocities in galaxies and quasars of various ages. Furthermore, the reionization of the universe by the first hot stars can be investigated in some detail. The development of this instrument is guided by an international science team picked from ESA member states.

MIRI is the most complex of the three instruments. It consists of a camera with coronagraph and a spectrometer for the mid-infrared range (5 to 28 µm). This instrument is built by a consortium of European institutes, including the MPIA, with NASA providing detectors and the cryogenic cooler. While NIRCAM can identify candidate high-redshift early objects, their confirmation and characterization requires the use of MIRI. Many of the most important diagnostic spectral lines – those that are key for building a physical understanding of these early objects – are in the rest-frame visible range. These lines are redshifted into the mid-infrared range for these objects (Fig. IV.1.4), permitting their reliable identification and study. The development of MIRI is headed by two principal investigators: Gillian Wright of the Astronomical Technology Center ATC, Edinburgh (UK), and George Rieke of the University of Arizona, Tucson (USA).

In addition to the three large instruments NIRCAM, NIRSPEC, and MIRI the star-sensor camera of the JWST will also be used for scientific studies. It contains a filter wheel for the narrow-band wavelength selection ($\lambda/\Delta\lambda \approx 100$) in the range from 1.6 to 4.9 µm. Because of its much simpler light path this »Tunable Filter Imager«

Fig. IV.1.4: Calculated spectra of quasars and galaxies in the early universe at a redshift of $z \sim 15$. The intense radiation emitted in the visible and ultraviolet range in the rest-frame of the galaxies is observed by us today in the near- and mid-infrared region. With NIRCAM's sensitive wide-field cameras for the range from 2 to 5 µm we will be able to identify possible young objects. However, the spectra of »genuine« first galaxies and those of galaxies after a star formation episode (enrichment in metals → older stars) differ only very slightly in the near-infrared range. With MIRI an exact classification will be possible via the strongly varying spectra in the range from 5 to 28 µm. In the visible range, these objects remain unobservable. (MIRI consortium).



(TFT) of the Canadian Space Agency is much more sensitive than NIRCAM and thus will be able to faster turn the attention to very young galaxies with their highly redshifted Lyman-alpha-lines.

Common to the three focal-plane instruments for JWST presented above is that they have to be operated in a cryo-vacuum. For NIRCAM and NIRSPEC a temperature of –240 °C suffices. MIRI has to be cooled to below –260 °C so that its own thermal emission will not outshine the cosmic infrared radiation. MIRI's infrared detectors have to be operated at –268 °C, only 5 °C above absolute zero, in order to keep the »dark current« of the camera sufficiently low. Another common property of the instruments is that all of them have large »optical exchange wheels« with numerous gratings, filters, beam splitters, mirrors, prisms and coronagraphic masks mounted on their peripheries (Fig. IV.1.5). By exchanging these elements in the light path (i.e. by turning the wheels) it is possible to select the different operation modes of the instruments (spectroscopy, imaging, coronagraphy, calibration) as well as the particular wavelength ranges. 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 the successful developments for the European space telescopes ISO and HERSCHEL, our institute was well prepared for these high-risk challenges with MIRI and NIRSPEC.

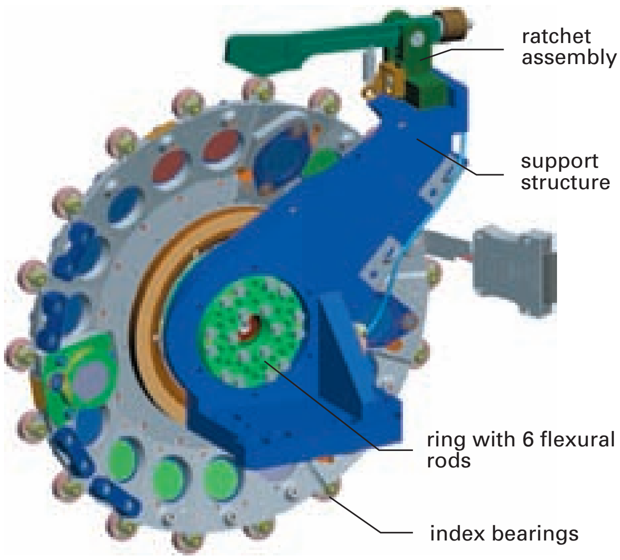
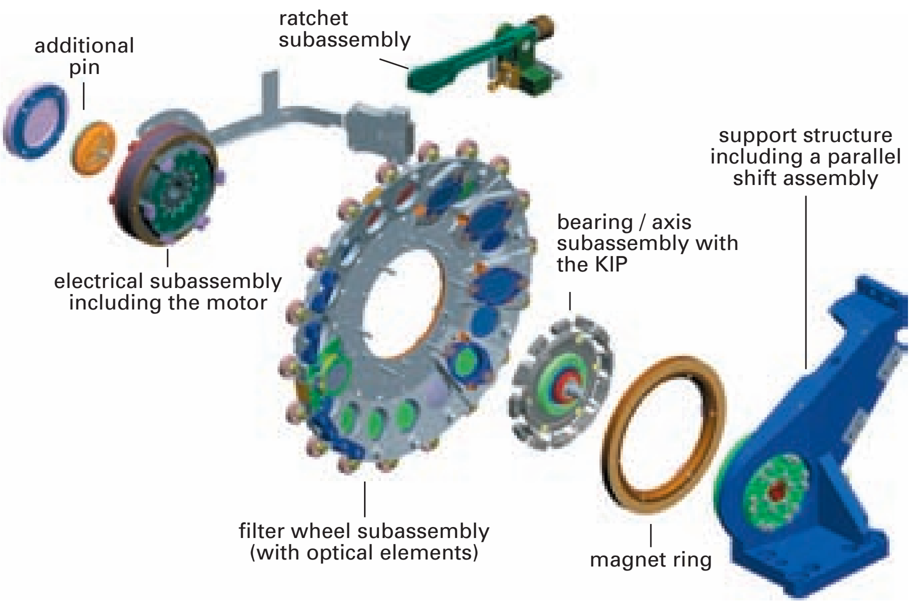


Fig. IV.1.5: Filter wheel for the Mid-Infrared Instrument (MIRI). The 18 positions are occupied by filters for the wavelength range from 5 to 28 μm and a prism for sensitive low-resolution spectroscopy. Several coronagraphic masks allow searches for extrasolar planets near a very bright star, which is masked out. The wheel is moved by a central torque motor and positioned with a detent latching into a ball-bearing outer race. (CEA, TTL, ADR, ZEISS, MPIA)



The mechanisms are provided by MPIA

Within the European MIRI consortium – comprising 21 institutes – the MPIA is responsible for the development of both grating wheels and the filter wheel since 2002. The demands on these »mechanisms« are high, including:

- Maximum reliability and most precise positioning for hundreds of thousands of movements
- Low electric driving power to avoid heating
- Vibration resistance during launch (~ 40 g)
- Operation both under cryo-vacuum and laboratory conditions
- Operation times of at least 10 years, reliable re-start even after a long rest
- Rapid and cost-effective availability

The working group »Infrared Space Telescopes« at MPIA has gained longstanding experience in building such cryo-mechanisms. The Institute, together with C. ZEISS and Dornier, had built three optical exchange wheels for the ISOPHOT instrument onboard the European satellite ISO. During the mission lasting 29 months these wheels performed hundreds of thousands of high-precision movements at $T \sim -270\,°C$. For ISOPHOT and the PACS instrument of the European HERSCHEL Space Telescope focal-plane choppers were developed that could perform hundreds of millions of movements at –270 °C with high reliability. This development and testing experience will be used for MIRI and NIRSPEC, although the challenges will increase: the wheels for the JWST are many times larger and heavier, and the precision requirements even higher. In particular, because of the »warm« launch of the JWST the wheels have to be operable in the entire temperature range from + 20 °C to –265 °C and from standard pressure to high vacuum.

All wheels of MIRI and NIRSPEC will have drives based on our detent concept that has proven its worth in ISOPHOT. As an example, Fig. IV.1.5 shows the filter wheel for MIRI. At the periphery 18 small ball bearings are mounted, according to the number of position settings. A wedge-shaped element on a moving lever latches between two ball bearings, thus locating the position of the wheel with a repeatability of ~ 1 arcsecond. The central motor is a direct drive (torque motor) without transmission. It is moved by an electric pulse by about 15 ° so that the tip of the detent moves over the neighbouring ball bearing. The exact positioning can then be carried out mechanically without electric power by the spring tension of the detent or even slowly decelerated electrically. This drive concept avoids feedback from an electrical position indicator and holding currents since positioning is always carried out mechanically with great reliability. Depending on the wheel size, small fractions of a Joule are applied for each step. Since no electric current flows after the ~ 1 second-long driving step, and the astronomical observations take 1000 to 10 000 seconds, the mean electric power loss of this drive concept is virtually negligible. To increase the precision the duplex ball bearings are engineered as integrated bearings, that is, one of the rings also serves as the bearing axis. The raceways are covered with a thin layer of molybdenite (MoS_2). It prevents cold welding in high vacuum and provides good lubricating properties at low temperatures. As an additional protection all ball-bearings have a thin titanium-carbide coat.

Sophisticated model philosophy

According to the current time schedule, filter and grating wheels of highest quality and reliability will have to be delivered in 2008. In order to meet this time schedule the development is done step by step – a method that always has paid off with space experiments. As early as 2004, prototypes of the wheels had been set up at MPIA, the design models followed in the year under report. In 2006 and 2007, qualification models will be built for which the full space-flight qualification (vibrations, endurance, …) will have to be verified. In 2008 the final flight models of all wheels will be delivered while at the same time the qualification models will be upgraded to serve as spare flight units (installation of new ball bearings and so on). Only this sophisticated model philosophy ensures that matured, highly reliable technology is used in the expensive space missions. For months, and under all environmental conditions required, each of the models mentioned above will be tested, refined, tested again and in the next step be equipped with components of ever-increasing quality (and cost).

The design models (Fig. IV.1.6) set up in the year under report at MPIA were already able to meet essential requirements during cryo-vacuum tests: high positioning accuracy, low power consumption… But unexpected weak points were found, too: 1) the integrated duplex ball bearings used were easily soiled by microparticles, increasing their friction coefficient, 2) a thermal decoupling disk between the steel components (ball bearings, motor) and the aluminum structure showed cold embrittlement of its flexible elements at –260 °C, 3) the TiC-coats of the balls did not withstand the high mechanical and thermal stresses. As far as the time schedule permits, these problems are eliminated in the same model, in particular if the improvements can be made in the technical workshops at MPIA. Retrofittings that take longer can only be used in the next model. So, e.g., the manufacturer of the ball bearings needs almost one year to fit in suitable uncoated balls and to design dust covers.

After a tendering procedure in the middle of 2005, the MPIA selected the offer by C. ZEISS for the building of the qualification and flight models of the wheels for MIRI. On November 29th, 2005, the relevant contract was signed in Oberkochen (Fig. IV.1.7). MPIA was granted the funds for this industrial fixed-price contract by the German Aerospace Center (DLR), Bonn. With the ISOPHOT instrument (ISO) and the PACS chopper (HERSCHEL) the C. ZEISS company has proven its high competence for building opto-mechanical instruments to be used in the cryo-vacuum of outer space.

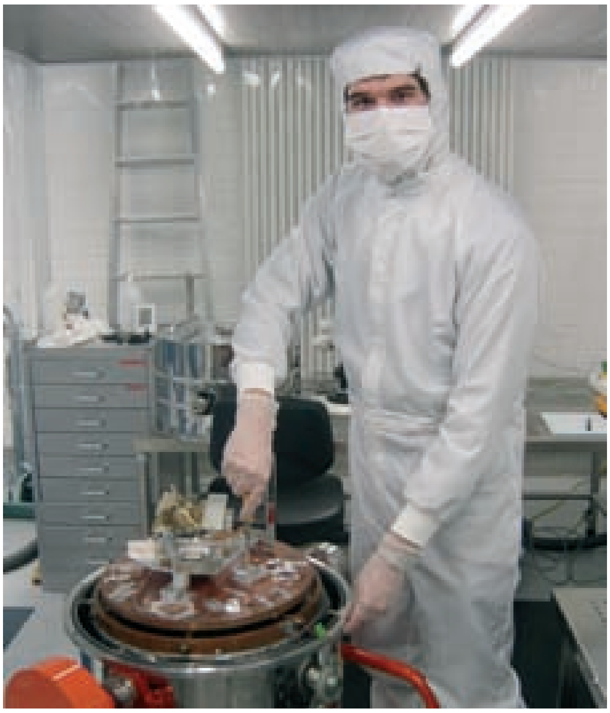


Abb. IV.1.6: Mounting of the MIRI grating wheel in the test cryostat for tests at –265 °C by C. Schwab. Extreme cleanliness requirements have to be fulfilled. (MPIA)

Abb. IV.1.7: Signing of the JWST contracts in November 2005 at C. ZEISS in Oberkochen. From left to right: Prof. Henning (MPIA), Prof. Lemke (MPIA), Dr. Kötter (C. ZEISS), Dr. Wiemer (C. ZEISS).

Together with the contract for MIRI, a contract for NIRSPEC, the European spectrometer for the JWST, could also be signed. Here the roles are reversed: MPIA contributes as a subcontractor to the development of the grating and filter wheels for NIRSPEC. In the consortium led by C. ZEISS, MPIA is responsible for the development of the electric components (motors, position sensors, …). Although the order placed with MPIA by C. ZEISS is smaller than the contract for MIRI, we and C. ZEISS are expecting a high synergy because of the many common goals in the development of both instruments.

Location: L2

According to the original time schedule the launch of JWST was forseen in 2011. Because of JWST's huge size and mass of about six tons this can only be accomplished by the European ARIANE 5 rocket. Shortly before and immediately after launch critical phases will begin for the Heidelberg mechanisms in the instruments. During the last tests of all instruments on the launch pad the optical wheels will be turned too, but now at a temperature of + 30°C and damp external air. This will require very high operating currents and may damage the sensitive MoS_2 layers of the ball bearings. After take-off of the rocket all mechanisms built delicately for weight reasons are exposed to strong vibrations, with accelerations of up to 45 times the gravitational acceleration on Earth. Only after surviving these dangerous hours the quiet phase of the flight through space will begin. Gradually the »feel-good conditions« for the mechanisms will be reached: vacuum and low temperatures. Now ground control can order the careful running-in of the wheels. As a result the humidity trapped in the MoS2 layers of the ball bearings will be slowly removed and the bearing friction will decrease by a factor of 3.

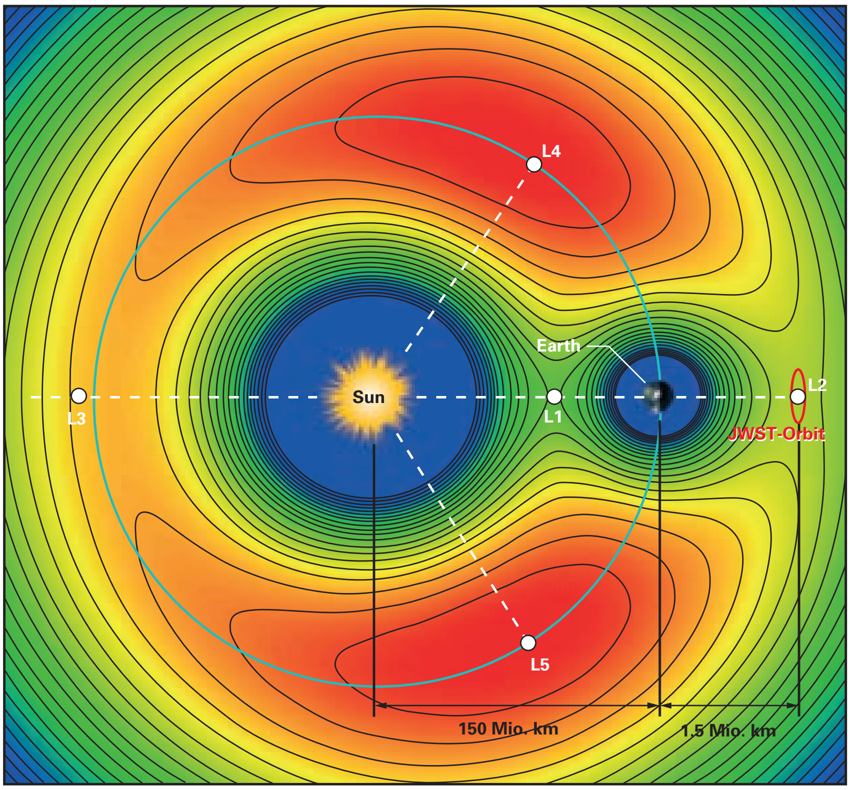


Fig. IV.1.8: Locations of the Lagrangian Points L1 to L5 in the Sun–Earth system (not to scale). At L2 a satellite orbits the Sun with the same angular velocity as the Earth. Since L2 is a metastable point, JWST will circle it on extended Lissajous orbits.

The destination of the journey is the Lagrangian Point L2 (Fig. IV.1.8). There, 1.5 million km from Earth on the prolongation of the line Sun–Earth, the satellite will »feel« the joint attractive forces of Sun and Earth, and despite its larger distance to the Sun it will orbit the Sun with the same angular velocity as the Earth. So for ten years, we will see JWST from Earth always in anti-solar direction. Although the point L2 is a solution of the three-body problem of celestial mechanics, JWST will not be stationed exactly at that point. There are at least three arguments against it: 1. L2 is a metastable point, that is, smallest perturbations will drive a satellite away from there (comparable to a pencil standing »stably« on a fingertip …), 2. for stationing braking manoeuvres would have to be carried out directly at L2, 3. the satellite would experience solar eclipses because the Earth is standing in between, interrupting its energy supply.

Therefore loop-shaped orbits around L2 are chosen in practice (Fig. IV.1.9). These Lissajous orbits around L2 can have very large diameters: some hundred thousand km in the ecliptic and perpendicular to it. The orbital period around L2 can be half a year and the deviation from L2 as seen from Earth up to ± 30°. The larger the diameter of these loops around L2 the easier are the orbital manoeuvres during closing-in and later orbit corrections. A limit is set, however, by the scattered-light requirements of the tube-less JWST. At large angular distances from L2 Sun and Earth would no longer be occulted simultaneously. Seen from L2, the Earth has the same angular size as the Sun, and in the mid-infrared range the Earth is bright!

Passive and active cooling

Already during the approach to L2 the unfolding process of JWST, which is tightly folded into the payload nose cone of the ARIANE 5, will be started (Fig. IV.1.10). More than 100 mechanisms (hinges, motors, sensors, …) have to be activated in order to open the tennis-court sized multilayered radiation shield and the 6.5 m-telescope. The radiation shield reduces the thermal radiation of the Sun by a factor of millions: of the 300 kilowatt incident on JWST, less than 0.1 watt will be left on the telescope side. In this way, the primary mirror can passively cool to –240 °C, sufficiently low for sensitive observations with all instruments on board. The radiation shield consists of five layers of Kapton foil each of which is vapor-coated with aluminium on the Sun-facing side. This way as much radiation as possible will be reflected back into space. The side of the foil turned away from the Sun is coated with silicon, which acts as a blackbody radiator in the infrared range, thus cooling the foil. Thermal radiation escapes through the 15 cm wide gaps between the foils (Fig. IV.1.2). The foil package will have to resist

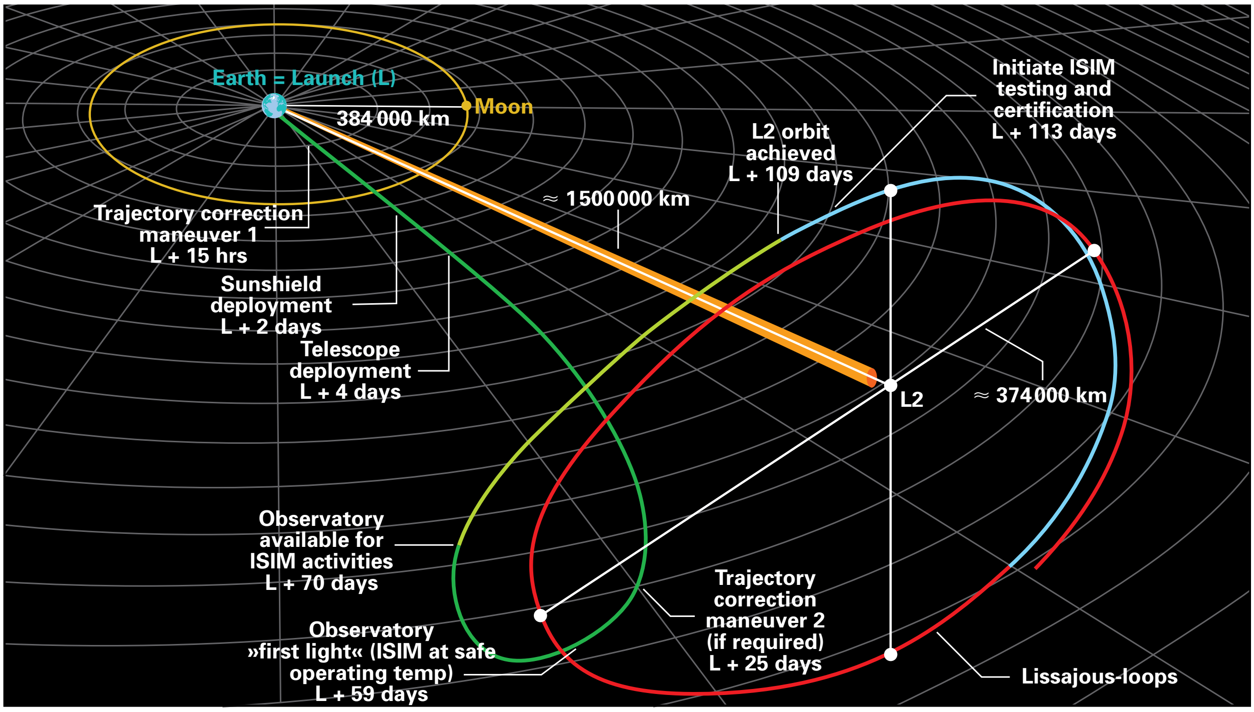
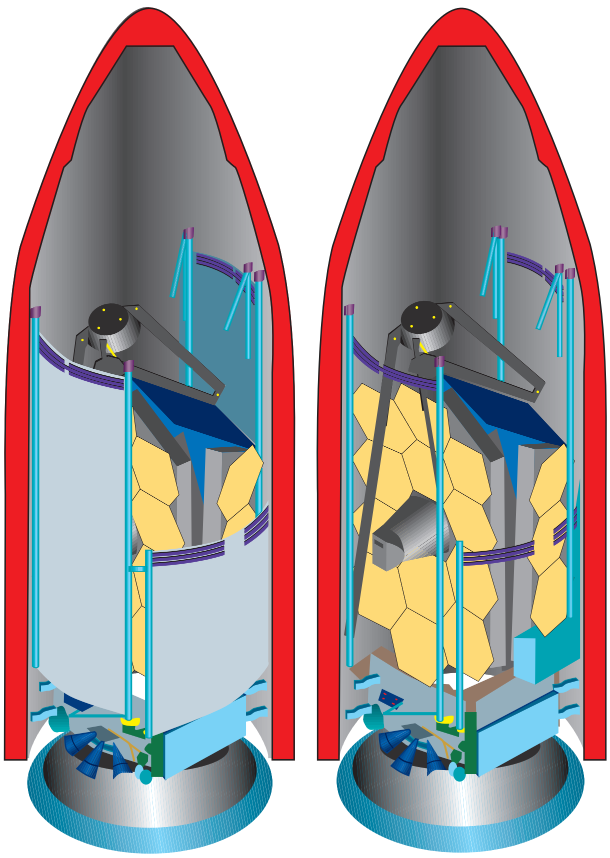


Fig. IV.1.9: Timetable for the flight of JWST to its orbit around the Lagrangian Point L2. After 119 days (launch + 109 days) the final orbit is reached. A few days later the test operation of the instruments will begin.

Fig. IV.1.10: For launch, the 6.5 m-telescope and its multi-layered radiation shield more than 30 m across have to be folded many times in order to be stowed within the 5 m wide nose cone of the ARIANE 5 rocket. Two days after launch, during the journey to L2, the unfolding process is started.



impacts of micro-meteorites, the solar wind, cosmic rays, extreme temperature variations and manifold mechanical stresses in order to ensure the millionfold radiation reduction over the entire duration of the mission.

The cameras of MIRI, however, have to be cooled to –268 °C (about 5 K). Here a decisive modification in the development took place in 2005. Up to then work on a cryostat with solid hydrogen was in progress. With this simple and well-proven technique a just sufficient operating temperature of –267 °C could be achieved. But in view of the desired weight cuts the cryostat soon appeared to be too heavy. Therefore a mechanical cooling machine was chosen. The motor-driven first compressor stage will be placed on the satellite part of JWST and linked to the cooling head in MIRI by flexible pipes. In principle this technique has advantages: lower temperatures, lower masses, almost unlimited operation times .... On the other hand there are risks concerning time, costs for development and testing, and the use of this new technique for a flagship mission without any possibility for maintenance or replacement. If this active cooling proves a success with JWST it probably will be used in many future missions.

The involvement in the JWST mission offers the MPIA the chance to carry on in its tradition of interesting technological developments in infrared instrumentation, and guarantees participation in the most exciting scientific research on the origins of our universe and the formation of planets and life in our Galaxy. These activities place MPIA in an excellent position to participate in ambitious future missions

(Th. Henning (Co-PI), D. Lemke (Co-PI), S. Birkmann, U. Grözinger, R. Hofferbert, A. Huber, U. Klaas, O. Krause, S. Kuhlmann, H.-W. Rix, A. Böhm, Monika Ebert, B. Grimm, S. Meister, J. Ramos, R.-R. Rohloff, Alexandra Bohm, Hannelore Heißler)

IV.2 Novel Concepts for Extremely Large Telescopes

With at least three large, international projects underway, the era of the Extremely Large Telescope (ELT) is dawning. Defined as ground-based telescopes with diameters in the range of 20–100 meters, the ELTs represent the next significant advance in the development of ground-based telescopes.

The MPIA is playing a leading role in ushering in the era of Extremely Large Telescopes. From involvement in policy-making bodies to the evaluation of science requirements and goals, to instrument design studies and technology development, MPIA scientists and engineers are positioning the Institute to take advantage of these gigantic, yet exquisitely precise instruments.

Adaptive Optics (AO)

One of the fundamental challenges for extremely large telescopes is adaptive optics, as the core science cases for such telescopes require refraction-limited, rather than seeing-limited imaging. Within the European Framework Program 6 (FP6), a design study for an ELT was started in 2005. Together with partners from INAF (Bologna), University of Durham, Technion Haifa, ESO, the University of Galway and Lundt Observatory, we will investigate new concepts of wavefront sensing techniques to overcome the limitations current AO systems would have on an ELT.

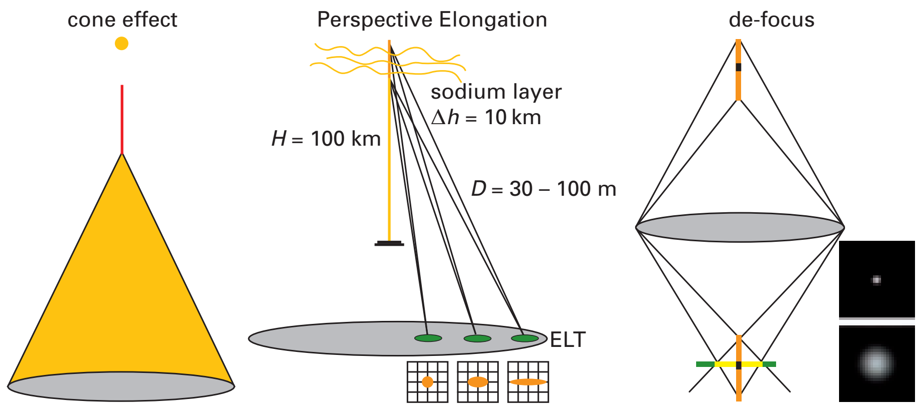
AO depends on natural or artificial guide stars bright enough to retrieve the information needed for atmospheric turbulence correction. This limits the sky coverage for AO observations. With an ELT, the limiting magnitude of a guide star will not change, as the sub-aperture size used in AO depends on the atmosphere and does not scale with the diameter. Ideas to increase sky coverage with natural guide stars and especially with a Laser Guide Star (LGS) are being investigated. Laser Guide Stars could increase the sky coverage to nearly 100 percent. Therefore, the group is currently focusing on the LGS concepts. However, LGS have certain inherent problems which severely increase with telescope diameter.

These problems can be distinguished in the following categories, which are illustrated in Fig. IV.2.1:

- Cone effect
- Spot elongation
- De-focus (extended focal depth – dynamic focal plane – differential aberrations)

A solution studied at the MPIA is the Pseudo Infinite Guide Star Sensor (PIGS, see Fig. IV.2.2), which uses two sensing devices, a mask in the infinity focus with annular slits which senses the radial component of the wavefront, and a reflecitve rod that senses the azimuthal part of the wavefront. Multiplying the sensor and using it with several LGS can overcome the cone effect. Intrinsically the sensor does not have the problem with spot elongation and extended focal depth; refocusing the sensor would also remove the problem of the dynamic focal plane, so that only the telescope aberation problem remains. Currently we set up an experiment in the laboratory to test the idea in a multi-guide star fashion.

Fig. IV.2.1: The finite distance and extended length in vertical direction of the LGS leads to several problems within an AO sensor: Cone effect (*left*): The LGS does not probe the full atmosphere like a normal guide star. Spot elongation (*middle*): Off axis projection of the LGS leads to an elongated spot on the sensor plane. De-focus (*right*): The LGS has an extended focal depth in the image space.



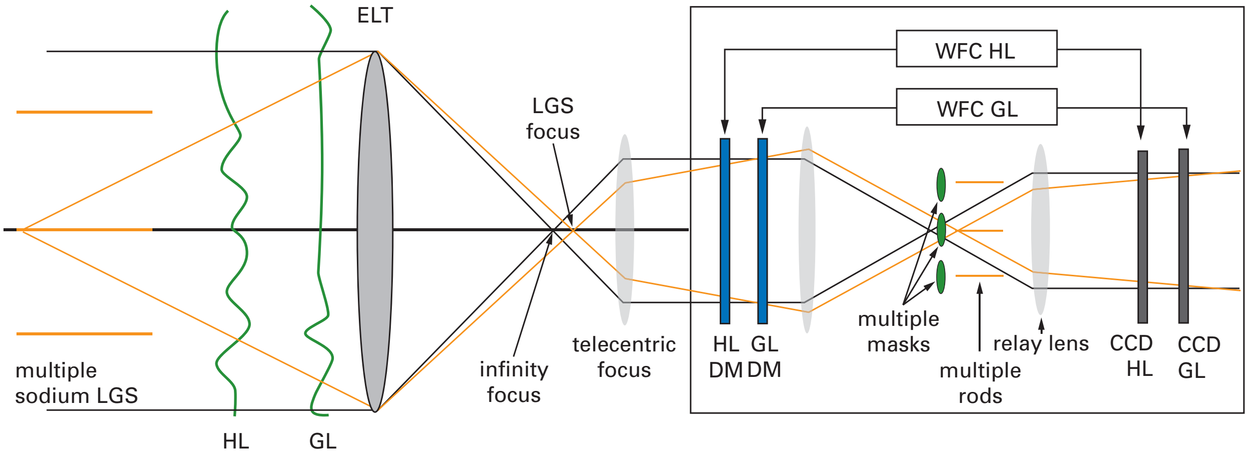


Fig IV.2.2: PIGS sensor as used in a Multi-Conjugated Adaptive Optics system based on the Layer Oriented approach.

An ELT Instrument for the Mid-Infrared Range

In collaboration with the University of Leiden, ASTRON (Dwingeloo) and ESO the T-OWL study was started at the beginning of 2005 on behalf of ESO to investigate possible concepts for a mid-IR instrument on a future 100 m telescope. At first, a list of astrophysical research projects for the wavelength range from 3.5 to 25 µm at the ELT was compiled from which the necessary specifications of such a mid-infrared instrument were derived and a design concept was developed. The first step was to simulate the atmospheric boundary conditions for different possible sites. Transmission and emission of the atmosphere, which limits the sensitivity of ground-based observations in the mid-infrared wavelength range, were calculated for spectral resolutions up to $R = 50000$. Comparison of the derived sensitivity of a mid-infrared instrument at a 100 m telescope with other instruments for the mid-infrared range – in particular with MIRI (JWST) – shows that a ground-based ELT is on par with satellite-based instruments in the mid-infrared range (Fig. IV.2.3). In some fields it is even vastly superior if one concentrates on extreme angular and/or high spectral resolution. An instrument for the mid-infrared at the ELT has to work diffraction limited (adaptive optics) and to provide optional high-resolution spectroscopy, preferably in combination with imaging optics.

Specific technical issues and problems were investigated in the T-OWL study: pupil and field rotation, atmospheric dispersion and its possible correction, chopping, coronagraphy, polarimetry, detector selection, data flow, observing modes and so on. No severe incompatibilities with the OWL design were found.

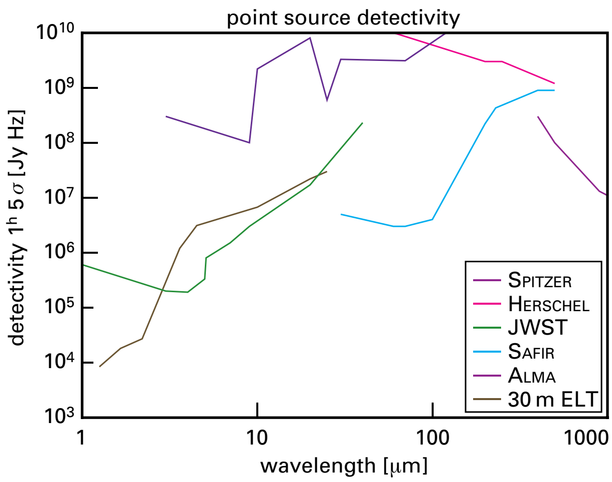
As planned, the study was completed with a report in September 2005. Since then, the EC-funded study MIDIR has begun to continue the T-OWL study and, in particular, to study the consequences of a reduction of the primary mirror diameter from 100 m to between 30 and 60 m on the sensitivity and thus the feasibility of scientific projects and the instrumentation concept.

A Near-Infrared Camera for the ELT

With colleagues at Arcetri, researchers at the MPIA also conducted a preliminary study for a near-IR camera on an ELT, called ONIRICA. An exploration of science cases yielded that a partial image correction (to 0.″1) over a wide field of view may be just as important as a full atmospheric correction over a smaller field.

(Wolfgang Brandner, Wolfgang Gässler, Roland Gredel, Tom Herbst, Thomas Henning, Hans-Walter Rix, Stefan Kellner, Rainer Lenzen, Eva Meyer)

Fig. IV.2.3: Comparison of the limiting magnitudes for one-hour exposure time (5 sigma) and the resolving power of various instruments for the mid-infrared through sub-millimeter range.



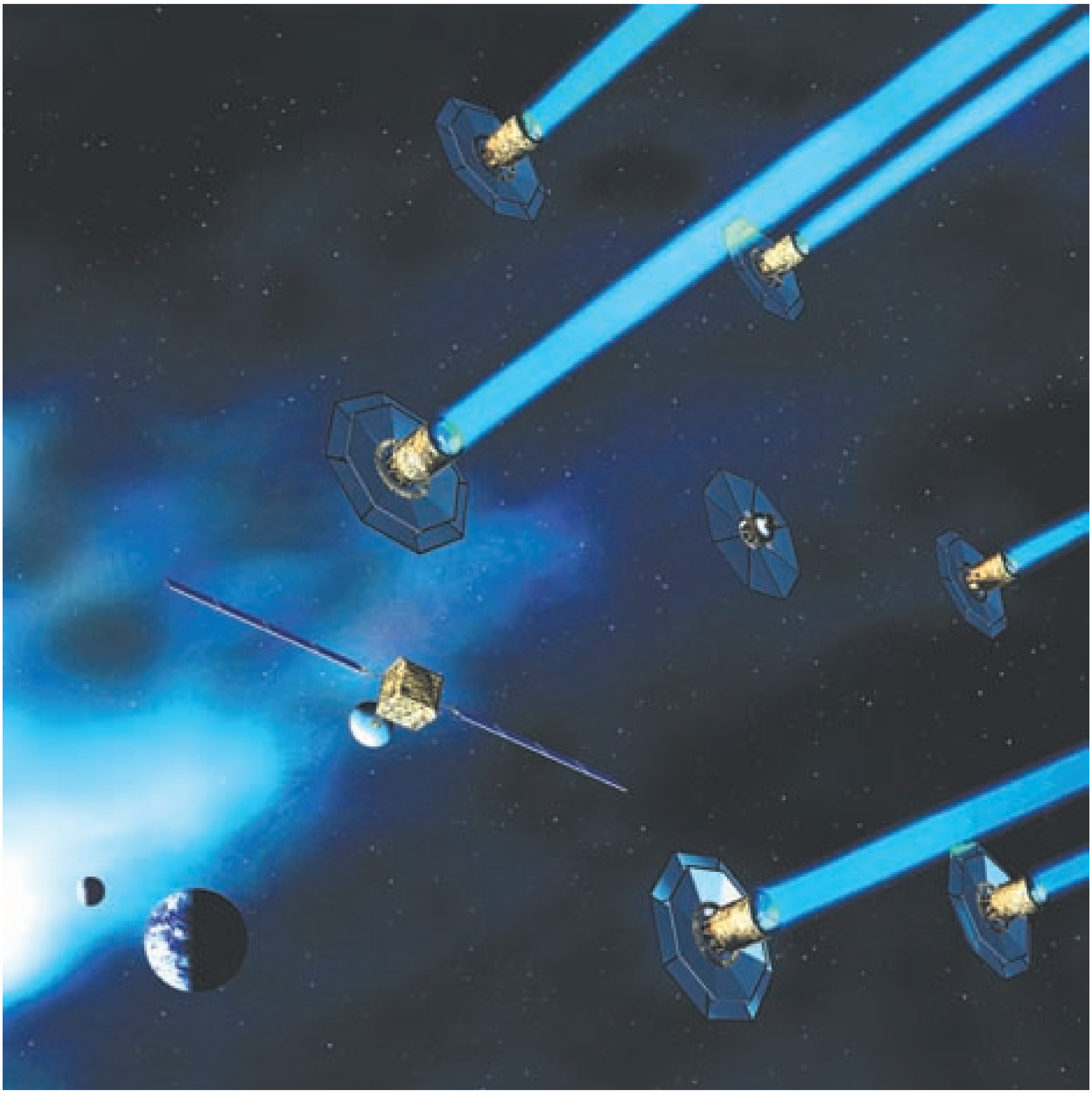
IV.3 Darwin

Darwin is an ambitious European Space Agency (Esa) mission with the explicit goal of finding Earth-like planets, characterizing their atmospheres, and searching for life. Darwin is being developed in a rich context of exo-planetary and exo-biological investigation. For example, the discovery over the last decade of close to 200 planets orbiting other stars has energized a renewed focus on the fundamental question of whether life exists on other planets in the universe.

Answering this question is a complex and difficult task, since planets like our own are typically 10 billion times fainter than their parent star. At the distances of even the most nearby stars, such worlds would also be very close to the intense glare of their suns. The combination of small angular separation and huge brightness ratio strongly restricts the ways in which astronomers can look for such planets.

Nulling interferometry, a technique in which the light of the host star is blanked out by superimposing phase-shifted images, offers a real prospect of overcoming these challenges. Earths are relatively bright and suns are relatively dim at mid-infrared wavelengths (6–20 μm). There are also a number of powerful »biomarkers«, spectral signatures of the presence of life in the mid-infrared regime. The improved contrast ratio and useful tracers, coupled with the easier task of aligning and controlling an interferometer at longer wavelengths, have led to the concept of the Darwin mission: a mid-infrared free-flying space interferometer.

Fig. IV.3.1: The flotilla of Darwin spacecraft searching for evidence of life in the Universe.



DARWIN will consist of three to six independent, free-flying spacecrafts of two different types: several telescope receiver satellites and a single beam combiner. Industrial and academic design studies are currently running to determine the optimum number, size, and flight configuration of the individual spacecraft.

DARWIN is being proposed as a large mission within the ESA Cosmic Vision program. With sufficient technological development, the interferometer will be ready to fly in 2020. The road to a successful DARWIN mission is long and difficult, but researchers at the MPIA are already attacking a number of core issues. In particular, the institute is working on a novel technique for achieving the necessary 180° phase shift that will cancel out the star light. A German-French collaboration, of which this effort is a part, will demonstrate a number of such techniques to ESA in late 2006.

Finally, MPIA scientists are deeply involved in planning for and executing DARWIN. Tom Herbst was on the original DARWIN Scientific Advisory Group (SAG) from 1997 through the end of an initial industrial study early in the new decade. ESA reconstituted this advisory board as the Terrestrial Exoplanet Scientific Advisory Team (TE-SAT), with both Herbst and Thomas Henning as members. The TE-SAT is currently writing the formal DARWIN proposal, and will guide a pair of industrial system studies through to their completion at the end of 2006. With a successful proposal outcome in early 2007, the MPIA will be ramping up its involvement and support of this most fundamental and important scientific space mission.

(Tom Herbst, Thomas Henning and the DARWIN APS group)

IV.4 Progress with LINC-NIRVANA for the LBT

LINC-NIRVANA is an innovative imaging interferometer fed by dedicated multi-conjugated adaptive optics systems. The instrument combines the light of the two 8.4 meter primary mirrors of the Large Binocular Telescope (LBT) on a single focal plane, providing panoramic imagery with the spatial resolution of a single 23 meter telescope. LINC-NIRVANA is being built by a consortium of four institutes led by the MPIA. Our other partners include the Istituto Nazionale di Astrofisica (Italy), the University of Cologne, and the Max Planck Institute for Radioastronomy (MPIfR) in Bonn.

LINC-NIRVANA will occupy one of the shared focal stations on the central platform of the Large Binocular Telescope (see Fig. V.1.4). At this location, the instrument receives light from both optical trains of the LBT. By creating a scaled-down version of the telescope entrance pupil, LINC-NIRVANA permits Fizeau-type interferometry over a wide field of view. The resulting images contain information at spatial frequencies up to that corresponding to the maximum dimension of the telescope (22.8 meters) along the direction connecting the primary mirrors, and up to 8.4 m spatial frequencies along the perpendicular direction. The Large Binocular Telescope has an alt-azimuth mount configuration, which means that the projected telescope pupil rotates with respect to the sky – so-called »earth rotation synthesis«. Combining multiple exposures taken at different projection angles

Fig. IV.4.1: The LINC-NIRVANA optical bench in the MPIA assembly hall.

allows the observer to synthesize panoramic images with full, 23-meter spatial resolution.

During 2005, LINC-NIRVANA passed its final design review, and is now well into the construction, integration, and testing phase. Highlights of the past year include completion of the large optical bench, receipt of the innovative hybrid cooling system, and the start of full-scale lab testing and verification of individual components.

The optical bench (Fig. IV.4.1) presented a particularly interesting design challenge. The focal plane of the LBT lies approximately 2.5 meters above the instrument platform. The optical bench must provide a lightweight, stiff, vibration-damping reference surface that can carry the substantial mass of the various LINC-NIRVANA subsystems. The solution adopted was a monolithic carbon fiber and aluminum honeycomb table supported by fourteen hollow carbon fiber legs. The large steel base ring interfaces to the telescope and absorbs flexures due to different telescope orientations and dimensional changes due to temperature variation.

With the bench now in place, the LINC-NIRVANA team has begun testing individual subsystems as they are delivered from our academic and industrial partners. One such subsystem is the ambient temperature fore-optics, consisting of two groups of three lenses for each side of the interferometer. Designing, constructing, and particularly, aligning these optics presents a serious challenge: not only must the lenses deliver diffraction-limited image quality over the wavelength range 0.6 to 2.5 μm, but also the two optical paths must be exactly matched to ensure maximum interferometric performance. During 2005 and the first part of 2006, the LINC-NIRVANA team tested and characterized the warm fore-optics. When properly aligned, the lens groups exceed optical performance specifications.

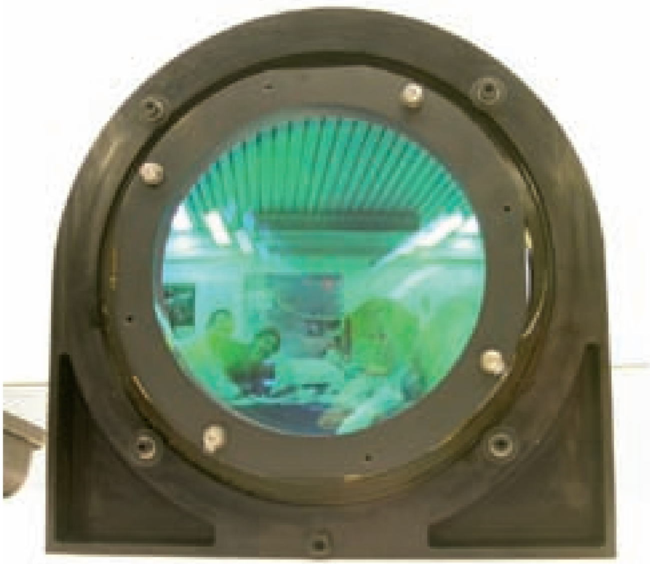
Completing the LINC-NIRVANA instrument will involve carrying these successful component tests forward into integration of sub-systems. For example, the warm fore-optics must now be integrated and tested with the large optical bench and other items currently being tested at the component level. Once the subsystems are complete, the team will begin testing and optimizing the performance of the instrument as a whole.

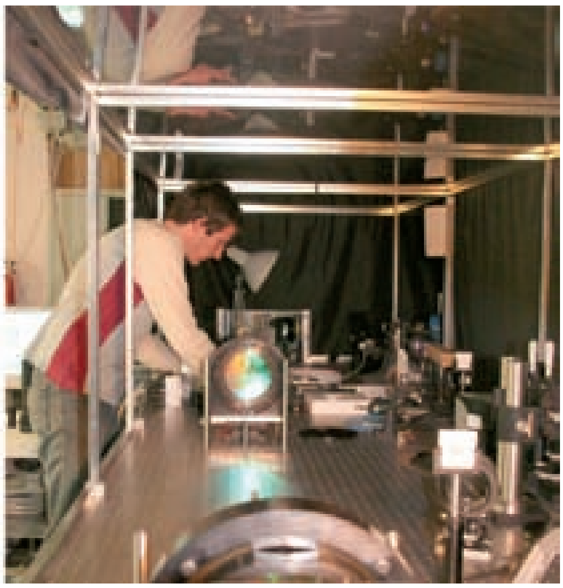
The assembly, integration, and testing phase of LINC-NIRVANA is now well underway. In the meantime, installation and commissioning efforts continue in Arizona on the telescope itself. With continued good progress on both fronts, the instrument will arrive at the LBT soon after completion of both adaptive secondary mirrors in Fall, 2008. At that point, the Large Binocular Telescope and LINC-NIRVANA can begin functioning as a Fizeau interferometer, delivering to MPIA astronomers unique observational capability.

A detailed description of LINC-NIRVANA can be found in the MPIA Annual Report 2004, p. 75 – 86.

(H. Baumeister, J. Berwein, P. Bizenberger, A. Böhm, J.L. Borelli, F. Briegel, F. De Bonis, M. Dörsam, S. Egner, R. Friedlein, W. Gässler, B. Grimm, S. Hanke, T. Herbst (PI), F. Kittmann, M. Kürster (PM), L. Labadie, W. Laun, U. Mall, L. Mohr, N. Münch, V. Naranjo, A. Pavlov, D. Reinmann, H.-W. Rix, R. Soci, E. Schinnerer, C. Storz, V. Volchkov.
Collaborating Institute:
INAF, I. Physikalisches Institut der Universität Köln, MPI für Radioastronomie, Bonn)

Fig. IV.4.2: *(Left)* One of the warm fore-optics lens assemblies. *(Right)* Aligning and testing the complete fore-optics on a large optical bench.





IV.5 LUCIFER I / II – Spectrographs for the LBT

LUCIFER is a pair of multi-mode imagers and spectrographs for the Large Binocular Telescope (LBT). LUCIFER is being built by a consortium of five institutes: the MPIA, Landessternwarte Heidelberg, MPE Garching, Ruhr-Universität Bochum, and Fachhochschule Mannheim.

Fig. IV.5.1: LUCIFER I and II in the dust-free experimental hall at MPIA. In the center, the assembled cryostat of LUCIFER I is seen during the first cooling tests. Partly obscured behind it and in the foreground are parts of the second cryostat.

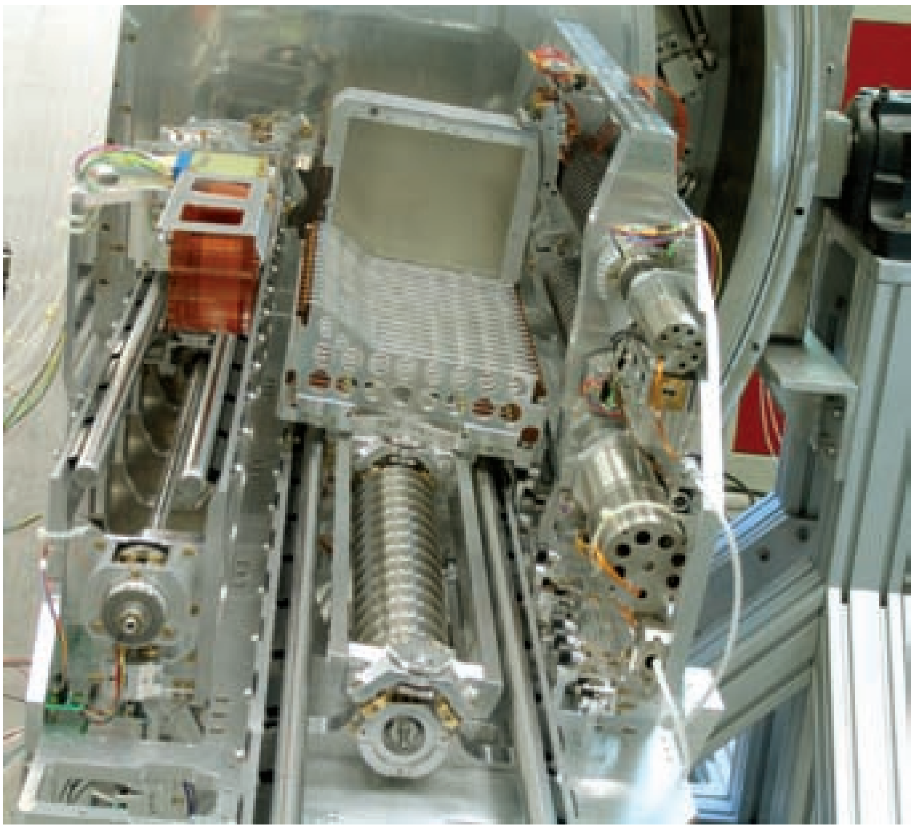
The assembly of the two infrared camera/spectrograph-systems LUCIFER I and II is making progress: in the year under report, both cryostats were completed, tested and delivered to the MPIA. One cryostat was subsequently transported to the Max Planck Institute for Extraterrestrial Physics in Garching for integration of the cryogenic multi-object spectroscopy unit (Fig. IV.5.2). Two auxiliary cryostats for changing the mask magazines were completed at MPE, allowing the team to test and optimize the process of magazine changing.

LUCIFER I is presently being integrated at the MPIA. The cold structure has been installed and tested at cryogenic temperatures. All opto-mechanical components will follow. In September 2005, the telescope simulator was delivered and set up in the experimental hall. Flexure tests will be carried out with this device to verify functional performance for varying telescope positions.

During spring and summer 2006, integration of LUCIFER I will be completed. Delivery is planned for spring 2007. LUCIFER II will follow about one year later.

(Bernhard Grimm, Werner Laun, Rainer Lenzen, Ralf-Rainer Rohloff. in cooperation with: Landessternwarte Heidelberg, MPI for Extraterrestrische Physik, Garching, Astronomisches Institut der Ruhr-Universität Bochum, Fachhochschule für Technik und Gestaltung, Mannheim)

Fig. IV.5.2: The MOS unit during the tests at MPE in Garching before installation into the cryostat. The worm drive with the two mask magazines in the foreground, while the exchange robot and locking device appear to the left and right, respectively. Since the end of 2005, tests have also been conducted in the original cryostat at cryogenic temperatures.



IV.6 Differential Delay Lines for PRIMA

Within a few years, the high-precision astrometric facility PRIMA (Phase Referenced Imaging and Microarcsecond Astrometry) will be available at the Very Large Telescope Interferometer (VLTI) of the European Southern Observatory.

PRIMA will be equipped with Differential Delay Lines (DDL), in order to perform high-precision astrometry at the 10 microarcsecond level. This precision enables the detection of extrasolar planets using the astrometric method, which is complementary to the radial velocity technique. In particular, the precise astrometry method can be used to search for planets around stars which are not suitable for the radial-velocity planet search programs. Astrometry allows a characterization of extrasolar planetary systems, because the mass of the planets can be determined by this technique.

During the astrometric observations with PRIMA, two stars will be observed simultaneously in a larger field of view (1 arc minute in diameter). If one of the stars is used as a reference, perturbations caused by atmospheric turbulence can be compensated for the other object in real time, leading to an increase in angular resolution and to a higher sensitivity.

The MPIA Heidelberg, Geneva Observatory and Leiden Observatory are cooperating in a consortium that has agreed with ESO to build and deliver the Differential Delay Lines for PRIMA, and then to carry out an astrometric planet search program at the VLTI with the auxiliary telescopes in the near-infrared K-band.

In the DDL project, the MPIA is primarily involved in the development of a high-precision, movable cat's eye telescope with an aperture of 20 cm driven by a linear motion mechanism and placed in a vacuum, the delay lines will compensate optical path differences of up to 12 cm with nanometer accuracy, corresponding to an accuracy of one part in 10^8.

In addition to this instrumentation project, the MPIA is also participating in the development of the astrometric operation software (AOS) and scientific preparatory programs for the astrometric observations. The MPIA is the leading partner in the preparatory observations for the planet search project with PRIMA.

The PRIMA-DDL and AOS projects have successfully passed the preliminary design review, which was held at ESO Garching in June 2005. The final design review is foreseen for July 2006.

(Harald Baumeister, Peter Bizenberger, Uwe Graser, Thomas Henning (Co-PI), Ralf Launhardt (Project Scientist, PM Optomechanics), Ralf-Rainer Rohloff, Johny Setiawan, Karl Wagner. Partners: Observatoire de Geneve, Sterrewacht Leiden)

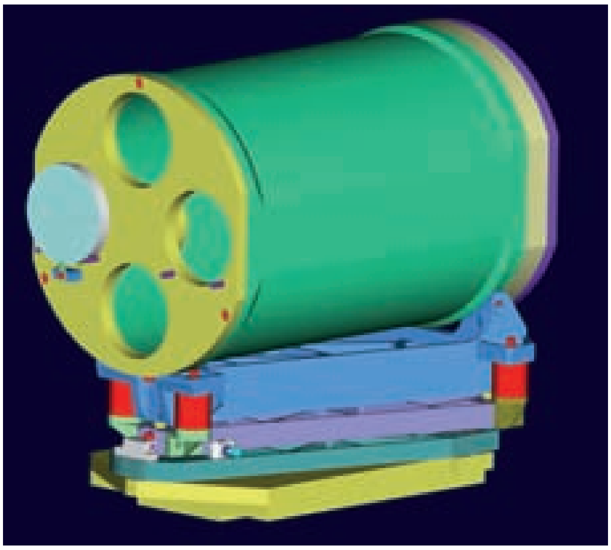
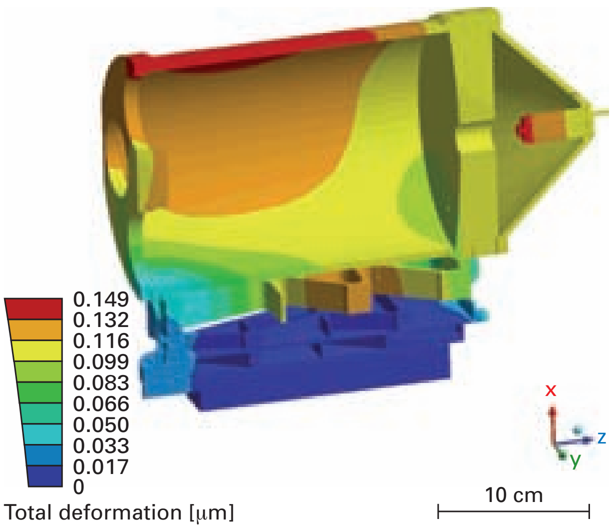


Fig. IV.6.2: Optics of PRIMA DDL on a kinematic mount and subplates for adjustment.

Fig. IV.6.1: Result of a Finite Element Analysis of the deformation by gravity forces and forces by the magnetic mount. The maximum deformation is 149 nm (red).



IV.7 Sphere – Search for Exoplanets at the VLT

Sphere, »Spectro-Polarimetric High-contrast Exoplanet Research«, is a project for direct imaging of extrasolar planets at the Eso-VLT. The project resulted from the merger of Cheops and Planet Finder, two competing feasibility studies for a corresponding VLT instrument.

After the Cheops consortium led by MPIA had officially lost the competition the scientific-technical advisory committee of Eso decided that both projects should be combined since essential parts of Cheops were superior to the proposal presented by Laog (Grenoble). MPIA now is Co-PI institute of the Sphere consortium comprising a total of 12 European institutes, including Eso. Phase B for Sphere is now expected to start officially in March 2006.

As with Cheops a scientific program will be developed within Sphere. With the resulting observing program being optimized on the basis of planet formation models, the spatial distribution of nearby stars as well as their age distribution, metallicity and so on, it should be possible to directly image several extrasolar gas planets of various ages (10^7, 10^8, and over 10^9 years old). The instrumental concept still includes an »extreme« adaptive optics system (Xao), and now three differential imaging components: the differential polarimeter Zimpol, a 3D near-infrared spectrograph (both from the Cheops concept), as well as an additional differential imaging Nir-camera with spectrograph and polarimeter from the Laog proposal. For highest stability, the entire instrument will be fixed on the Nasmyth platform of the VLT.

Phase B of the project is planned to last twelve months and will end with the preliminary design review. Phase C, until the final design review, is expected to take twelve months, too, whereas for construction, procurement and integration of the individual components 18 months are scheduled. First light is planned for the middle of 2010.

(Markus Feldt)

IV.8 Laiwo – Search for Exoplanets at Wise Observatory

Laiwo (Large Area Imager for the Wise Observatory) is an optical CCD camera that will be used to search for extrasolar Jupiter-like planets with the transit method. The camera will be mounted on the 1m telescope at the Wise Observatory (Fig. IV.8.1) in the Negev Desert, Israel. The field of view will be one square degree with a resolution of 0.7 arcseconds per pixel.

The MPIA, the University of Tel Aviv and the Göttingen Observatory initiated the Giant Transiting Planets Observations program funded by the MPIA and the German-Israeli Foundation. The aim of the research project is to detect extrasolar Jupiter-size planets around stars with magnitudes $I = 14 – 15$ using the transit method. This technique relies on the temporary drop in brightness of the parent star harboring the planet. If the planetary system is in a favorable orientation relative to the line of sight, then once per orbit, the planet passes between its star and the observer, causing an occultation or transit that results in a dip in the light curve. For Jupiter-size planets transiting a sun-size star, the expected dip or transit depth will be about 1 %. If three or more transits can be measured and confirmed to be caused by the same planet, the orbital period, the radius of the planet and the inclination angle of its orbital plane can be determined.

Currently, Laiwo is being built at the MPIA. The camera will have four Lockheed CCD 486 devices with 4000×4000 pixels 15 microns in size (Fig. IV.8.2). The CCDs are frontside-illuminated with a quantum efficiency of about 40 % between 600 and 850 nm wavelength and a read-out noise below 5 electrons. There will be one guider CCD located at the center of the mosaic: an e2V CCD 47-20, $1K \times 1K$ frame transfer device, with a pixel size of 13 microns. The camera will be mounted on the 1m telescope of the Wise Observatory. The field of view will be one square degree with a resolution of 0.7 arcseconds.

Fig. IV.8.1: The 1m telescope of the Wise Observatory in Israel.

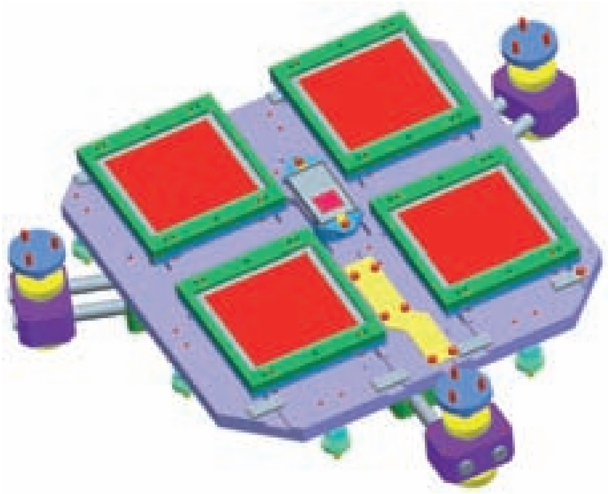


Fig. IV.8.2: Detector arrays for LAIWO.

B, *V*, *R*, *I*, *z*' and filters will be mounted on a ruler that fits into a drawer. Three separate plates of sets of filters can be mounted on the ruler at the same time. Each plate contains five filters, four for the imager CCDs and one for the guider CCD.

The observing strategy is to continuously monitor three fields at any given time, until 3000 images are acquired per field. We can expect to have more than 200 nights allocated per year during three years. This will allow a sky coverage of about 27–30 square degrees. Observations will be coordinated with the 1.2 m Monet telescope in Texas, USA, which is operated by the Göttingen Observatory. The expected number of detections over a three year campaign is around 15 planets, and the project will be operational in summer/autumn 2006.

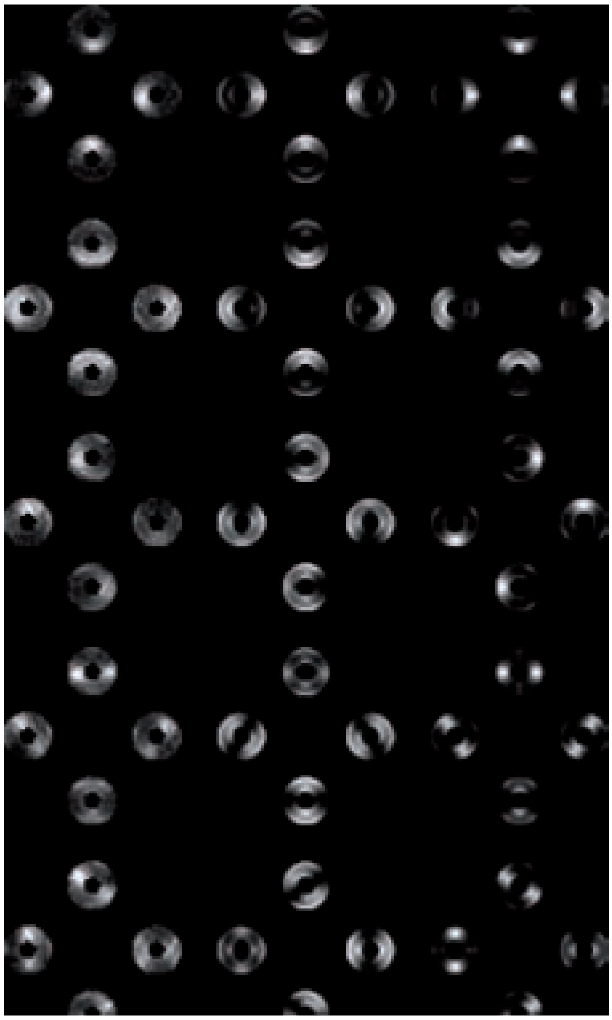
(Cristina Afonso (PI), Thomas Henning (Co-PI), Karl-Heinz Marien, Harald Baumeister, Armin Boehm, Florian Briegel, Bernhard Grimm, Ralf Klein, Ralf-Rainer Rohloff, Karl Zimmermann. Partners: Wise-Observatory, Israel and Universitätssternwarte Göttingen)

IV.9 PYRAMIR – A New Wavefront Sensor for ALFA

PYRAMIR (Pyramid Infrared Wavefront Sensor) is a novel wavefront sensor operating in the near infrared range. The instrument is intended for the adaptive optics system ALFA and will complement the Shack-Hartmann wavefront sensor working there in the optical range.

PYRAMIR will be the first pyramid wavefront sensor worldwide working on the night sky under the real atmosphere in a spectral region where the AO correction is highly efficient. It is only under these conditions that pyramid sensors can achieve their predicted 1.5 mag advantage in guide star brightness over Schack-Hartmann type sensors.

Fig. IV.9.1: Detector images of PYRAMIR. They show the sensor response to the fundamental optical aberrations which were applied to the deformable mirror during the calibration process. To the left, the actual detector images, in the middle and to the right, simulations with varying aberrations (75 nm RMS and 480 nm RMS) for comparison. Notice that the real calibration amplitude corresponds more closely to 480 nm RMS.



Meanwhile, the integration of the sensor is completed. Temporary problems with adjustment and alignment, particularly of the detector mount, could be overcome by the end of 2005. Until the end of the year 2005 PYRAMIR served in the AO laboratory of MPIA where all its functions concerning electronics, motors, temperature and pressure sensors as well as optics were thoroughly tested. After the successful completion of these tests PYRAMIR was shipped to Calar Alto for laboratory integration into the ALFA system. Here the first calibration with a complete set of modes took place (Fig. IV.9.1). PYRAMIR will have first light on the night sky probably in April 2006.

(Markus Feldt, Diethard Peter, Miwa Goto, Thomas Henning, Stefan Hippler, Karl Wagner, Harald Baumeister, Peter Bizenberger, Ulrich Mall, Ralf-Rainer Rohloff, Udo Neumann, Clemens Storz)

IV.10 Improvement of the Seeing at the 3.5 m Telescope on Calar Alto

While the optical design of the 3.5 m telescope on Calar Alto is excellent, the quality of the images obtained over the last 20 years was seldom better than one arcsec – in spite of various efforts to control the thermal stability of the telescope enclosure and of the mirror during daytime, such as active cooling of the floor and of the mirror cell. This could be substantially improved by adding a few simple steps, and 0.″7 imaging in the optical can now often be achieved.

As a first step in planning seeing improvements to the 3.5 m telescope, a rigorous, quantitative assessment of the site-seeing was necessary. In order to characterize the site and the local seeing degradations, a differential image motion monitor (DIMM) was acquired in the year 2000 from a commercial company. After a few months only of seeing measurements outside the telescope building, the median seeing measured with DIMM turned out to be well below one arcsecond and almost half an arcsecond below the average image quality at the telescope. A two-week campaign on Calar Alto with the Generalised Seeing Monitor (GSM) of the University of Nice (A. Ziad, R. Gredel, J. Aceituno, J. Borgnino, F. Hoyo, et al., 2005, MNRAS 362, 455) confirmed the measurements performed with DIMM, and demonstrated that increased efforts were needed to remove the effects which degraded the local seeing at the 3.5 m telescope.

First and foremost, 16 ventilation windows with a total cross-section of approximately 30 m^2 were cut into the 3.5 m dome. This intervention was in line with similar efforts at other telescopes such as the UKIRT. The additional windows resulted in a very efficient ventilation of the dome at the beginning of the night; it is supported by additional air extractors which were installed at the doors leading to the catwalk. An active ventilation of the mirror using fans installed right at the edge of the mirror cell was less successful. In general, mirror ventilators caused a degradation of the seeing, therefore their use was discontinued.

Additional measures were taken to increase the thermal stability of the 3.5 m telescope building. The building hosted a number of electronic laboratories, which induced a frequent access to the building during the day- and partly during the nighttime. Those labs were removed, and the heating of the telescope building was subsequently reduced to such a low level that in the winter freezing of the ducts is prevented, but otherwise the dissipated energy was minimal.

Observations with the adaptive optics instrument ALFA indicated that a severe tilt in the wavefront was present, and observations with the prime focus camera LAICA showed that the images obtained at the prime focus suffered from a quite severe de-centering coma. A de-centering coma was not apparent with imaging instruments in the Ritchey-Chretien focus, such as MOSCA. The origin of this aberration was not clear to us, mainly because we assumed that the mirror cell was maintenence-free, as suggested by C. ZEISS. The passive system of the axial mirror support consists of 27 hydraulic pads arranged in three sectors, but interconnected with each other. The source of the aberration could not be found, and an improper functioning of the mirror cell remained the last reasonable possibility. In fact, it turned out that an oil leak led to an inclination of the primary mirror by 0.035 degrees, which was corrected by the addition of 0.5 l of hydraulic oil. The inclination of the mirror was the major source of the aberration observed with ALFA and with LAICA, and thanks to the corrective maintenance to the mirror cell, the static aberration nearly disappeared.

Additional measures to minimize local temperature effects included the installation of cooled racks for the instrument electronics located near the telescope, the installation of motion sensors and time intervals to all light switches, and, last but not least, a change to instrument block scheduling, which minimized the access frequency to the telescope floor due to daytime operations. In the near future, after the successful termination of the 3.5 m upgrade, the 3.5 m control room located right next to the telescope will be moved down to a joint control room for the 3.5 m and 2.2 m telescopes, which is already in use for observations at the 2.2 m telescope.

(*Roland Gredel)*

IV.11 PACS – Far-Infrared Camera and Spectrometer for the HERSCHEL Space Telescope

Within a consortium of 15 European institutes, MPIA is participating – with a share of 15 percent – in the development of the PACS instrument, a camera and spectrometer for wavelengths of 60 to 210 µm.

The most important contributions from Heidelberg are the focal plane chopper, the characterization of the large Ge:Ga-spectrometer-cameras and their –270 °C cold readout electronics, the investigation and avoidance of radiation damages to these components, and the calibration of the instrument before and during flight.

Already in June 2005, MPIA was able to deliver the focal plane chopper – as one of the consortium's first contributions to the PACS flight model – to MPE Garching, which is responsible for the overall instrument. The chopper manufactured by C. ZEISS is a derivative of a prototype designed and tested at MPIA. It is of excellent quality and surpasses many of the technical requirements. In the summer of 2005, construction of the flight spare unit of the chopper was started, which promises an even better performance.

During the characterizations of the 16 × 25 Pixel-Ge:Ga-cameras for the flight model unexpectedly numerous

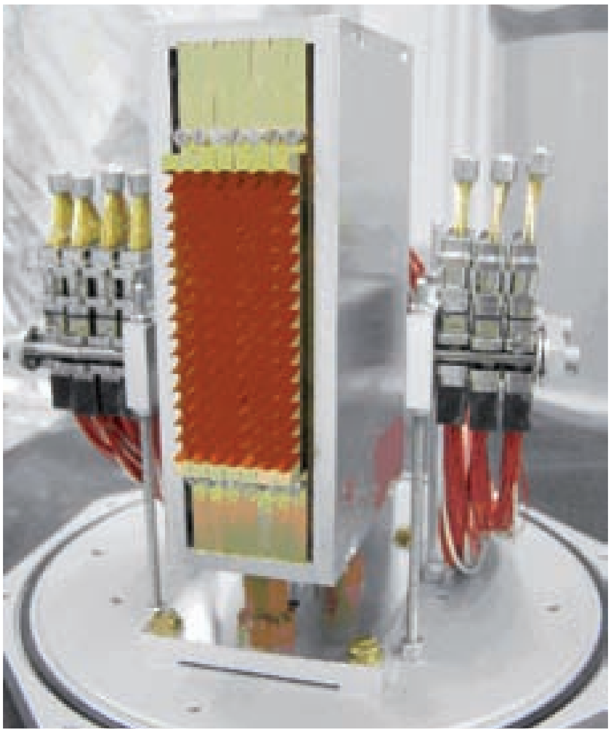


Fig. IV.11.1: Seven detector rows with 16 pixels each of a camera for the PACS spectrometer unit. The light funnels in front of the Ge:Ga pixels are visible. The two cameras each have 25 of such modules. At MPIA, these detector modules are characterized in detail with respect to their sensitivity, noise, dark current etc. at temperatures below –270 °C.

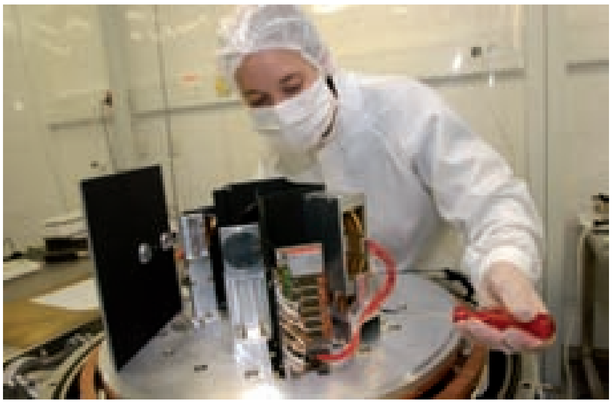


Fig. IV.11.2: PhD student Jutta Stegmaier prepares a test of detector modules (as in Fig. IV.11.1) to be conducted in the liquid helium cryostat of MPIA.

failures occurred. MPIA participated in a series of experiments lasting several months to explain the malfunctions. For this we had to move the extensive test facilities of MPIA to the manufacturer of the cameras. Finally, two main causes for the high failure rates were determined: 1. destruction of electronic amplifier and readout stages by electrostatic discharges and 2. bad bonding of the thin steel connecting leads; steel is used because of its low thermal conductivity. To avoid the electrostatic problems the handling of the components had to be regulated very carefully at the institutes and firms involved (air humidity, groundings, protection circuits …). With the new procedures the success rate of the detector/readout electronic tests rose steeply. So by the end of the year most of the camera modules were fully characterized and could be delivered to the manufacturer ASTEQ for the assembly of the cameras. Because of the unexpectedly time-consuming tests with the Ge:Ga-spectrometer-cameras, the radiation tests with gamma-ray sources to simulate an optimal operation at the Lagrangian Point L2 were delayed.

After the work for the actual instrument is drawing to a close at MPIA, the tests and development of the ground observatory are reaching the critical stage. Scientists from Heidelberg were involved in the cold tests of the PACS qualification model and in the integrated module tests of all three HERSCHEL instruments. For this, test procedures were designed and an extended data analysis was carried out. Naturally, the focus of the contributions from Heidelberg was on detectors, chopper, and calibration. Because the development of subsystems and their mutual interfaces from the 15 institutes of the PACS consortium are still not quite perfected, all these tests took noticeably more time than originally planned.

Moreover, MPIA is contributing to the design of the scientific observing templates for future users of the HERSCHEL Observatory and has taken on a leading role in the development of the interactive data analysis for PACS.

The launch date of the HERSCHEL Far-Infrared Space Telescope has been postponed by almost one year to the spring of 2008 owing to several technical difficulties encountered in fabricating the largest-yet space observatory. The novel 3.5 m primary mirror – made of silicon carbide – showed large focus variations when it was cooled down to −200 °C, and the three scientific instruments needed more time to optimize their extremely sensitive detector systems.

(Dietrich Lemke, Stephan Birkmann, Helmut Dannerbauer, Ulrich Grözinger, Thomas Henning, Ralph Hofferbert, Ulrich Klaas, Jürgen Schreiber, Jutta Stegmaier, Manfred Stickel)

IV.12 PIA – A Mainframe Computer for the MPIA

Since September 2005, 264 processors and an efficient network at the Supercomputer Center in Garching are »glowing« exclusively for MPIA. With this new supercomputer, unprecedented processing power is available to MPIA researchers. With a total processing power of 1.1 teraflop, corresponding to 1100 billion arithmetic operations per second, we just miss a place on the top 500 list of the worldwide fastest supercomputers.

Hubert Klahr and Rachel Somerville, the leaders of the two theory groups at the MPIA, and Walter Rauh, head of computing at the MPIA, together devised the specifications for this computer and succeeded in getting it approved and largely financed by the computer advisory committee of the Max Planck Society (BAR). First scientific results obtained with this computer have already been published.

The case history

Since the computing system Origin2000 was handed over to the Max Planck Computing Center in Garching, a 24-processor Beowulf cluster named Beehive with relatively slow Ethernet connections had been the most powerful computer available to theorists at the MPIA. In summer 2004, Stefan Hippler, together with Walter Rauh and Hubert Klahr, succeeded in procuring an up-to-date 16-processor Opteron cluster with the help of the BAR. This mini-cluster comprises four modern Opteron quadboards with fast infiniband connections. However, soon these computing resources no longer sufficed, and MPIA researchers had to resort to external computing capacities. Above all, the simulation of turbulences in protoplanetary accretion disks is computationally very demanding. Here, the influence of turbulences on the formation of planets is investigated (cf. Chapter II.4: Planetesimal Formation by Gravitational Instability, p. 26 ff). However, the use of external computing resources always means narrow restrictions of computing time, a low priority compared to other users, and dependence on the goodwill of the operators of the computer facilities.

In the spring of 2005, Rachel Somerville arrived at the MPIA to take over the theory group within the galaxy and cosmology department. Her simulations of galaxy evolution also depended on the use of mainframe computers. So the theory groups formed a strategic alliance,

Fig. IV.12.1: The PIA cluster of the MPIA shortly after its commissioning at the computing center of the Max Planck Society in Garching. The middle rack contains in its lower part the 144-port infiniband switch from Mellanox and in the upper part the two V40z access servers with the FC-Raid systems. The four other racks harbor 32 computer nodes (V20z) each.

jointly applying for a cluster of 256 processors at the BAR. On July 1st, 2005, Walter Rauh and Hubert Klahr successfully defended the application at a BAR meeting in Munich. The application was fully granted, and the BAR even promised to cover two thirds of the costs. Procurement proceeded rapidly: by September 1st, the PIA cluster was handed over to the MPIA theory groups.

Specifications

To simplify logistics, we chose to install the computer at the computing center of the Max Planck Society in Garching. There enough room, power, and cooling capacities as well as specialists for this kind of hardware are present – a general set-up that would have required a great deal of effort to be created at the MPIA in Heidelberg. With the modern internet connections, researchers can hardly tell whether the computer they are working at is standing in the room next door or in Garching.

PIA is a cluster with 128 × 2.6 GHz Double-Opteron computers from SUN (V20z), which can exchange information through a 144-port infiniband switch from Mellanox (MTS 14 400) for rapid intercommunication. Each node is equipped with 4 gigabyte main memory and 2 × 73 gigabyte hard disks. For storing the extensive simulation results, a total of about 10 terabyte is available on two-fibre channel RAID systems which are connected to the two access servers (V40z), each with four AMD Opteron 848 processors (2.2 GHz) and 8 GB main memory.

First results

Since the theory groups had already prepared software for PIA, we could immediately start the simulation runs. The first publications based entirely on data obtained with PIA are already in print in the Astrophysical Journal, further ones are being submitted. Meanwhile, PIA has ten active users, which on one hand means full utilization of the capacities, but on the other hand still allows for immediate access to the facility's enormous computing power. Thus PIA is one of the most important collaborators within the theory groups at the MPIA.

(Hubert Klahr, Walter Rauh, Rachel Somerville)

V People and Events

V.1 First Light for the Large Binocular Telescope

On October 12th, 2005, the first astronomical pictures were taken with the Large Binocular Telescope (LBT). This »First Light« was an important milestone in the commissioning of the world's largest single telescope. Under the coordination of the MPIA, five German institutes are LBT partners contributing to the development of this unique telescope. The LBT will open up completely new opportunities for extrasolar planet research and the investigation of the distant Universe.

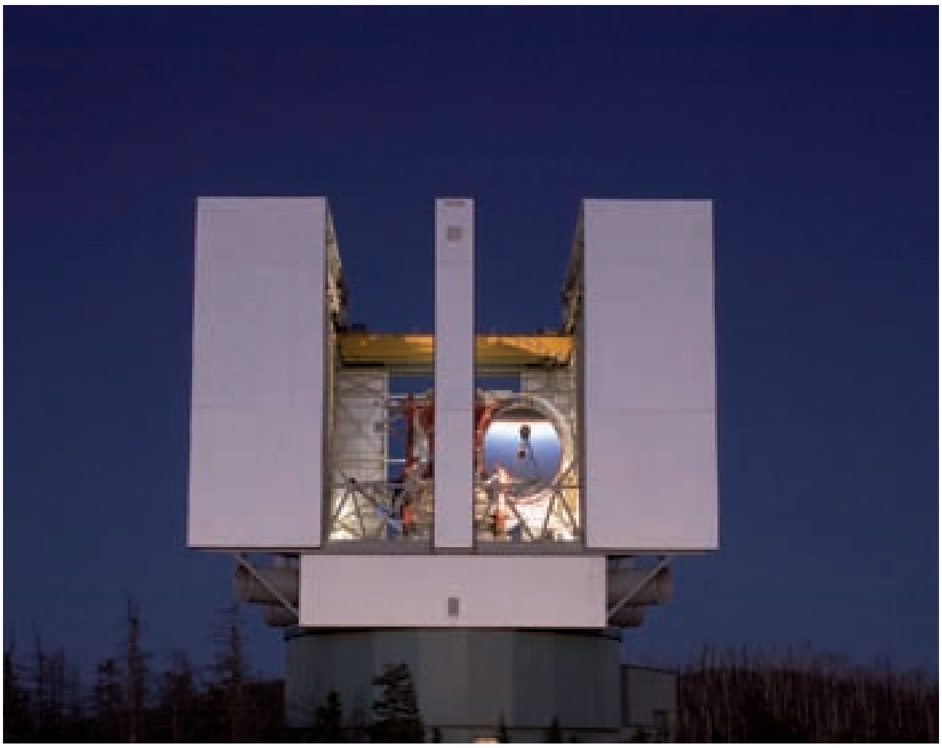
Located on the 3190 m high Mount Graham, Arizona, the LBT is one of the outstanding scientific-technical projects of modern astronomical research. The telescope is equipped with two primary mirrors of 8.4 m diameter each that are fixed on one common mount and thus can be pointed simultaneously to distant celestial objects. By combining the light paths of both mirrors, the LBT gathers as much light as a telescope of 11.8 m aperture, thus surpassing the HUBBLE Space Telescope's light gathering power by a factor of 24.

Even more important, however, is the fact that the LBT should be able to achieve the resolving power equivalent to a single 22.8 m telescope. This ambitious goal can only be accomplished by using an adaptive optics system combined with Fizeau interferometry. Some components of the LBT necessary for this technique are still under development. These include the extremely thin adaptive secondary mirrors and the LINC-NIRVANA instrument which will provide the interferometric combination of the two light beams. MPIA is the PI Institute for the building and development of this central LBT component (see Chapter IV.4).

The go-ahead for first light was given when the first primary mirror was mounted into the telescope structure. On October 12th, 2005, the telescope was pointed towards the spiral galaxy NGC 891, which lies at a distance of 24 million light years in the constellation of Andromeda. The first high-quality images were taken with the Large Binocular Camera (LBC) in the telescope's primary focus through a blue filter (a camera version for the red spectral range is under construction). The LBC, with its core of four CCD detectors of 2046 × 4608 pixels each, has been provided by the Italian partners of the project.

Several exposures with a total of five minutes exposure time were combined into a single image with

Fig. V.1.1: Still one-eyed: The LBT on Mount Graham.



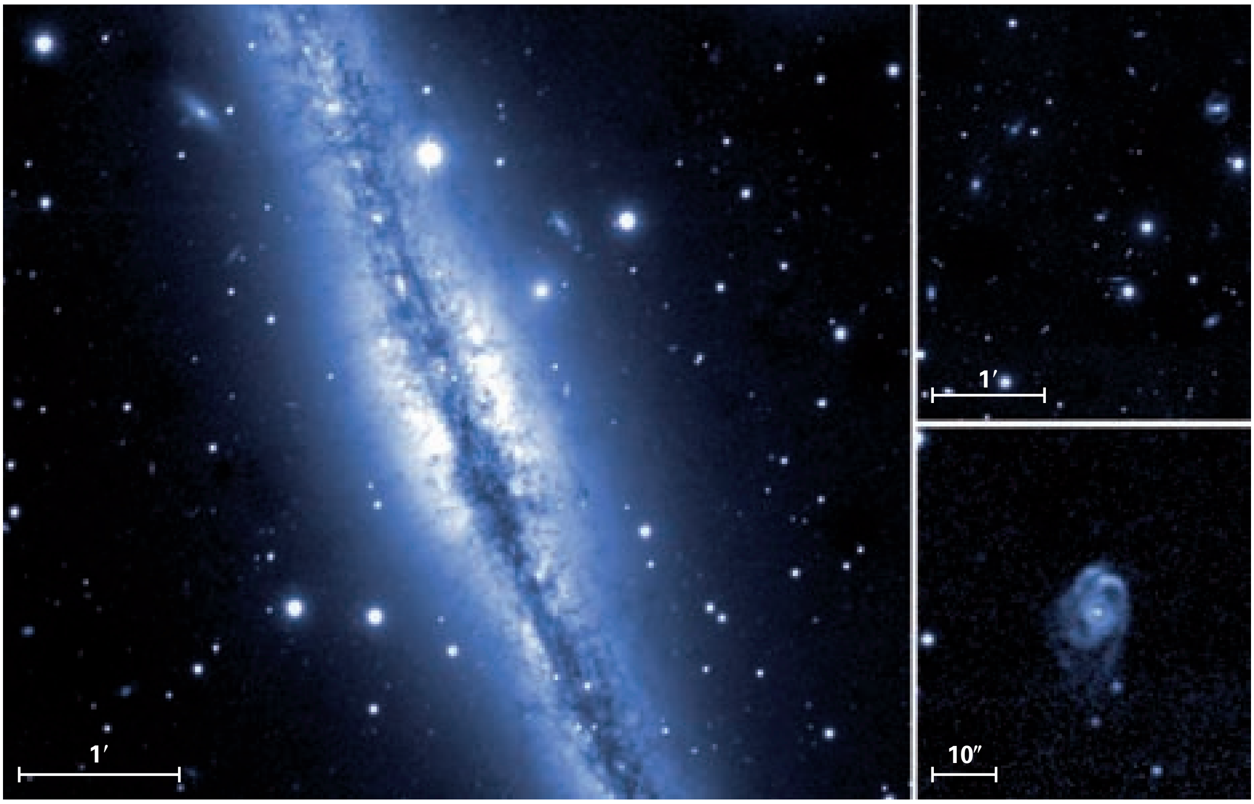


Fig. V.1.2: The first image taken by the LBT on October 12th, 2005, shows the spiral galaxy NGC 891, which is 24 million light years away. These enlarged views display the central region (*left*) as well as an object lying far beyond NGC 891 in the complete image directly at the central lower border (*lower right*) and a cluster of galaxies a bit further to the right (*upper right*).

a seeing of 0.8 arcseconds, shown in Fig. V.1.2. The interstellar dust aligned along the disk, a typical feature of spiral galaxies, is clearly visible. Together with the gas, it constitutes the material from which new stars and planets will form.

Despite the short exposure time and without using adaptive optics, the image shows a wealth of details in the central region of the galaxy and also in other areas of the camera's field of view, which at a width of 30 arcminutes is very large (see sectional enlargements of Fig. V.1.2).

The LBC camera is the first of a series of high-tech instruments the LBT will be equipped with.

The German Contribution to the LBT

Under the coordinating leadership of the MPIA, five German institutes are participating in the LBT and belong to the »LBT-Beteiligungsgesellschaft« (LBTB). Besides the MPIA, these are the Max Planck Institutes for Extraterrestrial Physics (MPE) in Garching and for Radioastronomy in Bonn (MPIfR) as well as the Astrophysical Institute in Potsdam and the Landessternwarte Heidelberg (LSW, part of the Center for Astronomy, Heidelberg). The German partners will obtain 25 percent of the observing time in return for their investment as well as the development and construction of instruments. The remaining time is shared by Italy (also 25 percent) and a number of institutions in the USA.

Fig. V.1.3: In the LBT control room, Italian astronomers are watching closely the first images taken by the LBT.

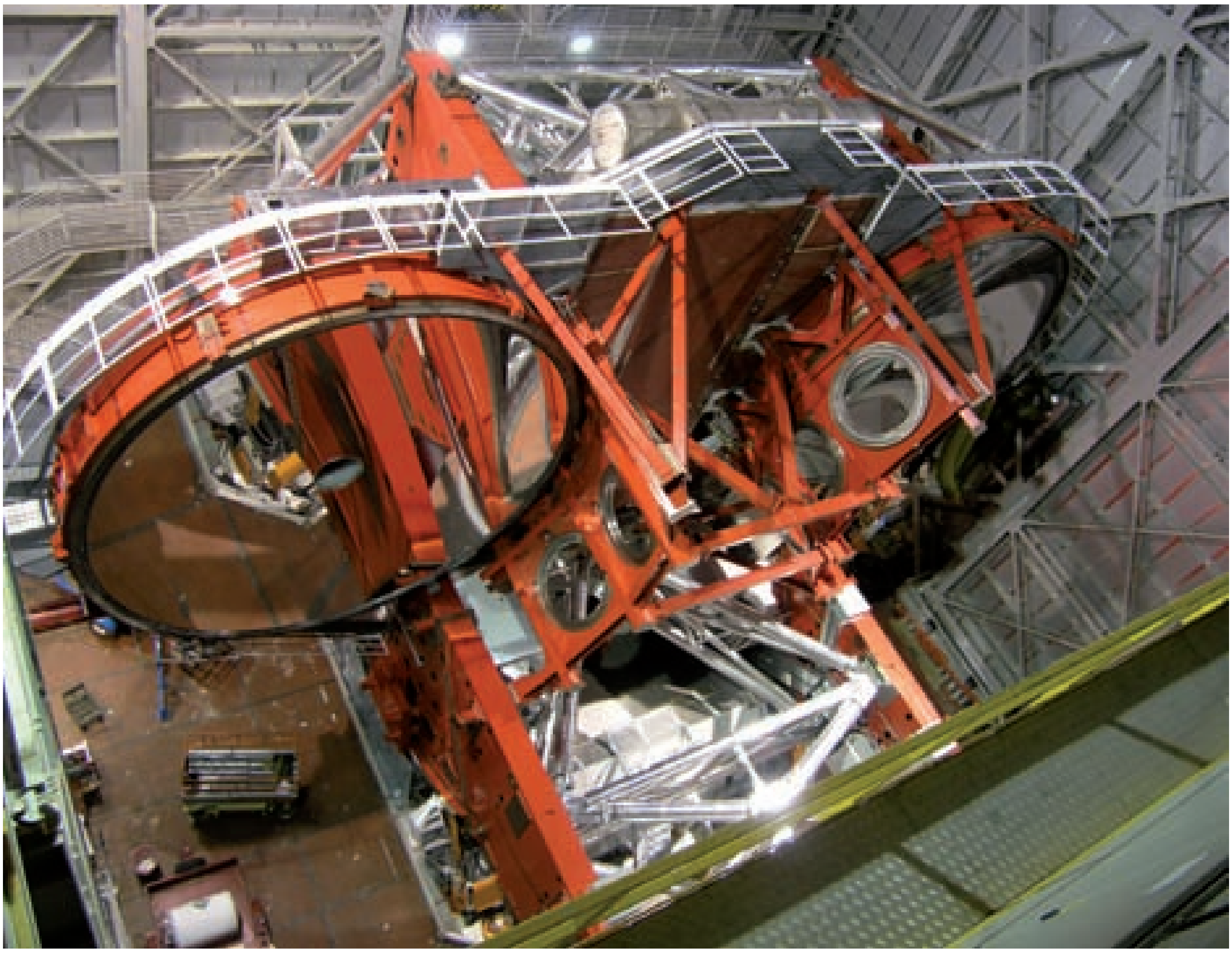
Scientists, technicians, and electronic engineers of the German LBTB consortium are building the instrument clusters Lucifer 1 and 2 (PI Institute is the LSW, see Section IV.5), which will deliver both images and spectra of celestial objects in the near-infrared range. These instruments are ideal for studying very distant and thus very faint galaxies. Pepsi, on the other hand, is a high-resolution echelle spectrograph that is excellently suited for studying the structure and dynamics of stellar surfaces, for example. The AIP is the PI Institute for Pepsi, as well as for the AGW unit (AGW stands for Acquisition, Guiding, and Wavefront Sensing), built within the LBTB, too. The components of this unit ensure the exact guiding of the telescope as well as the adaptive correction of the mirrors.

In order to lastly provide the full power of the LBT and its instruments, Linc-Nirvana is being built (see Section IV.4). This instrument, developed in collaboration with our Italian partners, represents the very heart of the LBT. It combines the light beams from both primary mirrors at a common focal plane and corrects the image perturbations caused by the Earth's atmosphere. This will make maximum demands on the optical, electronic, and mechanical components, as parts of Linc-Nirvana will have to be cooled down to –196 degrees Celsius for its operation in the near-infrared range. Scientists and engineers at the MPIA have acquired excellent competence in this field of cryo-technology – not least because of their participation in large scientific space observatories such as Iso.

Although not all LBT components are in place yet, the impressive first images prove that the extensive planning, development, and building operations are worthwhile and that the 120 million dollar project is well on the way to becoming the most powerful single telescope in the world.

(Thomas Henning, Klaus Jäger)

Fig. V.1.4: On January 18th, 2006, the second primary mirror (*left*) was installed at the LBT.



V.2 Open House at the MPIA

On September 25th, 2005, MPIA opened its doors to the public again for the first time in eight years. On a beautiful fall day more than 5000 visitors flocked to Institute grounds on the Königstuhl – also thanks to the support of local public transportation services and authorities – to learn more about the Universe and the scientific projects of MPIA. An instructive and entertaining program had been arranged for the youngest visitors, too.

»Thank heaven the weather cooperated!«. This and similar comments could be heard repeatedly from MPIA staff in the days after the event, after some areas of the Institute had temporarily been so swarmed by our guests, requiring some patience on their part now and then. In the sunny weather, however, the open grounds could be fully utilized, certainly making things much easier. A detailed information flyer informed the visitors of the locations and subject matters of a total of 35 stations that could be visited on the premises.

Outside the entrance area of MPIA, our guests were already confronted with two terms which would play an important role over and over again at many stations: LBT and space astronomy. Two circular areas marked in blue – each 8.4 m across – illustrated the actual size of the primary mirrors of the Large Binocular Telescope, and an almost 6 m tall model of an ARIANE 5 rocket represented one of the important vehicles for carrying satellite observatories into space.

In the experimental and assembly hall, in the cleanroom, and in the infrared space laboratory the visitors received detailed information on the MPIA's participation in past and future projects such as ISO, HERSCHEL, the James Webb Space Telescope, and the LBT. Here, remarkable exhibits like components of LINC-NIRVANA could be found as well as essential background information on the technical-scientific challenges.

Whether design and CAD, building of control electronics, or the operating principle of detectors or CCD measuring systems – the whole range of activities needed for the development and building of astronomical instruments and for the analysis of scientific data was presented. This also included the precision mechanics workshop, where computer-numerically-controlled (CNC) machines could be watched in action. The visitors were introduced to the particular challenges of ground-based and space infrared astronomy (including a »cryo-show«) or the principles of adaptive optics and interferometry in special demonstrations. One highlight was certainly a live transmission to the dome of the Calar Alto 3.5 m telescope. This made it possible to see a real large telescope at work. Furthermore, big models of the Calar Alto telescopes and the LBT illustrated the basic principles of modern observatories.

With the help of computer workstations, employees of the Institute explained how digital image processing is used for analyzing astronomical data. Here, the astronomers had to clarify the difference between scientific image processing and picture »improvement« with Photoshop on their computer at home, particularly for the younger visitors. The significance of supercomputers and their networking was explained in the computer center. At several other places, the importance of computers for present-day top research in theory (simulations) and observations (data analysis) was made clear.

Fig. V.2.1: The crowded main entrance of MPIA, decorated with a model of an ARIANE 5 rocket almost six meters tall.

Fig. V.2.2: Young and old on a quick tour of the MPIA precision engineering workshop.

Fig. V.2.3: Stefan Hanke explains the principles of interferometry to visitors of the LBT laboratory.

In various areas the visitors could obtain astronomical background information. For instance, the importance of multi-color surveys for analyzing the large-scale structure of the Universe was illustrated. Numerous attractive astronomical pictures displayed on the walls of the Institute continued to trigger conversations between visitors and MPIA staff. In addition to the presentation of actual projects of the MPIA in the fields of stellar and planet formation or galaxies and cosmology, basic astronomical knowledge was also imparted. Besides films and an all-day lecture series, the visitors had the chance to learn something about our immediate cosmic neighborhood via three planet trails. One of these trails was also part of the diverse children's program which playfully illustrated astronomical and physical terms both indoors and outdoors. In addition to simple physical experiments and a presentation of the starry sky with the help of planetarium software, the kids were able to build and launch water rockets or use amateur telescopes to make simple observations of the sun. Finally, the visitors were offered insight to the operating principle of a professional telescope at the 70 cm reflector located in the eastern dome of the Elsässer Laboratory.

Here, in the Elsässer Laboratory, there was also an opportunity to learn about the editing of the journal »Sterne und Weltraum«. Moreover, those whose thirst for knowledge was great could purchase astronomical books and journals or carry on conversations with MPIA employees about apprenticeships and practical trainings offered at the Institute, or find out how one becomes an astronomer.

Many visitors may have been surprised to learn that the MPIA not only trains physics students, but also offers apprenticeships in skilled trades and in the technical and administrative field. In an astro-quiz, the visitors could prove their astronomical knowledge and win attractive prizes. More than 400 visitors participated in the quiz.

However, our guests not only had the opportunity to satisfy their intellectual cravings; their physical needs were also cared for by means of lots of hot dogs, cakes and beverages.

A sneak preview took place before the actual open house. Two days beforehand, we presented some highlights to 30 invited guests from social and political circles on a special tour. Like the visitors of the main event, these guests were quite impressed. With such a successful outcome, everybody at the Institute agrees that – despite the huge amount of work required – it should not be another eight years before the next Open House is held again.

(Klaus Jäger)

Fig. V.2.4: For a special tour, prominent guests are greeted by Mathias Voss (left) and Klaus Jäger in front of the main entrance. At right: Eckart Würzner, responsible for environmental affairs within the council of Heidelberg.

V.3 Further Events and Activities

The Spanish Prince on Calar Alto

On September 28th, 1979, the Calar Alto Observatory, then already equipped with the 1.2 m and 2.2 m telescopes, was officially inaugurated by King Juan Carlos I of Spain. On the occasion of the 25th anniversary of the foundation of the German-Spanish Astronomical Center (DSAZ/CAHA) and also in recognition of a new equal partnership between the Spanish and German side, the observatory again had a royal visitor on June 29th, 2005. This time the son of the King of Spain, the Prince of Asturias, Felipe de Borbón, came to the 2168 m high peak in the Sierra de los Filabres.

During the ceremony in the dome of the 3.5 m telescope, Prince Felipe surprised not only the guests but also his staff, who had been intent on the strict observation of the protocol in the run-up, with an unexpected final speech. The Spanish Crown Prince welcomed the guests and the staff of the observatory and confirmed above all the Spanish royal dynasty's support of scientific research. In particular, the Prince expressed his special liking of astronomy. Obviously, this was not a mere polite phrase. On the contrary, the Prince was especially well-informed and enthusiastic with regard to astronomy.

The formal focus of the event was on the new contract between the Consejo Superior de Investigaciones Científicas (CSIC) and the Max Planck Society (MPG) concerning the further operation of the observatory. In the coming years, both institutions will jointly operate and use CAHA on a fifty-fifty basis, thereby creating one of the largest scientific cooperation projects between Germany and Spain.

External Retreats and Internal Symposium

On April 25th, about 25 senior staff members of the MPIA met at Hirschhorn Castle for a two-day external retreat.

An idyllic but somewhat sequestered location outside the MPIA was chosen to focus on the discussion of important long-term issues for the MPIA without being

Fig. V.3.1: The Prince of Asturias (*left*) during his visit on Calar Alto, welcomed by Hans Zacher, former President of the Max Planck Society.

distracted by everyday affairs. In a rigorous two-day program, matters of scientific projects and goals, teaching, instrumental developments, as well as organizational structures were explored. At first, different aspects of the work at the Institute were examined in a kind of status report. Goal of the intensive discussions was to then develop strategies for both the immediate and the long-term future and to initiate decisions. One final result of this productive and for all participants very helpful event was a detailed action-item list.

An obvious side-benefit of such a retreat is that the participants working in different fields are able to keep one another informed. The internal symposium, held on December 8th and 9th at the MPIA lecture hall had a similar goal, at least with respect to the informative character. PhD students, post-docs and staff members presented their scientific projects in roughly 30 talks. The program was literally a mixed one, as was the intention from the outset to avoid forming thematic blocks. So the whole range of the MPIA's main working fields – planet and star formation, galaxies and cosmology, instrumentation, theory and observations – was presented.

Incidentally, the term »internal« only referred to the lecturers. The symposium actually was open to visitors from all other Heidelberg astronomical institutes and had been announced accordingly. Thus several colleagues from neighboring institutes used the opportunity to participate in this event.

Furthermore, on May 30th to June 2nd, the first Planet and Star Formation Group Workshop took place in Buchenbach (Black Forest). The idea of the group workshop was to get to know each other scientifically and personally within the PSF department. Presentations were given by the participants on their own work or, e.g., on particular publications for group-wide discussions of scientific topics.

Board of Trustees Meeting

On September 15th, the annual meeting of the MPIA Board of Trustees took place in the Institute's multi-purpose room. Besides the members of the board, Hermann-Friedrich Wagner (chairman), Klaus Tschira, Ranga Yogeshwar, and Mathias Schenek (standing in for Wolfgang Fröhlich), we were also able to welcome Hardo Braun, Deputy Secretary General of the MPG, and Christoph Ettl, MPIA's institute liason at the MPG Central Administration.

One mission of the board is to support the MPIA in establishing relations and contacts to the general public and politics, and to sponsoring institutions. It acts as a consultant and may also contact the MPG leadership directly.

At the meeting, the board was provided with an overview of current research and instrumentation projects in several talks; ideas for future perspectives were also

Fig. V.3.2: The internal symposium was a successful event, which was also open to guests from the other astronomical institutes in Heidelberg.

presented. In addition, the MPIA presented several concepts aimed at increased public outreach of the Institute. Information on the budget situation was provided by the MPG.

After stimulating discussions on all these points, the chairman, Dr. Wagner, stated in his summary that the Board of Trustees will support the presented new concepts for the future of the MPIA. The board deemed the report on the budget situation as positive. It particularly welcomed the successful construction activities for the expansion of the MPIA. Moreover, the board recommended that the MPIA should get more deeply involved in the discussion about an Extremely Large Telescope (ELT). Furthermore, the Institute should examine the detailed logistic boundary conditions for its further commitment in connection with the establishment of an observatory in the Antarctic. The board will continue to support the efforts made with regard to public outreach – in particular, an extension of the concepts presented would be welcomed.

The Board of Trustees rated the ongoing project »Science into Schools!«, which initially had been intended for physics lessons in senior grades, as being very successful. It would like to see it be extended to younger target groups (junior-high level). With regard to the Virtual Astro Lab, the concept of a public area for a multi-media presentation of science, the board would be very pleased with an extension of the concept towards other fields of research.

News from the Theory Group within the Galaxies and Cosmology Department

The theory group within the galaxies and cosmology department led by Hans-Walter Rix deals with issues of the formation and evolution of galaxies and with the interpretation of their observable properties based on analytic and semi-analytic models, n-body simulations, and hydrodynamical simulations. Since the beginning of the year under report, this working group has been led by Rachel Somerville. She previously worked at the Space Telescope Science Institute in Baltimore and at the universities of Michigan, Cambridge (UK), and Jerusalem. In addition, Frank C. van den Bosch has been leading an independent junior research group supported by the MPG in close cooperation with R. Somerville since the fall of 2005. Before coming to the MPIA, F. van den Bosch had worked in Leiden, Washington, at the Max Planck Institute for Astrophysics in Garching, and at the ETH in Zurich.

One of the main subjects of the theory group is the comparison of theoretically predicted morphologies, structure parameters and merger rates of galaxies with actual observations from deep surveys such as GOODS and GEMS. This is an important link to the observations made by the galaxies and cosmology department because here the data of deep surveys are also being studied. The same applies for problems of dark matter or the co-evolution of black holes and galaxies.

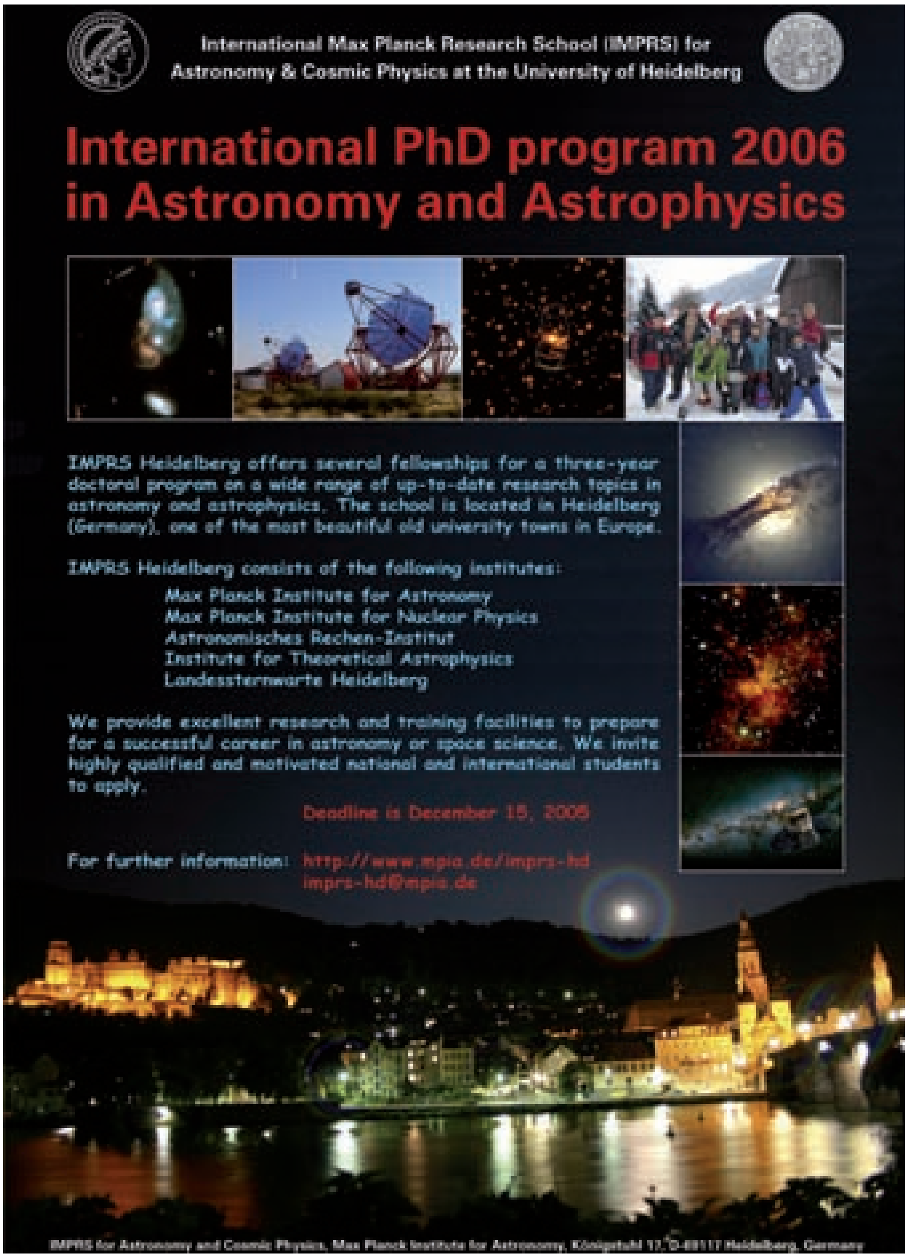
(Klaus Jäger)

V.4 International Max Planck Research School in Heidelberg

Starting in the year 2000, the Max Planck Society (MPG), together with universities throughout Germany has been setting up a network of graduate schools in order to attract and support particularly talented junior scientists from home and abroad. The »International Max Planck Research Schools« (IMPRS) offer students a structured scientific education combined with excellent research opportunities leading to a PhD after their first university degree. In 2005, the »IMPRS for Astronomy and Cosmic Physics at the University of Heidelberg« was started. Coordination of this IMPRS lies at the MPIA.

The education of the new generation of scientists is of fundamental importance to the future of science, research, and innovation in Germany. Therefore, the Max Planck Society, in collaboration with universities, is setting up a network of graduate schools in Germany. As of 2005, 37 such institutions existed across all disciplines and a total of about 1500 PhD students registered there in the winter term 2004/2005, 40 percent of them women.

Fig. V.4.1: This IMPRS poster has been dispatched to numerous institutes and universities.



The IMPRS for Astronomy and Cosmic Physics at the University of Heidelberg (IMPRS-HD for short) is a joint initiative of the MPIA, the MPI for Nuclear Physics, and the three institutes comprising the Center for Astronomy at the University of Heidelberg (Institute for Theoretical Astrophysics, Astronomisches Rechen-Institut, Landessternwarte). Scientific coordinator of IMPRS-HD is Christian Fendt of the MPIA, spokespersons are Hans-Walter Rix (MPIA) and Wolfgang Duschl (Institute for Theoretical Astrophysics).

In late 2004, the first cycle of applications to the IMPRS were advertised internationally, following a broad campaign to raise awareness of this new opportunity to prospective students in their home countries. For instance, all members of the American Astronomical Society were informed by e-mail, and, in addition, 350 copies of a special poster were sent to all astronomical institutes all over the world as well as to all institutes for physics in Germany. Moreover, a homepage was installed where all the information is available and applicants can register (www.mpia.de/imprs-hd).

Based on the professional qualification required for the particular field of research, scientists from the participating institutes select their PhD students among the applications received. More than 80 candidates had applied to the IMPRS-HD for the 2005/2006 term; of these, seventeen highly qualified students were admitted after an interview visit to Heidelberg. Once word about the Heidelberg IMPRS spreads, we expect considerably larger numbers of applicants. In 2005, already over one hundred applications for the 2006/2007 term were received.

One of the goals of the IMPRS is to offer international students the opportunity of becoming familiar with the German research scene. This will pave their way for a future job in German research institutes and at the same time develop a worldwide network of astronomers and astrophysicists trained in Germany. The hope is that in the long term, both effects will strengthen Germany as a scientific base.

Some of the sought-after positions are being filled with outstanding German students. In 2005, the proportion of foreign students was about 80 percent. A positive side-effect of the international recruitment of IMPRS PhD students is an increased proportion of women of almost 50 percent.

The IMPRS training program is intentionally more structured than the free-format PhD study in Germany. Students have to follow lectures and seminars of a defined curriculum and pass examinations. First reactions show that the IMPRS students actually appreciate this structured approach. For one, they receive broad, first-rate training through lectures held in English. Furthermore, the frequent contact among students fosters a strong social bond within the group, which makes itself apparent, e.g., in that they enjoy trips and private events together. In addition to the specialist teaching program, the IMPRS also offers students an education in soft skills, with external trainers instructing them in presentation techniques and application strategies, etc..

Fig. V.4.2: Hans-Walter Rix at the introductory lecture for the IMPRS students.

The overall goal is to give the IMPRS fellows a comprehensive education preparing them as internationally competitive post-doc candidates in astronomy and astrophysics and enabling them to get a PhD at one of the Heidelberg institutes. The financial support comprises a PhD fellowship as well as a workplace at the Institute. Additional funds for participation in summer schools and international conferences are available. The standard curriculum is scheduled to take five semesters; the PhD should be obtained within three years, on average. In the end, the doctoral degree awarded by the University of Heidelberg will be supplemented by an IMPRS certificate on the successful participation in the additional IMPRS program.

Heidelberg is a naturally-suited environment for the IMPRS, as the participating institutes cover almost every field of modern astrophysical research. The University of Heidelberg is in fact the largest university in Germany with respect to the annually awarded doctoral degrees in astronomy/astrophysics. More than 30 university lecturers and a further scientific staff of 200 are employed at the Heidelberg institutes. The MPIA particularly contributes to the following research topics: planet and star formation, extrasolar planets, sub-stellar objects, galaxy evolution and dynamics, active galactic nuclei, gravitational lenses, cosmology, structure formation, dark matter as well as the development of ground-based and extraterrestrial observing instruments.

Initially, the MPG limited each IMPRS program to six years. However, the Heidelberg astronomers hope for an extension since it has turned out to be such a successful approach to attracting excellent students.

(Christian Fendt)

V.5 Ringberg Workshop on »Distant Clusters of Galaxies«

Clusters of galaxies are the most massive bound entities known in the universe. They thus play a key role in our understanding of the formation of large-scale structures as well as the evolution of galaxies. By studying more and more distant objects, we look back in time, making studies of the most distant clusters of particular importance for understanding their evolution. Hermann-Josef Röser from the MPIA and Hans Böhringer from the MPI for Extraterrestrial Physics organized a workshop dedicated to »Distant Clusters of Galaxies« at Ringberg Castle, the workshop venue of the Max Planck Society. Close to 60 scientists from Europe and North America met from October 24th to 28th, 2005, at Ringberg to discuss their work on clusters of galaxies across all wavebands, both in theory and observations, in ten review papers and 35 contributed talks. Two summary speakers concluded the stimulating workshop.

The workshop started with a review by Simon White (MPI for Astrophysics, Garching), who placed the evolving clusters of galaxies in a cosmological context. Alan Dressler (Carnegie Observatories) then discussed the clusters as laboratories for studying the evolution of galaxies. Michael Balogh (Waterloo, Canada) and Andrea Biviano (Trieste) gave an overview of the influence of the environment on the evolution of galaxies and the structure of clusters as deduced from optical observations.

Optically visible galaxies are not the only constituents of galaxy clusters. The space between them is filled with a plasma ten to a hundred million degrees hot, radiating in X-rays. Investigations of this plasma and its evolution over time also provide important insight into the cosmological evolution of clusters. The topic of the structure of clusters was carried on by Monique Arnaud (Paris), when she discussed this on the basis of studies of hot plasma in X-rays. The plasma also makes its imprint on the cosmic background radiation via the Sunyaev-Seldovic effect. Therefore, this so-called SZ-effect is important for finding clusters through disturbances of the smooth microwave background. Surveys in the millimeter wavelength range of the SZ-effect will soon reveal large samples of distant clusters, as the effect is essentially independent of the distance to the cluster. Joe Mohr (Illinois) brought the participants up to date on the latest studies of cluster structure based on the SZ-effect. An overview of the physics of the hot intracluster medium by Stefano Borgani (Trieste) concluded the first part of the workshop.

Following tradition, participants took a break for an excursion on Wednesday afternoon, when most of the participants hiked, jogged or used the cable car up to the Wallberg, where an exquisite view of the Alps was enjoyed.

The second part of the workshop was devoted to searches for distant clusters of galaxies in various wavebands and to theoretical modeling. Howard Yee (Toronto) reviewed optical searches, the traditional wavelength range for finding clusters. However, with the advent of sensitive X-ray observatories, such searches have become equally important in this wavelength range and

Fig. V.5.1: The mild autumn weather also permitted discussions on the Ringberg Castle terrace.

Fig. V.5.2: Some of the participants climbed to the summit of the Wallberg mountain and enjoyed the fantastic panorama of the Alps.

were summarized by Chris Mullis (Michigan). He had just recently found the record-holder in redshift, a cluster at a redshift of 1.4. We see this cluster as it was when the Universe was only one third its present age! This record was not to remain long, however, as during the workshop Adam Stanford reported that a candidate had been found as counterpart of an X-ray source at redshift 1.45, and Peter Eisenhardt announced that another one had been found at redshift 1.41 in the SWIRE survey conducted with the SPITZER infrared space observatory. As already mentioned, surveys based on the Sunyaev-Zeldovic effect are gaining importance and Clem Pryke (Chicago) informed us of the current state-of-the-art and expectations here. The last session on Friday morning was devoted to theory and modeling, before Bianca Poggianti (Padova) and Hans Böhringer (MPE Garching) nicely summarized the talks and results we had heard during the week.

Hermann-Josef Röser and Hans Böhringer were joined in the scientific organizing committee by Frank Bertoldi (University of Bonn), Stefano Borgani (University of Trieste), Patrick Henry (University of Hawaii), Piero Rosati (European Southern Observatory), and Howard Yee (University of Toronto). Our web page (www.mpia.de/ringberg-clusters) provides a list of all participants, all the talks in electronic form as well as a picture gallery with impressions from the workshop and from a beautiful autumn week in the valley of Kreuth.

(Hermann-Josef Röser)

Fig. V.5.3: Group photo in front of Ringberg Castle in the brilliant sunshine.

V.6 The Wilhelm and Else Heraeus Physics School on »Extrasolar Planetary Systems«

From October 17th through October 21st, 2005, a Wilhelm and Else Heraeus Physics School on extrasolar planetary systems took place at the Physics Center in Bad Honnef. The event met with lively interest: a total of 64 participants arrived from 13 countries, almost all of them PhD students. The world-wide interest in this School not only demonstrates the interest in this exciting field of research, but also proves the increasing international significance of such research done in Germany. This session of the Heraeus Physics School was organized by Sebastian Wolf and Thomas Henning (both MPIA) as well as Willy Kley (University of Tübingen) and Joachim Wambsganss (Astronomisches Recheninstitut Heidelberg).

The formation and evolution of planetary systems and their connection with the origin of life are among the most fascinating questions of modern astrophysics. Since the discovery of the first extrasolar planets ten years ago, this field has grown at a whirlwind pace. At present, more than 200 extrasolar planet candidates are known, with the smallest one six times as massive as the Earth. These topics constitute one of the main research fields at the MPIA.

The newly discovered »worlds« differ dramatically in part from the planets of our solar system, presumably because the current detection strategies are biased. There are so-called »hot Jupiters«, Jovian planets that circle their central stars on very narrow orbits. Objects revolving on orbits with remarkably large eccentricities up to $e = 0.9$ have also been found. In our solar system, the orbit of Mercury is the most elongated one at $e = 0.2$. These findings show that existing theories on the formation of planetary systems that have been calibrated to our own solar system have to be revised. New results in this field suggest that interaction between the planets themselves as well as between the planets and the protoplanetary disk crucially affect the evolving structure of the planetary systems.

In addition to the detection of extrasolar planets, it is now also possible to obtain spatially highly resolved images of protoplanetary disks – the equivalent of the solar nebula. Modern astronomical observation methods such as adaptive optics and infrared and millimeter interferometry today enable us to investigate the physical and chemical structure of these disks and thus the place of origin of planetary systems.

The classical method of detection of extrasolar planets is the radial velocity technique. Meanwhile other methods have been used successfully, too, such as the transit method and the micro-gravitational-lens effect. However, one of the long-term objectives is to spectros-

Fig. V.6.1: A dignified conference venue: The historical building of the Bad Honnef Physics Center.

Fig. V.6.2: Group photo of some of the participants in front of the portal of the Physics Center.

copically study the atmospheres of these celestial bodies and possibly find evidence of life on Earth-like planets. This research goal is included in the instrumentation programs for the already working telescopes of the 10 m category and for the Extremely Large Telescope as well as for the Cornerstone Missions of the European Space Agency ESA.

These activities make it necessary to comprehensively prepare a new generation of scientists for this subject. This was precisely the intention of the event that took place at the Bad Honnef Physics Center. The 64 participants mainly came from Western and Eastern Europe; some students even traveled from Argentina and Australia to attend the school.

Fig. V.6.3: The Heraeus physics students during one of the lectures.

A total of 17 astrophysicists, geophysicists, experimental physicists, and mineralogists from German institutes reviewed the current state of knowledge and the expectations of future developments. Thomas Henning of the MPIA gave an introductory lecture about the still young history of extrasolar planet research and later explained the currently discussed scenario of planet formation. Hubert Klahr explained numerical methods for modeling planet formation, while Martin Küster discussed the chances of the radial velocity method for detecting invisible stellar companions. Finally, Sebastian Wolf provided an account of the results obtained up until now when observing and modeling protoplanetary disks. All talks covered theory and observations as well as the history and future. The interdisciplinary astrobiologists also had a chance to present their emerging field.

The participants in this Physics School particularly benefited from the opportunity to ask questions and start discussions, not only during the lectures, but to also have the speakers »at their disposal« all week long until late at night. An e-mail we received a few days after the Physics School ended summarizes the general mood and positive impressions experienced by the participants: »Many thanks for this very fruitful workshop! I've really enjoyed the contents and the discussions with the speakers. B.O. Demory (Observatoire de Geneve)«.

All lectures can be accessed on the internet at www.mpia.de/EXTRA2005

(Sebastian Wolf)

V.7 Two New Junior Research Groups at the Institute

During 2005 a third Emmy Noether Group started its work at MPIA under the leadership of Henrick Beuther; and Frank van den Bosch started an independent Junior Research Group of the Max Planck Society.

Henrik Beuther: Massive Star Formation

With its Emmy Noether Program, the German Research Association (DFG) is supporting young post-doctoral scientists, offering them the opportunity to establish their own junior research groups. After two such groups led by Sebastian Wolf (Protoplanetary Disks) and Coryn Bailer-Jones (Formation and Properties of Sub-stellar Objects) had commenced their work in 2004, a third Emmy Noether Group started at the MPIA in 2005 under the lead of Henrik Beuther.

Henrik Beuther studied physics at the University of Cologne and received his PhD from the Max Planck Institute for Radioastronomy in Bonn. Subsequently, he worked as a post-doc there for several years, as well as at the Harvard-Smithsonian Center for Astrophysics (Cambridge, USA). His research group at the MPIA will mainly study the early stages of the formation of massive stars. Many questions are still open here. For instance, it is not yet clear whether most massive stars form in accretion processes similar to low-mass stars, or whether other processes, such as mergers of protostars, are of major importance. Henrik Beuther and his group plan to tackle the issue of massive star formation from different directions and turn their attention to the following questions: What are the properties of massive accretion disks? What are the effects of the initial fragmentation of massive star-forming regions? What chemical processes occur in the dust and gas of the star-forming regions? And, what is the role of the outflow and infall of gas?

Fig. V.7.1: Henrik Beuther in front of the Königstuhl scenery.

Since massive stars form in stellar clusters and are usually at great distances, high spatial resolution is essential to resolving these questions. At the same time, these regions emit intensive millimeter and submillimeter radiation. Accordingly, Henrik Beuther wants to concentrate on interferometric observations in these wavebands. From late 2007 on, this will be possible with the first telescopes of the Atacama Large Millimeter Array (ALMA).

Henrik Beuther has already worked in this field with other interferometers, in particular with the Submillimeter-Array (SMA) on Mauna Kea, Hawaii, and the interferometer on Plateau de Bure in France. His group will continue to gain crucial experience using existing interferometers in order to later be able to better exploit the great capabilities of ALMA.

Beuther's group is growing rapidly: one PhD student from Argentina and one PhD student from the USA have already accepted offers and will come to the MPIA in summer 2006. They will deal mainly with two fields. The first involves a so-called legacy-proposal for the observation of massive accretion disks using the SMA. The other project focuses on an existing data set on the fragmentation of massive star-forming regions. Other projects are in preparation as well.

Frank van den Bosch: Theoretical Cosmology and Galaxy Evolution

In 2005, the cosmology group of the Institute was able to recruit an outstanding new colleague, Frank van den Bosch, who will head an independent research group dealing with galaxy evolution. The head of such a group is under no teaching obligations, and is guaranteed financial support for his or her research for at least five years.

These opportunities were decisive in convincing van den Bosch to apply for the position. At the same time, the MPIA is the ideal workplace for him: the Institute is participating in the Sloan Digital Sky Survey and other galaxy surveys, and it is equipped with large, up-to-date Beowulf-supercomputers. Moreover, the existence of other theory groups ensures a vibrant environment for intellectual interchange.

Van den Bosch has broad experience in his field. In 1997, he received his PhD from Leiden Observatory. Afterwards he went to the University of Washington as a Hubble Fellow. Stays at the MPI for Astrophysics (Garching) and the ETH (Zurich) followed before he came to the MPIA. Here he plans to focus on various aspects of cosmology.

A primary subject of his research is the structure and formation of disk galaxies. In these systems stars and gas circle around the center. The key to understanding these galaxies is therefore the question of how the angular momentum has developed and which factors affect it. Van den Bosch and his group will tackle these problems using a combination of analytical methods and numeric calculations. The observed relations between the sizes, luminosities and rotation velocities may be of crucial importance for this.

Another focus of his research is the connection between galaxies and dark matter halos. For this, van den Bosch has developed a new statistical method based on the properties of galaxy clustering. The resulting statistical description of the so-called galaxy-dark matter connection yields strong constraints on the theory of galaxy formation. The same technique can also be used to constrain cosmological parameters, such as the matter density of the universe. In the years to come, van den Bosch wants to improve these and similar methods and apply them to large redshift surveys, such as the 2dF Galaxy Redshift Survey and the Sloan Digital Sky Survey.

A third major research subject of van den Bosch is the formation and structure of dark matter halos, which he addresses using a combination of numerical simulations and semi-analytical techniques.

Fig. V.7.2: Frank van den Bosch at the MPIA.

V.8 Prizes for Young Scientists

Scientific awards have various purposes. They encourage the recipients in their work and give them confidence for future career prospects. At the same time, they often are an important means of support to enable students and post-docs from Germany and abroad to work at a certain institute. For the MPIA, the year 2005 has been quite successful in this respect. Sebastian Wolf was awarded the Heinz Maier-Leibnitz Prize, and Elena Masciadri the Marie Curie Excellence Grant, while the Ernst Patzer Prize for Supporting Junior Scientists at the MPIA went to Jorge Penarrubia, Marco Barden, and Anders Johansen.

Heinz Maier-Leibnitz Prize for Sebastian Wolf

Since 1977, the Heinz Maier-Leibnitz Prize has honored young scientists in recognition of their excellent work. It is the most prestigious price for young scientists in Germany. The award includes a prize money of 16000 euros and is intended to promote the prizewinners' further scientific career. The prize funds are provided by the Federal Ministry of Education and Research. In 2005, the presentation of the prizes took place on June 6th in Bonn.

The jury acknowledged Wolf's significant work on the study and modeling of protoplanetary disks in the field of planet and star formation. It placed particular emphasis on the fact that his work stands out because of its originality and the high level of the physical-mathematical treatment of the complex problem.

Sebastian Wolf studied physics at the University of Jena. After periods of research at several institutes such as the European Southern Observatory (Eso) and the California Institute of Technology in Pasadena, he came to the MPIA in 2002. Since 2004, he has been the head of an Emmy Noether Junior Scientists Group dealing with circumstellar dust disks evolving into planetary systems (see Annual Report 2004, p. 107).

Sebastian Wolf deals with the complex problem of planet formation. His working method is based on a combination of numerical simulations on the one hand and astronomical observations on the other. In order to better study the dust component of a protoplanetary disk, he developed a novel simulation program that allows the radiation transport within the dust disks around

Fig. V.8.1: Ernst-Ludwig Winnaker, President of the German Research Association (DFG) presents the Heinz Maier-Leibnitz Prize to Sebastian Wolf. (Photo: DFG)

Fig. V.8.2: Sebastian Wolf during his talk on protoplanetary disks. (Photo: DFG)

young stars to be traced in three spatial dimensions. These simulations enable predictions of observational quantities that reflect the growth of dust to planetesimals and later to planets, among other things. Such observational quantities can be spectra, images, polarization maps or interferometric data of circumstellar disks. These predictions can be verified by observing real stars.

One such prediction is, for instance, that young massive planets can be detected by the warm, dense dust in their immediate surroundings and by the gaps they leave along their orbits in a gaseous disk around the star. Observations of this kind will be made possible with the Atacama Large Millimeter Array (ALMA) that is scheduled to go into operation within the next few years in the Chilean Atacama Desert. Within these simulations, Wolf also investigated the questions as to how the appearance of protoplanetary disks can be affected by variously shaped dust grains, clumpy spatial distributions of the dust, and the sizes and chemical compositions of the dust particles.

Even now, observations of protoplanetary disks allow little insight into the first steps of planet formation. So with the aid of his simulations, Wolf was able to make a breakthrough by demonstrating that within a prominent protoplanetary disk – the one around the »Butterfly Star« – the growth of dust grains proceeds faster than in the circumstellar envelope of the same object. The dust grains in the circumstellar disk are already 100 to 1000 times bigger than those in the surrounding thin envelope, which obviously still harbors the original dust population. This result corroborates the theoretical predictions and is based on high-resolution images obtained in various wavebands with different telescopes, e.g., the HUBBLE Space Telescope and the Radio Observatory in Owens Valley, California.

It is customary at the presentation of the prizes that one of the prizewinners – in 2005 there were six of them – gives a scientific talk about his subject. It is considered a special honor for Sebastian Wolf to have been chosen for this task. His topic was: »Can we observe planet formation?« This, too, proves the attractiveness of astronomy on the general research scene.

Marie Curie Excellence Grant for Elena Masciadri

Elena Masciadri was hired at the MPIA at the time of the feasibility study of the PLANET FINDER, a sophisticated second generation instrument for the VLT. During her stay at the MPIA, she concentrated on two topics. She supported the PLANET FINDER project on the instrumental side. In particular, she carried out a study on the scintillation effects on this instrument, which was fundamental to quantify these effects, to optimize the conception of the PLANET FINDER, and to define the number of deformable mirrors needed to correct the wavefront perturbations induced by the atmospheric turbulence.

As her second area of work, she realized surveys for searches for extrasolar planets and Brown Dwarfs orbiting around nearby young stars, employing the direct imaging technique. To do so, she used high-contrast imaging techniques, taking advantage of the high-performance infrared camera NACO installed on one unit of the VLT, in particular the new state-of-the-art SDI/NACO. This latter instrument is based on the simultaneous differential imaging technique, with the double goal of reducing the speckle noise at sub-arcsecond separations and revealing methane-rich faint objects such as the majority of the young and massive planets potentially orbiting young (100–200 million years old) nearby stars. It is therefore a technique that may greatly improve our ability to detect faint objects with a contrast of 9 to 11 magnitudes in H at 0.5 seconds of arc separation from the central star. This corresponds to planets having masses on the order of 3 to 10 Jupiter masses and ages of 1 to 200 million years.

These studies permitted her to strongly constrain the planet formation models. Her interest was also directed towards the conception of alternative techniques for image processing, aiming at an automatic detection of planets in deep imaging such as the wavelet technique, and she investigated the possibilities of detecting outflows from very low-mass stars and brown dwarfs. This topic is particularly interesting because the detection of

Fig. V.8.3: Elena Masciadri at her office in Arcetri near Florence.

these outflows might throw light on the formation mechanisms of Brown Dwarfs.

The Marie Curie Excellence Grants are part of the Marie Curie Actions to Promote Excellence. The project is prepared in connection with an institute, in this case the Osservatorio Astrofisico di Arcetri, in Florence, Italy. The project is focused on a topic that Elena considers strategic for ground-based astronomy: the characterization of the optical turbulence.

The European funds will give her the opportunity to create an independent research team working on a European strategic and multidisciplinary topic at the boundary between astrophysics and physics of the atmosphere. The final goal of the project is to set up an automatic system for 3-D simulations and forecasts of the optical turbulence (OT) above astronomical sites. The estimate of the OT is essential for astronomers to forecast the spatial and temporal distribution of the OT above a telescope and to schedule scientific programs (so-called flexible scheduling) to be executed. The simulation of the OT can also play a crucial role in the selection of the astronomical sites and the optimization of the adaptive optics techniques.

The financial resources invested in ground-based astronomy are huge and only an efficient management of telescopes can make ground-based astronomy competitive with respect to space-based astronomy. The technique proposed in this project is presently the only one that can provide a solution to a precise need of astrophysics and can place Europe in a leading position in this research field. Besides this, the technique proposed will also provide new insight into the formation and development mechanisms of optical turbulence, unaccessible through other methods.

The long-term goal is to create a nucleus of people specialized in turbulence effects on wavefront propagation for astronomy applications, who will join other Italian groups working on high angular resolution techniques (AO, interferometry etc.) that are already internationally recognized. The intention is to strengthen the national tradition in this discipline and to lay the foundations for the realization of a European Center for High Angular Resolution Techniques.

Since part of the work will be focused on Mt. Graham, the LBT Consortium and thus also the MPIA have an interest in Elena Masciadri's work. Mt. Graham will be the first objective for the realization of the forecasting system. All projects related to the LBT, in particular those whose performance critically depends on turbulence (such as LINC/NIRVANA), might benefit from these studies. The goal of the forecast is quite ambitious, the road will be long and difficult, but Masciadri thinks that the final feedback can justify this effort. It is therefore interesting for everybody at »LBT's home« to try and stay informed on reciprocal progress of everyone's work in order to get the maximum output from this project.

Ernst Patzer Prize for Jorge Penarrubia, Marco Barden and Anders Johansen

The Ernst Patzer Prize for Supporting Junior Scientists is funded by the Scientific Ernst Patzer Foundation established by the widow of the philosopher and art lover, Ernst Patzer. The goal of the foundation is to sponsor and support science and research mainly in the field of astronomy.

The award goes to young scientists at the MPIA for the best publication in a refereed journal during their time as PhD students or post-docs at the MPIA. An evaluation board set up for this purpose – consisting of two MPIA scientists and one external scientist – examines the proposals submitted. Each of the three prizewinners was awarded 2000 euros.

Marco Barden was awarded the prize for an outstanding paper on the evolution of disk galaxies. In his comprehensive study, he analyzed images obtained with the HUBBLE Space Telescope within the GEMS project (Galaxy Evolution from Morphologies and SEDs). He combined these with data from the COMBO–17 galaxy survey carried out at the MPIA. By precisely determining the average object size of 5700 galaxies, he was able to establish the evolution of disk galaxies from redshift $z = 1$ (about seven billion years ago) to the present time. This corresponds to about half the age of the Universe.

Fig. V.8.4: The prizewinners of the Ernst Patzer Prize: Marco Barden, Anders Johansen, and Jorge Penarrubia (*from left to right*).

An important result of Barden's study is the fact that the surface brightness of galaxies changes continuously as a consequence of the aging of their stellar populations. In contrast, the stellar surface density remains almost constant over the same period of time. Since the stellar mass of galaxies increases with time because of the formation of new stars, it was concluded that disk galaxies grow from the inside to the out on the average.

Anders Johansen was awarded the prize for his computer simulations of turbulent processes in protoplanetary disks. According to current theories, dust particles during the first stage of the formation of a protoplanetary disk sink towards the central plane, accumulating there. This process is affected by a large number of physical processes that so far cannot be completely treated numerically. In his models, Johansen has been the first to study the effect of turbulences that can be triggered by the so-called magneto-rotational instability in detail. An important result was the fact that turbulences do not impede the formation of dust grains and planetesimals, as was often assumed, but can even stimulate it (see Chapter II.4 of this Annual Report).

Jorge Penarrubia was awarded the prize for his theoretical study of the Monoceros star stream. He based his research on data from the Sloan Digital Sky Survey in which a ring-like structure of stars stands out, covering about 100 degrees in the sky. It is a tidal stream of stars that was ripped off away from a dwarf galaxy during its merger with the Milky Way System. Penarrubia constructed a comprehensive model of this so-called Monoceros stream using all observational data available and was able to obtain information on the suspected association of globular clusters and other star groups with this tidal stream (see Annual Report 2004, p. 28).

V.9 Girls' Day – Girls Visiting the MPIA

On April 28th, the fifth annual Girls' Day was held all over Germany. This nationwide event is an opportunity for schoolgirls from grades 5 to 10 to catch a glimpse of job areas that are seldom considered as a potential career path by girls. On this day, mainly technical companies and departments as well as universities, research centers and similar facilities demonstrate their kind of work in numerous events. Sixty girls came to the Königstuhl, curious to see what they would find there, where they met very dedicated employees of the Institute who tried to answer their main question: »What do astronomers actually do?«

This year, Girls' Day broke a new nationwide participation record. A total of almost 7000 companies and organizations offering almost 130 000 positions had registered on the Homepage www.girls-day.de. At the MPIA, under the coordination of Eva Schinnerer, the girls were able to visit the workshops of the technical department and learn something about the work astronomers do.

At 16 stations, a total of 50 colleagues of the Institute did their best to convey the fascination of research and technology. Klaus Meisenheimer offered the girls some insight into the research on galaxies and showed them the intriguing sky images obtained by the GEMS project. With the help of a game, other colleagues imparted some knowledge to the young ladies about the nature of active galaxies and why astronomers are interested in these strange objects.

At the laboratory, one of the questions was, e.g., how a telescope functions in space, where temperatures are very low. The girls especially liked Jutta Stegmaier's explanations concerning low temperatures. Jutta is a PhD student in the team developing instruments for the future HERSCHEL Space Telescope. A real telescope could also be examined: Ernest Krmpotic and Stefan Birkmann explained the working principles of the 70 cm telescope.

The visit to the electronics laboratory turned out to be a spectacular action, too, since the girls were permitted to do their own soldering under the guidance and supervision of Frank Whrel. In the design department, they tried out the CAD software under the direction of Monika Ebert, which also turned out to be a magnet for the young ladies eager to learn. Another highlight was the afternoon break, when Werner Laun experimented with liquid nitrogen and conjured up homemade ice cream. Other exciting stations were the computer center, the CCD laboratory, the precision mechanics workshop, the experimental set-up for interferometry, and many more. The editorial staff of the journal »Sterne und Weltraum« was also involved in Girls' Day and let those interested take a look behind the scenes. Maybe one or the other future subscriber was among them!

Girls' Day is supported by numerous institutions, among them the Federal Ministry for Education and Research as well as the Federal Ministry for Family Affairs, Senior Citizens, Women and Youth. In 2006, the MPIA will again open its doors for curious, future women scientists.

(Eva Schinnerer)

Fig. V.9.1: Axel M. Quetz (*left*) and Ernest Krmpotic (*below*) answer the questions posed by the girls.

V.10 The Project »Science Into Schools!«
with our Journal »Sterne und Weltraum«

Since the beginning of 2005, the school project organized at the Institute has been running at full steam. Early in June, a kick-off meeting was held at the Academy of Advanced Teacher Training of the Land Baden Württemberg in Donaueschingen: 38 interested teachers temporarily played the role of pupils, testing the practicability of our offer.

The basic idea of this school project is as follows: We want to utilize the motivation and enthusiasm our readers derive from studying »Sterne und Weltraum« (SuW) for school teaching. Rather than making the journal more school-like in structure, we felt that we should preserve the journal's free and entertaining character and in addition offer didactic materials ready for use on selected topics treated in SuW to teachers and pupils. This will allow them to deal with our fascinating subjects in a suitable way for teaching. The materials are made available to everyone each month on our website.

We were able to arouse interest in this concept at the Academy of Advanced Teacher Training in Donaueschingen. Olaf Fischer, an experienced expert in physics and astronomy teaching methods, now works there full time developing the monthly didactic materials, thanks to the generous support of the Klaus Tschira Foundation. These are not just intended for the »hardcore« astronomy fans found at only a few schools, but are suitable for general physics lessons in higher grades. And the newly established school subject »Sciences and Technology« will also soon be taught at junior high level: this is possible thanks to the many aspects of astronomy.

Olaf Fischer tests his newly developed materials each month by teaching as a guest teacher at the astronomy teaching center at the Helmholtz-Gymnasium in Heidelberg. And once a quarter, an advanced teacher training is held at the academy in Donaueschingen.

The first event of this kind took place from June 9th to 11th: 38 invited teachers met with Olaf Fischer and the entire editorial staff of SuW in Donaueschingen. After a formal welcome by the local dignitaries and an interesting address by Dr. h.c. Klaus Tschira, who proved himself an astronomy aficionado and attached the greatest importance to a sound scientific education of our younger generation, the SuW topics of the first half-year of 2005 were discussed: the landing on Titan, analysis of HUBBLE pictures, supernovae and radioactive decay, planet formation and dust experiments on the International Space Station. The teachers were enthusiastic and confirmed that the materials offered can make physics lessons really fascinating. And in the evenings, the attractions of the summer night sky were observed from the academy garden.

Fig. V.10.1: Teachers testing the didactic materials of the SuW school project at the Academy in Donaueschingen. (Picture: Siegfried Zedler)

The Road Ahead for the School Project

There is certainly a lot more to be done for all those involved. The future of the project depends on a lively exchange of views with teachers and pupils in order to tailor our offer to the physics curricula for the senior grades as precisely as possible. And we should extend our offer to the grades of junior high: all teachers were thoroughly convinced that in most cases, the interest of young people in »hard« sciences stabilizes – or fades – as early as at the junior high level. Therefore, it is of great importance to make lessons interesting early on, for instance by using examples and applications from theoretical and observational astronomical research. This didactic transfer work cannot be accomplished by each teacher alone. Thanks to the internet, however, it need only be done once and in an optimum way, immediately available to all those interested.

An important aspect of the project is the strong motivating effect our journal has on the pupils. Teachers benefit from this motivation sparked by the didactic materials coordinated with the subject matters of the journal. The didactic materials can be found under: http://www.wissenschaft-schulen.de.

(Jakob Staude)

V.11 Hanno and Ruth Roelin Prize for Popular Science Writers

At the 2005 annual meeting of the Astronomical Society in Cologne, the newly founded prize was awarded for the first time. The first prizewinner is Thomas Bührke.

Mr. and Mrs. Roelin from Essen had tried for years to find an appropriate way to realize their idea of a foundation when they happened to meet Jakob Staude. Wanting to honor the work of astronomers and cosmologists and the results of their work, the Roelins were willing to show their appreciation by donating a considerable sum to award scientists or science journalists who have been particularly successful in imparting new findings in astronomy, space research, and cosmology to the general public. Presentations written with didactic-educational intentions and publications of every kind (print, radio, television, internet, etc.) were also to be admitted to the competition.

To maintain its honorable intention – so important for the whole astronomical community – it was necessary to win the support of several authorities to protect the foundation from the usual economic vagaries. The Max Planck Society was persuaded to provide free management of the endowment. The prize is awarded by the Max Planck Institute for Astronomy, Heidelberg. For this purpose, a jury is summoned together each year, made up in part of scientists and in part of science journalists. The presentation of the prize takes place at the annual meeting of the Astronomical Society, thus attracting the necessary attention of the general public. The expenses incurred by the work of the jury are covered by the publishing company Spektrum der Wissenschaft. In this way, a sum of 3000 euros could be allocated for the first presentation of the prize in 2005. The prize will be awarded every two years.

The first prizewinner

When the prize was advertised in early 2005, more than twenty applications came in. The jury agreed on awarding the first Hanno and Ruth Roelin Prize for Science Journalism to Thomas Bührke. After achieving a university degree in physics, a doctorate in astronomy, and doing active astronomical research for some years, Bührke (48) became editor of the »Physikalische Blätter«. Since 1990 he has been an editor of the journal »Physik in unserer Zeit«. The main emphasis of his work, though, is the presentation of astronomical subjects as a freelance journalist and author. Thomas Bührke had submitted his book »Albert Einstein« as well as his comprehensive presentations of current astronomical topics published in 2004/2005 in the »Süddeutsche Zeitung«, the »Welt«, the »Berliner Zeitung« and in »Spektrum der Wissenschaft« and »Bild der Wissenschaft« with his application for the Hanno and Ruth Roelin Prize.

»Albert Einstein« (dtv portrait, Munich 2004; 3rd edition) had already been reviewed in SuW with the following words: »The book is a vivid biography in which Bührke skillfully connects Einstein's life, his scientific thinking, and the turbulent circumstances of his time together. Einstein's discoveries are graphically described and put into the context of contemporary physics. The astronomical relations, particularly to cosmology, are accentuated in detail. $E = mc^2$ remains the only formula

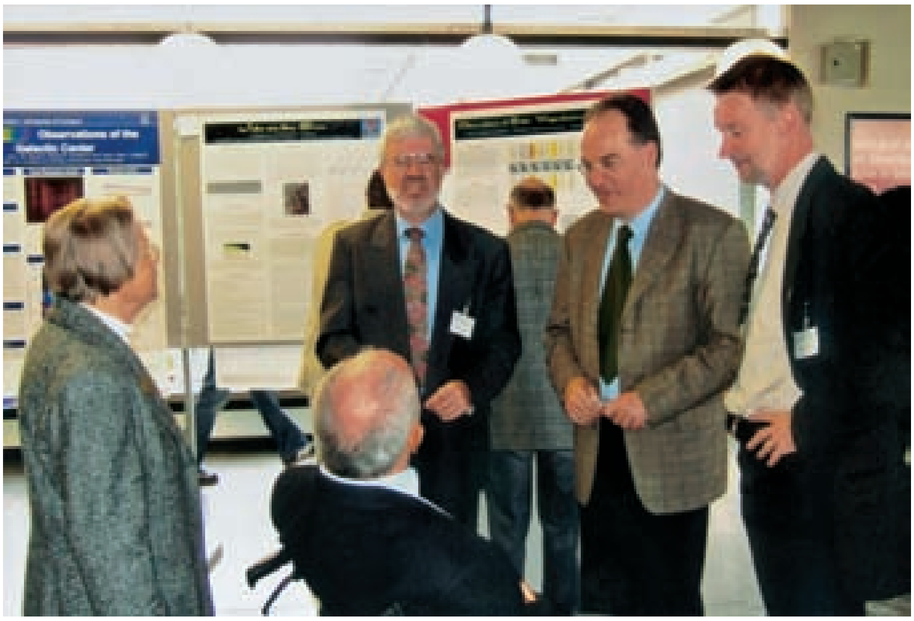


Abb. V.11.1: At the 2005 annual meeting of the Astronomical Society (AG) in Cologne. From left to right: the founders Mrs. Ruth and Mr. Hanno Roelin, Joachim Krautter (chairman of the AG), Jakob Staude, and Thomas Bührke, the first prizewinner. (Picture: Tobias Roelin)

within the entire book – and even this formula is explained descriptively!« (SuW 4/2004, p. 96). This opinion was unanimously shared by the jury.

Thomas Bührke convinced the jury with his coverage of a broad range of astronomical and space research subjects published in national newspapers and journals and his thorough explanation of complex relationships and their background. However, Bührke continuously bears the entertainment value of his texts in mind.

The jury arrived at the conclusion that the latest contributions submitted by Bührke as well as his longstanding work fully meet the foundation's expectations. The astronomical community should be grateful to both the founders and the prizewinner!

The second round of the Hanno and Ruth Roelin Prize for Science Journalism will begin in early 2007. The number and high-quality of the applications during the first round promise a successful future of the prize.

(Jakob Staude)

V.12 Farewell Colloquium in Honor of Immo Appenzeller

From June 30th to July 1st, the farewell colloquium in honor of Immo Appenzeller, Director of the Landessternwarte Heidelberg (LSW), was held in the lecture hall of the MPIA. It was no coincidence that the scientific part of this event organized by the LSW was presented at the MPIA: the long-standing close cooperation between the two astronomical institutes on the Königstuhl was largely attributed to the guest of honor himself. From 1998 to 2000, Appenzeller was the provisional Acting Director of the MPIA.

»From T Tauri Stars to the Edge of the Universe« was the apt title of the colloquium on the occasion of the forthcoming retirement of Immo Appenzeller, to which almost one hundred invited guests, among them the 22 speakers, had come to the Königstuhl. The title of the colloquim was »meaningful« indeed, because it illustrates the enormous range of scientific topics Appenzeller dealt with during his life as an astrophysicist. It was this great scientific variety that – in addition to numerous personal words – was the special focus of the talks.

At the beginning of his scientific career in Göttingen, Immo Appenzeller mainly worked on stars. Later he increasingly turned his attention to extragalactic issues, too. Besides the fact that he tackled »his« astronomical objects both theoretically and observationally, his intensive involvement in the building of instruments was also emphasized in the talks. A signature project was the construction of FORS 1 and FORS 2 (FORS = Focal Reducer and Spectrograph) for the ESO-VLT. This instrument, built under ESO contract by the LSW and the University Observatories of Göttingen and Munich, provided excellent images and spectra from the start and is generally called »the workhorse« of the VLT. Immo Appenzeller was PI of the project and was very involved in the scientific use of the instrument after its commissioning. One example of this work is the FORS Deep Field.

Fig. V.12.2: Immo Appenzeller with a special present alluding to his second great area of interest apart from stars: cacti.

Fig. V.12.1: A large number of guests attended the colloquium for Immo Appenzeller (in front to the left) in the lecture hall of the MPIA.

Currently, his name is also linked to the building of the LUCIFER 1 and 2 instruments (LBT NIR spectroscopic Utility with Camera and Integral Field Unit for Extragalactic Research) for the Large Binocular Telescope (LBT). Immo Appenzeller is co-PI of these instruments, which will provide spectra and images in the near-infrared range and are being built by the LSW in cooperation with four other institutes, one of them the MPIA. This project also demonstrates the close scientific cooperation between the two institutes on the Königstuhl.

From 1975 until 2005, Immo Appenzeller was in charge of the fate and fortune of the Landessternwarte; on September 30th he retired. The colloquium held in advance was not only an appropriate scientific setting. With the barbecue that took place on the grounds of the LSW in the evening of the first day, it also represented a social highlight which will certainly be fondly remembered by all participants.

(Klaus Jäger, Jochen Heidt)

V.13 Four Decades on the Königstuhl – an Interview with Christoph Leinert and Dietrich Lemke

On December 1st, a Festkolloquium entitled »Frontiers of Infrared Astronomy« took place in the lecture hall of the MPIA. The occasion was the impending retirement of Christoph Leinert and Dietrich Lemke, who both have been key scientists at the MPIA since its beginnings and who considerably contributed to the international reputation of the Institute. The retirement of Leinert and Lemke marks the departure of the last two astronomers who have been at the Institute since its establishment and have played an influential role in its development. In this interview, they talk about the pioneering spirit that initially prevailed on the Königstuhl, the rise of the Institute to an internationally-oriented scientific research facility, and their ideas about the future orientation of the MPIA.

You came to the Königstuhl in the early 1960s, and at first worked at the Landessternwarte. The MPIA did not yet exist at that time. What was the situation for astronomy students like yourselves at that time?

Leinert: When I came to Heidelberg in 1962 to study physics, I already was interested in moving on to astronomy. I became better acquainted with the Landessternwarte during a practical training, where the newly acquired Schmidt mirror had to be adjusted using a Hartmann stop. Then the Director, Hans Elsässer, offered me a diploma thesis: a newly developed polarimeter was to be tested thoroughly and then be used at the Bruce Telescope of the Landessternwarte in order to measure interstellar polarization. This was an interesting task at a modern instrument of the time, so that's how I started my career in observational astronomy. From a present-day perspective, the observing conditions were somewhat adventurous: the dome had to be opened and moved manually – I still hear the rumbling in my head – and the solid carbon dioxide, the coolant for the light-sensitive photomultiplier, first had to be put through a meat grinder. But the students were in good spirits and we were quite confident that we would be able to contribute interesting facts to astronomical research.

Lemke: My case was somewhat different. I had obtained a degree in nuclear physics and not really been interested in going into astronomy. But then I heard a lecture on astrophysics by Elsässer that was quite different than anything I had ever heard before. Other lecturers more or less centered on classical astronomy. Elsässer, however, included a lot of physics in his talk. This fascinated me, so in 1965 I applied as a PhD student with him. Accordingly, the subject of my PhD thesis was all physics. It was about using synchrotron radiation from DESY as a source for calibration of UV rocket experiments.

Leinert: We PhD students – there were about half a dozen of us – actually considered ourselves laboratory

Fig. V.13.1: Thomas Henning (*left*) expresses his thanks to Dietrich Lemke at the end of the colloquium.

Fig. V.13.2: Hans-Walter Rix (*left*) expresses his thanks to Christoph Leinert at the end of the colloquium.

physicists. We tried to precisely calibrate faint light sources or build baffle systems for reducing perturbing scattered light by many orders of magnitude. These were important pre-requisites for future observations. But only one of us, Thorsten Neckel, really carried out astronomical observations on a larger scale.

Lemke: I only stayed at the Institute because of its physical character. All experiments served as a start into astronomy with rockets, and later with balloons and satellites. Elsässer had jumped on this bandwagon quite early. He also offered me a part in building the Thisbe balloon telescope. I thought this was an extremely interesting task, although my knowledge of it was almost nil. We immediately began to visit institutes abroad which had carried out first balloon flights. And two years later, our own instrument was flying …

Why was Elsässer so farsighted in promoting extraterrestrial astronomy so early on?

Lemke: As far as extraterrestrial research is concerned, particularly in the infrared, Elsässer was very farsighted. This was of great significance, as Steve Beckwith later emphasized in particular. But another important factor was that funds were available then in Germany for space research. Part of the building of the Institute was financed with such funds.

Did Thisbe *work right from the beginning?*

Lemke: No, but we were completely entering new technical territory. Never before had we built a telescope floating in the stratosphere and working at 70 degrees Celsius below zero and a hundredth of the normal atmospheric pressure. During the first flight, started from a site in Emsland, not much really worked. Many moving parts virtually failed, only the electronics worked. We then had to go through a long learning process, testing many components in vacuum cryo-chambers. Today, this is called quality assurance. And, of course, it was great fun to go to Texas with the small team of students and technicians to start balloons. At that time it was possible to do everything on our own. With present-day satellite experiments, researchers are generally highly specialized and only a cog in the machine. The fascination today is a different one: You work in international teams on worldwide unique projects with exciting scientific goals.

By the way, Thisbe was still operated using punched tapes and the data were saved on punchcards. We were always running around carrying big cardboard boxes with the IBM punchcards stacked in them. Calculations were partly made using mechanical calculators operated with a crank. The receivers were built with electronic tubes, holes were drilled into the chassis and so on. Today this would be unthinkable. Then came the advent of semiconductor electronics. On Thisbe, we flew the first integrated circuits, a real novelty then.

Over the decades we became contemporary witnesses of a technological revolution. New materials, electronic computers, fast-control engineering, and, above all, cryogenic engineering were developed. And I was very impressed by the parallel opening of more and more spectral regions with the help of space telescopes. We were lucky that this »golden age of astronomy«mostly overlapped with our professional life.

Were you interested in the task of building Thisbe *only for physical and technical reasons, or for astronomical reasons as well?*

Fig. V.13.3: Christoph Leinert and Dietrich Lemke at the end of the festive colloquium.

Lemke: I was just as interested in the astronomical problems. Elsässer had worked on zodiacal light and now wanted to observe it in the infrared and mid-UV range as well. The long-term objective was the separation of the zodiacal light from other components of the night sky brightness, and THIBSE was to contribute to this. It was absolutely fascinating for me to observe the glowing gaseous nebulae, such as the Orion Nebula, with ground-based telescopes in the infrared range and to detect embedded point sources in addition to the huge extensive emission. At that time, the observation of star formation in gas and dust clouds actually started. Today this is one of the main research fields at the MPIA.

All this still took place at the Landessternwarte. How do you remember the establishment of the MPIA?

Lemke: Elsässer had hired me on February 1st, 1969, together with seven more colleagues, including Thorsten Neckel, Joachim Hermann, Josef Solf, Elsässer's secretary Traudl Filsinger as well as Bodo Schwarze, Wolfgang Hormuth, and Franz Pihale from the workshops. At that time, the Institute consisted of nine persons. In the beginning, some of the MPIA staff worked in a hut on the grounds of the Landessternwarte, and in 1975 we finally moved into the new building.

The development of HELIOS ran parallel to this.

Leinert: The German participation in this space probe was the result of a meeting between the German Chancellor Ludwig Erhard and the U.S. President Lyndon B. Johnson in 1965. The question as to which kind of instruments should be contributed by Germany was entrusted to Ludwig Biermann, the most renowned German astronomer at the time. Naturally he suggested studying the solar winds he himself had discovered, but also interplanetary dust. He regarded Hans Elsässer as the specialist in this field, who then received the zodiacal-light photometer project (first at the Landessternwarte, later at the MPIA).

It was Germany's first participation in an interplanetary space probe, and technologically, at least one double step forward – therefore meaning new territory for all of us. It was a young project pursued in many areas by professional novices with great enthusiasm. I was made P.I. (Principal Investigator) for the photometer, although I didn't even have my PhD then. It was a project worth millions – something like that would be unthinkable today. But it was another time then – in many respects. For instance, it was not so important to publish anything – only if the work on the project was proceeding well. Five years after I recieved my PhD, I still had not published a paper in a refereed journal. Can you imagine that? Technically, our instrument was state-of-the-art and very successful. We used carbon fiber material for the first time in space astronomy then.

What is your present-day view of the decisions Elsässer made at that time?

Leinert: With the participation in HELIOS, Elsässer received a great deal of funding and was able to attract PhD students to the Institute. This certainly was important for the development of the MPIA. But at the time, he very swiftly rejected participation in successor projects without consulting us, although ULYSSES – a space probe flying above the poles of the sun – would have been an interesting opportunity. In his opinion, the scientific problem had essentially been solved with HELIOS, or at least was no longer a suitable main field of research for the Institute.

Fig. V.13.4: Hans-Walter Rix between the two professors emeriti, who are each just announcing »first light« for a »Small Binocular Telescope« presented to them by the Institute.

Was this behavior typical of Elsässer's style of leadership?

Lemke: He made many decisions on his own. Each application for travel expenses and each purchase was personally signed by him. The individual working teams had little administrative freedom of choice. What I always missed was a wide opening of the Institute for guests from abroad. In the beginning, the MPIA had very little international recognition. Incidentally, the same was true for Calar Alto. The observatory was set up by us and operated almost single-handedly: a fascinating feat, but in my opinion, too few international colleagues were coming there.

Today the MPIA most certainly has an international reputation. What initiated this change in your opinion?

Leinert: Despite this criticism, I see the completion of the Calar Alto Observatory as the beginning of the new era. It earned us respect in astronomy. I look back at the discovery of jets from young stars by Mundt and Fried, the successful introduction of what is grandly called spectro-astrometry today by Solf, and more of the same. A next important step was the appointment of Guido Münch as second Director. He was an astronomer with an international reputation at the MPIA who directed the attention of the international community to the Institute. Prerequisite for this appointment, however, had been Calar Alto.

Lemke: Guido Münch undoubtedly contributed significantly to the reputation of the Institute. In the USA, you occasionally were asked if you came from Guido's institute … Nonetheless, I still think Calar Alto is not sufficiently known internationally, whereas the telescopes of Eso are common talk. Given the increasing Europeanization, I have my doubts whether it was and is a good idea to operate a national observatory of our own. This »service« ties up a lot of energy and means of the Institute. With the increased participation of Spain, our directors initiated a welcome new orientation here.

And then the next step was the appointment of Steven Beckwith.

Leinert: Yes, Beckwith changed everything completely, and with him the Institute opened up more. He really forced us to act more internationally!

Lemke: Beckwith was a real stroke of luck for the MPIA. His arrival marked the transition from a style of leadership by individual persons, as was typical until the 1960s and 1970s, to a collegial leadership and the assignment of responsibility to the working teams. We already had gotten to know this style of working, that it is also strongly competitive, during our time as postdocs in the USA. This marked a time when many guests from abroad came to the MPIA. Beckwith established a scientific advisory committee. All issues were discussed quite openly and swiftly decided on. Responsibility for budgets, for instance, was given to the team leaders. With Steve, a new, democratic era began. Today, this style is being continued rigorously by both directors.

Leinert: Beckwith was also very interested in solving technical problems swiftly. Whenever it appeared that we were not making enough progress in our own workshops, he didn't hesitate to place the orders outside. During Elsässer's time this never would have happened.

Fig. V.13.5: During the year 1972 Dietrich Lemke worked as a Research Associate at the Lunar and Planetary Laboratory of the University of Arizona in Tucson. Using the helium-cooled bolometer invented there by Frank J. Low at the 28 inch telescope on the Catalina Mountains, he could perform important measurements of HII regions at wavelenghts around 20 micron, which is very difficult to do from the ground. At that time, infrared astronomy was just in its infancy, and the technical equipment of the observatory, very simple by today's standards, was the most efficient world-wide. During each observing night he had to work 12 hours in the open air.

Was the transition painless?

Leinert: No. I still remember Beckwith saying in his inaugural address that Calar Alto was no longer competitive considering the large telescopes at Eso and elsewhere. Of course, that was a heavy blow to all of us.

Lemke: But it was not altogether wrong. After the commendable establishment of Calar Alto, Elsässer mainly concentrated on his observatory. But there were no plans for extension and internationalization. In the 1980s, he was not an advocate of a German large telescope, although the Ministry apparently was willing to support this project.

Leinert: Yes, at that time the further development of Calar Alto also stagnated. On the other hand, we started building major instruments for Eso, such as Conica, back in Elsässer's day. That must have been around 1989 or so. And then I heard about an infrared-interferometer to be built for the VLT. I was very interested in that, because I believed in the future of this technique and hoped to be able to contribute to it based on my experience gained with the speckle-method. Elsässer was quite open to this opportunity. Steve Beckwith then strongly supported and promoted this Midi project.

Which direction do you think the Institute should be headed?

Lemke: At present, the Institute is on an excellent road; we are growing into a very large international institute. I am a staunch supporter of participation in Esa and Eso projects. These two organizations are a real blessing for science and really powerful instruments in Europe. Projects are carried out there with high reliability and transparency. The services for professionally operationing large telescopes on the ground and in space are free for astronomers of the member countries. And Germany is an important contributor to both organizations. We are building instruments for these observatories and receiving guaranteed time in return. Now and then our Institute, with its excellent technical departments, can and should take over the leadership of such an instrument consortium. It is a different case with corresponding facilities in the USA, where large projects that have been supported for years are suddenly at disposal because political interests have shifted. One example that concerned us was the infrared telescope Girl; another current example is the airplane-based infrared telescope Sofia. After investing far more than one hundred million dollars in this project, it now may be stopped because all of a sudden there is allegedly no money left for the running operation. But it was clear from the beginning that there would be high operating costs.

Leinert: Given the current general situation, I see things similarly. But during the 1970s and 1980s, it was a great advantage for us to have privileged access to the large telescopes on Calar Alto. There we could test and improve our ideas and instruments, and many PhD students came to our Institute because of these opportunities. Even a successful astronomer like Reinhard Genzel told me then that he envied us for these opportunities. Today the situation is quite different. Now it is more important to participate in the development of instruments for the major observatories, ground-based as well as space-based.

What do you think of the chances with the LBT, the James Webb Space Telescope, a possible observatory in the Antarctic, and an Extremely Large Telescope?

Lemke: With the LBT, we may encounter problems like those we had with Calar Alto: the high annual running costs could be a problem one day since they have to be met jointly by various institutes at home and abroad. This is why I am, like I said before, a staunch supporter

Fig. V.13.5: Christoph Leinert among his colleagues in the control centre of the DFVLR (today named DLR) in Oberpfaffenhofen shortly after the start of Helios B in January 1976. (Courtesy: Norbert Salm)

of international participations with strong partners, as was the case of ISO with the ESA. And it will probably be similar with MIRI and NIRSPEC on the James Webb Telescope of ESA/NASA.

One should absolutely continue to pursue the idea of an observatory in Antarctica, but there are lots of unsolved problems. How, for instance, can instruments be set up about 30 meters above an ice shield steadily and for a long period of time? What are the influences of the aurora and how good is the seeing? It is certainly an interesting location – but do we really have to join in during the exploratory phase?

Leinert: The ELT will be realized in all probability about 15 to 20 years from now. The Americans are seriously working on a national 30 m telescope, and the Europeans are rightly pursuing the development of a telescope of similar size. The contribution of our Institute to such a huge project can only be a small one, though. However, a collaboration in the definition phase, such as that currently taking place for the infrared instrument TOWL, may pay off later when an influential participation in the construction or better opportunities in the use of such a telescope are involved. These are difficult decisions, and I wish our directors the right intuition for making them. At any rate, the example of the SDSS sky survey has shown that even a small contribution to a large project can produce very satisfactory results for our Institute. Taking the long-term view, it is a question of whether larger and larger telescopes are the right and only road to the future of optical astronomy. Maybe one should, like radioastronomers, bet on interferometric arrays, for instance by linking a dozen 10 m telescopes distributed over an area of one kilometer.

Former director in the Federal Ministry of Education and Research, Hermann-Friedrich Wagner, recommended in an interview (see following section) that a third director be hired for the MPIA. What is your opinion?

Lemke: I would also approve of that. Other Max Planck Institutes of similar size indeed have three or four directors. For us, it would be important to have a third person acting as a connecting link between the fields of work of Henning (star and planet formation) and Rix (galaxies and cosmology). That could be a connecting scientific subject or state-of-the-art technology in astrophysical instrumentation, such as interferometry, infrared, wide-field imaging, or adaptive optics as well.

Mr. Leinert, Mr. Lemke we thank you for this interview.

Leinert, Lemke: We don't want to conclude this interview, though, without expressing our pleasure at still having an office (now common) available in the Institute, even after our retirement. Here we can continue our work that is not yet completed and give our successors our advice and support – if we are asked!

(The questions were asked by Thomas Bührke and Jakob Staude)

V.14 Where is the MPIA Standing in our Research Scene?

An interview with Hermann-Friedrich Wagner, former Director in the Federal Ministry of Education and Research and Chair of the Board of Trustees at the MPIA.

Hermann-Friedrich Wagner has been involved with astronomy for at least half a century. At the age of 12 he built his first telescope. In 1960, he began to study physics and astronomy at the University of Tübingen, attending Heinrich Siedentopf's lectures there. There he also met Hans Elsässer, the later founding director of the MPIA, who in 1959 had habilitated with Siedentopf. But then Mr. Wagner switched over to the booming field of nuclear physics where he earned his PhD in 1969 in Bonn. From 1970 to 1972 he held a chair in the faculty of physics at the University of Kabul. After that he first worked for the Federal Ministry of Economic Cooperation and Development and then in the Federal Ministry of Education and Research. There he worked for large research centers and was engaged in energy research for a long time. From 1998 until 2005 he then was responsible for the allocation of funds for basic scientific research. In this interview, Mr. Wagner comments on the position of the MPIA in the national and international environment and gives his assessment of the future prospects of astronomical research on the one hand and the chances of astronomers on the job market in a high-tech country like Germany on the other.

Since when do you know the Königstuhl?
HFW: I first came to the Königstuhl in 1962 when Siedentopf invited us students there. There was no talk of the MPIA and its large telescopes then (the foundation of the Institute was not decided upon until 1967), but Hans Elsässer had just been appointed director of the Landessternwarte.

You then decided against a PhD in astronomy. Why?
HFW: One single argument had been the decisive factor then: I considered the career prospects of astronomers to be very poor, and I therefore joined the nuclear physicists, although I felt very much tempted to do a PhD with Professor Priester in Bonn. The largest telescope in the Federal Republic of Germany then was the 1-m reflector in Hamburg-Bergedorf (built in 1910!), and only very few people were dreaming of space astronomy. I even remember Siedentopf proving down to the last detail why it never would be possible to build space telescopes. He had been firmly convinced that it was impossible to receive the signals with sufficient clarity. »Forget signal reception from Mars«, he told us. Today it is obvious how much Siedentopf was mistaken in this respect.

And how do you see your decision from a present-day point of view?
HFW: I had no idea then of the meteoric development awaiting astronomy in our country. Those who are still thinking the way I did then are strongly mistaken. Young astrophysicists generally get an excellent education in the high-tech and information technology area, that is, exactly in those fields that are very much in demand today. At that time I thought astronomy was just for fun. Current astrophysics is for fun and has excellent career prospects – that is its big advantage. Solid state physicists, I think, are fixated on too narrow a field, so maybe they will be able to do solid state physics later with Siemens. Astrophysicists, however, have a broad education and can do all sorts of things.

Where would you place present-day astrophysics in the sequence of other physical research areas?
HFW: For me, astrophysics is the most interesting field of all. After all, which field of research is providing more excitement then?

Do you also support the building of new large telescopes?
HFW: Absolutely. I always considered telescopes to be »discovery machines«. If you have a telescope more powerful than its predecessors you will always find something new with it. You never can be sure what it will be, but you will always come across something new. That is the fascinating thing for me. In comparison, a large-scale particle accelerator like the LHC of CERN is a dedicated facility used to search for something specific, as if you were looking for the sea route to India. This is why I supported the LBT from the start, or now the new X-ray laser X-FEL at DESY.

A large number of young people are being educated at observatories like that.
HFW: Exactly. Only people who have a certain love of adventure and are really good will go there. And they are getting an excellent training – exactly what the German industry needs.

So, more money for large observatories like the LBT in the future?
HFW: Absolutely. The tough competition found at such an institution ensures that only the very best students get

there. Not all of them will remain in research, but the others will have no problem finding a job – I am sure of that. I see such institutions as magnets for the future elite of researchers in Germany, to put it dramatically. This has to be the main reason for the state authorities to support these projects.

Is this a widely held opinion among your former colleagues at the Ministry?
HFW: Yes, I think so. And I always did emphasize that.

And how do politicians see the support of applied research compared to basic research in principle?
HFW: We have pumped billions of Marks and Euros into various areas of applied research, into energy research, for example, or into information technology. The outcome had been rather disappointing in my experience, considering the amount of taxpayer money involved and the actual industrial results. With ambitious instruments for basic research, however, we always were very successful in supporting the future generation of good high-tech and IT people, and those are needed in our country. This was one of the reasons Mrs. Bulmahn (then Federal Minister of Education and Research) farsightedly had approved, for example, the two large-scale projects FAIR (the new accelerator at the GSI in Darmstadt) and X-FEL. By the way, the head of a project is very important, too. In the past, when I realized that the applicant for a project absolutely wanted the instrument and turned out to have good leadership qualities he was well placed right away. To achieve something you have to really want it. This is an important criterion to get a grant. Half-hearted maneuvering will never lead to success. Funds are very often granted to heads rather than to projects.

Where do you locate the MPIA in the national and international research scene?
HFW: The MPIA exemplarily combines excellent science with ambitious technological development, which is speeding up the field. Moreover, the Institute has the biggest German share in what will become the most powerful telescope in the world, the LBT. This puts the MPIA in a very strong position. At the same time the Institute is equipped with excellent workshops. And I can say from my own experience that the MPIA and its excellent scientific work have earned a very good reputation. But according to my experience with research facilities, you are understaffed in order to use your potential to your full advantage.

Almost every institute is asking for more staff. What do you think the MPIA would need above all?
HFW: For its long-term strategic invigoration the Institute above all would need a third director. It would be a pity if the two present directors, who are fully involved in research, would be worn down by management responsibilities. And then I would expressively plead for a female director, equal qualifications provided.

Why a woman?
HFW: For one thing, at least 50 percent of humankind consists of women, whose potential is invaluable for the sciences and who therefore should have much better access to research, also in leading positions. For another thing, women have a different, complementary way of thinking and a different style of leadership compared to men so that a symbiosis in the management of the MPIA would be of great advantage to the Institute. In Germany, there are far too few women in leading positions. So the MPIA could also lead the way in this field!

Where do you see specific chances for the MPIA?
HFW: Based on its experience gained in both fields, the MPIA has a good chance to position itself in the discussion on earthbound vs. space-based astronomy. I am a staunch supporter of earthbound observatories because I think they are cheaper and more versatile. This concerns the huge potential of the LBT and should also be considered in the case of the ELT (the Extremely Large Telescope planned by ESO) and other next-generation telescopes. There is no doubt that with its large know-how, for instance in the fields of adaptive optics and interferometry, the MPIA can play a major role in the telescopes of the 30- to 100-m class. The decisive role of the MPIA in the instrumentation of the flagship mission JWST also demonstrates how much the know-how gained at the Institute is appreciated internationally. However, I don't want to create the impression that I am

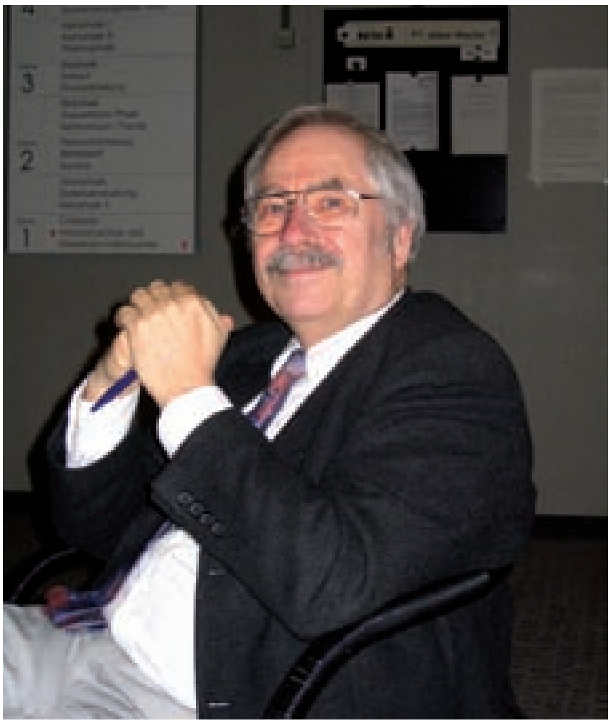


Abb. V.14.1: Hermann-Friedrich Wagner, Chair of the Board of Trustees at MPIA.

against space astronomy. But I expect the competition between the two kinds of observation to get increasingly tougher in the future and thus the price-performance ratio of investment and operation to play a very important role. So in view of the technical developments I think that earthbound astronomy has advantages.

Are there also any risks?
HFW: Of course there is always a certain risk that the administration of the Max Planck Society (MPG) might not realize clearly the educational and discovery potential of astrophysical research. So there is a danger that two or several of the astrophysically oriented MPIs will be combined one day. I would consider that a big mistake because the other MPIs in Bonn, Garching, and Katlenburg-Lindau are also excellent and complement one another perfectly. Fortunately, the General Administration of the MPG is represented in the Board of Trustees by very high-ranking representatives so that such problems can be discussed there without reservation. I also would be very pleased if the boards of trustees of these institutes would coordinate more closely with one another.

In the long term, do you think the survival of the MPIA to be endangered?
HFW: Definitely not. The Institute has a great potential which it has to use to its full advantage. The MPIs also live on their ability to undergo continuous change. Stagnation means scientific death. But I see an incredible dynamic force being present at the MPIA. And – as I said before – a third, hopefully female director could give this dynamic force yet another boost.

You are Chair of the Global Science Forum of the OECD in Paris, which among other things is striving for a coordination and cooperation in space- and earthbound astronomy. Can you briefly describe these problems?
HFW: Space telescopes undoubtedly are justified in certain fields. But the activities in space and on the ground have to be better coordinated. I don't believe that ESO and ESA can continue to coexist without making arrangements with one another. But this is only my personal opinion. »Space astronomers« apparently are not very much interested in a coordination, as ESA and NASA did not participate in the Astro-Workshops 2003/2004 of the Global Science Forum where a kind of roadmap over the next 20 years for the large-scale instruments for astronomy was worked out. A similar activity in high-energy physics, in contrast, greatly influenced in 2004 the start of the worldwide work on the Linear Collider.

A group of German astrophysicists under the leadership of Günther Hasinger recently wrote an »urgent request« to the Ministry. The reason for this letter was the decrease of national funds for extraterrestrial research. What do you think about this?
HFW: I fully agree with Mr. Hasinger. Germany is the largest contributor to ESA and thus financing a considerable part of the European projects. At the same time, however, our researchers don't have the national means to participate in these projects with instruments, for ex-

Abb. V.14.2: Having a conversation: Jakob Staude (*left*) and Hermann-Friedrich Wagner.

ample, or to hire scientists for analyzing the data obtained. So Germany is paying for the seed corn but cannot participate enough in bringing in the harvest.

So what has been neglected then?
HFW: You cannot speak of negligence here. Public funds for research are limited; that's just the way it is. The situation is similar in other countries although in Germany we benefit from the fact that science and research are ranking high on the political scale of values. But politicians have to establish priorities about how the funds should be used. In this case the priorities unfortunately turned out not to be in favor of extraterrestrial research. I think you have to acknowledge the political significance, but without accepting the result as far as the matter goes. The Dutch, in contrast, have decided differently.

Back again to the MPIA. How do you think the Institute presents itself to the public?
HFW: This is an aspect that indeed should never be underestimated. A top institute has to present its scientific results in such a way that even the people on the street can understand them. And I think it is a marvelous idea of the MPIA to promote the further training of teachers and support the physics teaching in schools with »Sterne und Weltraum«. This is considerably more profound than the public outreach usually found in an institute or university.

Did articles in »Sterne und Weltraum« sometimes contribute to forming your opinion in the Ministry and thus maybe to the support of certain projects?
HFW: For me and many of my colleagues »Sterne und Weltraum« was part of the standard reading. And there were many articles from which I learned a lot and which therefore contributed to my decisions. This is quite an amazing journal. I have been a reader since 1974.

How do you see your responsibility as Chair of the Board of Trustees?
HFW: The Board of Trustees does not have direct influence on the direction of the research or the staff of the Institute. But I see the board as a mediator between the Institute on the one hand and the industry, the media, and politics on the other. I am really very proud of this position and always prepare myself, like my colleagues, in great detail for the meetings. Our influence probably consists first of all in asking intelligent questions from the various fields we represent and thus starting further discussions. That's why I am so glad about the very active involvement of the MPG administration in the board.

And how do you come up with intelligent questions?
HFW: All year long, I am collecting every article and information on the Institute published anywhere in the internet, newspapers, and journals or which I get at conferences. And of course I go through the Annual Report thoroughly.

Mr. Wagner, thank you very much for this interview.

(The questions were asked by Thomas Bührke and Jakob Staude.)

Staff

Directors: Henning (Acting Director), Rix

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

Scientists: Afonso (since 15.9.), Bailer-Jones, Barden, Bell, Beuther (ab 15.9.), Brandner, Butler, Cannon, Dannerbauer, De Bonis (since 19.7.), De Jong (since 1.8.), Dullemond, Feldt, Fendt, Fernandez, Fried, Fujita (since 15.9), Gässler, Graser, Herbst, Hippelein, Hippler, Hinz (since 5.12.), Hofferbert, Huisken, Jäger (since 17.5.), Jahnke (since 16.9.), Klaas, Klahr, Kornet, Krasnokutski (until 30.4.) Krause (since 15.9.), Kürster, Kuhlmann, Launhardt, Leinert, Lemke, Lenzen, Marien, Mehlert, Masciadri (1.9. until 30.11.), Meisenheimer, Mundt, Przygodda (until 31.1.), Pitz, Re Fiorentin (since 1.10.), Rockenfeller (15.8. until 14.12.), Röser, Sakelliou (since 1.3.), Schinnerer, Schreiber, Setiawan, Semenov, Soci (until 31.7.), Somerville (since 6.6.), Staude, Steinacker (until 30.11.), Stickel, Stolte (since 1.10.), Tapken, van den Bosch (since 1.9.), Walcher (until 15.3.), Walter, Wolf R., Wolf S.

Ph. D. Students: Arold (since 1.10.), Berton, Bigiel (since 1.3.), Birkmann, Borelli (since 1.10.), Boudreault (since 1.10.), Brauer (since 1.4.), Carmona (since 1.11.), Chen, Debieu, Dib (until 14.5.), Dziourkevitch (until 5.7.), D'Souza (until 31.3.), Egner, Falter, Fujita (since 15.9.), Franco Rico (since 1.4.), Györyova (until 31.1.), Haan (since 1.10.), Hanke, Häußler, Heinzeller (since 1.9.), Hennemann (since 5.9.), Janson (since 1.8.) Johansen, Keil, Kellner, Klement (since 1.8.), Kovacs (until 30.4.), Krmpotic, Linz (until 31.7.), Llamas Jansa (until 31.3.), Mignone (1.12.), Neumayer, Nicol (since 1.9.), Peter, Puga (until 31.1.), Quanz, Ratzka, Riechers, Roccatagliata (since 18.8.), Rodler, Rodmann (until 15.9.), Rodriguez (since 1.7.), Schartmann, Schegerer, Schütz (until 28.2.), Smolcic, Stegmaier, Stumpf, Tam (1.10.), Tamburro, Tristram, Umbreit (until 31.3.), Zub (1.10.), Zatloukal (since 15.9.)

Diploma Students and Student Assistants: Geißler (until 30.9.), Hormuth, Kerzendorf (1.7. until 30.9.), Kitzing (until 31.10.), Koposov, Meyer (since 1.11.), Moster (since 1.5.), Rockenfeller (until 30.6.), Schmidt, J., Schmidt, T. (since 15.11.), Stilz (since 10.10.9; Volchkov (since 21.2.), Weise

Diploma Students/Master Students (FH): Dörsam (14.3. until 13.9.), Eggert (since 1.3.), Rehbein (since 19.9.)

Science Project Management: Berwein (since 1.7.), Bizenberger, Grözinger, Huber, Kittmann (since 1.9.), Laun, Leibold, Naranjo, Neumann, Pavlov, Quetz, Schmelmer

Computers, Data Processing: Briegel, Hiller, Rauh, Richter, Storz, Tremmel, Zimmermann

Electronics: Alter, Becker (until 30.11.), Ehret, Grimm, Klein, Lehmitz (since 1.4.), Mall, Mohr, Ramos, Ridinger, Salm (until 30.6.), Wagner, Westermann, Wrhel

Precision Workshop: Böhm, Heitz, Maurer (since 27.2.), Meister, Meixner, Morr, Pihale (until 30.4.), Sauer F. (since 27.2.), Sauer W.

Drawing Office: Baumeister, Ebert, Münch, Rohloff, Rosenberger (until 8.5.)

Photo Shop: Anders-Öczcan

Graphic Artwork: Meißner, Müllerthann (since 27.6.), Weckauf (until 30.11.)

Library: Dueck

Administration: Apfel, Gieser, Heißler, Hölscher, Kellermann, Ollenhauer (since 15.11.), Papousado, Schleich, Voss, Zähringer

Director's Office and Administrative Support: Bohm, Janssen-Bennynck, Koltes-Al-Zoubi, Seifert

Technical Services: Behnke, Herz, Jung, Lang, Nauß, Witzel B., Witzel F., Zergiebel

Trainees: Baumgärtner, Euler, Finzer (since 1.9.), Gärtner, Maurer (until 26.2.), Müllerthann (until 26.6.), Resnikschek, Sauer. F. (until 26.2.), Schewtschenko, Schmitt, Stadler

Freelance Science Writer: Dr. Th. Bührke

Postdoctoral Stipend Holders: Afonso (until 31.8.), van Boekel (since 15.1., Bouwman, Coleman (since 1.10.), De Bonis (until 18.7.), Dziourkevitch (since 6.7.), Goldmann, Gouliermis, Goto, Heymans (until 1.7.), Jester (since 1.10.), Kasper (1.2. until 30.4.),Khanzadyan (until 30.11.), Knudsen, Krasnokutski (1.5. until 30.6.), Lsinceadie (since 21.11.), Linz (since 1.8.), Masciadri (until 31.8.), Mosoni (until 31.1.), Pasquali (since 1.10.), Pavlyuchenkov (since 12.9.), Penarubbia, Prieto, Roussel (since 1.10.), Sicilia Aguilar (since 1.9.), Staicu (1.2. until 31.12.), Swain (since 1.9.), Tisserand (1.2. until 31.5.), Trujillo (until 31.8.), Umbreit (15.7. until 31.12.), Weldrake (since 1.6.), Zheng (since 30.7.2004), Zucker (until 31.10.)

Guests: Zinchenko, Novgorod (January), Naab, München (January). Maoz, Tel Aviv (January). Somerville, STScI

(January-February), Klessen, AIP (January-February), Cappellari, Leiden (February), Mayer, Zürich (February), Dolag, MPA Ottobrunn, (February), Tisserand, CEA/DAPNIA/SPP, Paris (February), Brosch, Wise Observatory, Tel Aviv (February), Mazeh, WISE Observatory, Tel Aviv (February), Sicilia-Aguilar, CFA Harvard (February), Balbus, Ecole Normale Superieure (February), Croton, MPA Ottobrunn (February), Meijer, Univ. Amsterdam (February), Ligori, INAF Torino (February), MacArthur, British Columbia (February), De Jong, Groningen (February), Fujita, Univ. of California (February), Pontappidan, Leiden (February), Yaitskova, ESO Garching (February), Fan, Steward Observatory (February), Krause, Steward Observatory (February), Navarro, British Columbia (February), Scoville, California Institute of Technology (March), Jester, Fermi Lab (March), Tsalmantza, Univ. of Athens (March), Beaulieu, CNRS Paris (March), Mokler, MPE Garching (March), Voshchinnikov, Sobolev Astron. Inst., St. Petersburg (March), Botzler, Univ.sternwarte München (March), Mayer, Univ. Zürich (March), Tisserand, CEA/DAPNIA/SPP, Paris (April), Kiss, Budapest (April), Abraham, Budapest (April), Kospal, Budapest (April), Carmona, ESO Garching (April), King, Frankfurt (April), Boersma, Groningen (April), Somerville, STScI (April), Swain, Grenoble (April), Lahouis, SRON Groningen (April – June), Smith, Armagh Observatory (May), Günther, Tübingen (May), Lawson, New South Wales (May), Waters, Amsterdam (May), Schmid, ETH Zürich (May), Gratton, Padova (May), Turatto, Padova (May), Pascucci, Steward Observatory, (May), Allard, Lyon (May), David, Lyon (May), Labadie, Grenoble (May), Oka, Chicago (June), Stuart, Univ. of Canterbury, New Zealand (June), De Jelte, Groningen (June), Collioud-Marichallot, Observatoire de Cote d'Azur (June), Wilhelm, Ohio (June), Vasyunin, Ural State University (June), Swain, Grenoble (June), Le Roux, Arcetri (June), Bondi, IRA (June), Walker, Rutherford Appleton Laboratory (June), Ciliegi, Bologna (June), Abel, FH Hannover (June), Roccatagliata, ESO (June), Fedele, ESO (June), Toergensen, Lund (June), Stecklum, Tautenburg (June), Westra, Stromlo (June), Wolf, Oxford (June), Madau, Univ. of California (July), Osmer, Ohio (July), van den Bosch, ETH Zürich (July), Pasquali, ETH Zürich (July), Schiminovich, Columbia Univ. (July), Kodama (July), Peng, STScI (July), De Jong (July), Theverin, Nice (July), Smith, Armagh Observatory (July), Kiss, Konkoly Observatory (July), Abraham, Konkoly (July), Coleman, Mount Stromlo (July), Hartung, ESO Chile (August), Barrado y Navascues, LAFFF-INTA, Madrid (August), Pelegrina, I.E.S. Marmaria (August), Blain, California Inst. of Technology (August), Lawson, UNSW, Canberra (August), Mazeh, Wise Observatory (August), Reiners, Univ. of California (August), Shields, Ohio University (August), Higuchi, Nat. Astron. Obs. Japan (September), Natta, Arcetri (September), Beckwith, STScI (September), Wang, Purple Mountain Obs. (September), Tamuz, Wise Observatory (September), Mosoni, Konkoly Observatory (September), Trager, Groningen (September), Dole, Inst. d'Astrophysique Spatiale (September), Wiebe, Russian Academy Moscow (October), Wünsch, NCAC, Warsaw (October), Martin, Univ. California (October), Takami, Subaru Telescope (October), Toft, Yale (October), Tsalmantza, Athens (October), Livanou, Athens (October), Dutton, ETH Zürich (October), Maulbetsch, AIP (November), Lo Curto, ESO, Santiago (November), Mizuno, NSSTC (November), Nishikawa, NSSTC (November), Ellis, CalTech, Pasadena (November), Di Folco, Genf (November), Lawson, New South Wales (November), Beckwith, STScI (November), Tolstoy, Groningen (November), Toth (December), Vasyunin, Ural State University (December), Wooden, NASA (December), Posch, Wien (December), Hübener, Göttingen (December)

Interns: Brenner (since 1.10.), Dieminger (11.7. until 2.9.), Friedlein (1.4. until 30.9.), Häcker (1.3. until 31.3.), Hauck (1.8. until 15.9.), Hinum (18.4. until 13.5.), König (since 1.9.), Kordell (until 28.2.), Reymann (1.8. until 31.8.) Wagenblaß (until 28.2.); Zechmeister (1.9. until 30.9.)

Calar Alto, Almeria/Spanien

Local Director: Gredel

Astronomy, Coordination: Thiele

Astronomy, Night Assistants: Aceituno, Aguirre, Alises, Cardiel, Guijarro, Hoyo, Pedraz, Sánchez

Telescope Techniques: Benitez, Capel, De Guindos, De Juan, Garcia, Helmling, Henschke, Hernandez L., Hernández R., Raul López, Marín, Morante, Müller, W., Nuñez, Parejo, Usero

Technical Services: Aguila, A., Aguila M., Ariza, Barbero, Barón, Carreño, Corral, Domínguez, Gómez, Góngora, Klee, Rosario López, Márquez, Martínez, Romero, Sánchez, Tapia

Administration, Secretary: Hernández M., Hernández M.J., López M.I., Wagner M.

Working Groups

Department »Planet and Star Formation«
Director*:* Thomas Henning

Infrared Space Astronomy
Dietrich Lemke/Oliver Krause, Stephan Birkmann, Helmut Dannerbauer, Ulrich Grözinger, Martin Hennemann, Jörn Hinz, Ralph Hofferbert, Armin Huber, Ulrich Klaas, Ernest Krmpotic, Sven Kuhlmann, Jürgen Schreiber, Jutta Stegmaier, Manfred Stickel

Star Formation
Christoph Leinert, Aurora Aguilar Sicilia, Jeroen Bowman, David Butler, Andrés Carmona, Xuepeng Chen, Markus Feldt, Miwa Goto, Tigran Khanzadyan, Ralf Launhardt,

Rainer Lenzen, Hendrik Linz, Yaroslav Pavlyuchenkov, Diethard Peter, Elena Puga, Sascha Quanz, Thorsten Ratzka, Veronica Roccatagliata, Oliver Schütz, Dmitri Semenov, Mark Swain, Patrick Tisserand, Roy van Boekel

Brown Dwarfs, Extrasolar Planets
Reinhard Mundt, Cristina Afonso, Alessandro Berton, Wolfgang Brandner, Matilde Fernandez, Kerstin Geißler, Bertrand Goldmann, Markus Janson, Elena Masciadri, Boris Rockenfeller, Florian Rodler, Jens Rodmann, Victoria Rodriguez Ledesma, Johny Setiawan, Andrea Stolte, David Weldrake

Theory
Hubertus Klahr, Frithjof Brauer, Cornelis Dullemond, Natalia Dziourkevitch, Anders Johansen, Bernhard Keil, Stefan Umbreit

Laboratory Astrophysics
Friedrich Huisken, Marco Arold, Olivier Debieu, Isabel Llamas Jansa, Serge Krasnokutski, Angela Staicu

Frontier of Interferometry in Germany (FRINGE)
Thomas Henning, Uwe Graser, Ralf Launhardt, Frank Przygodda, Thorsten Ratzka, Jürgen Steinacker

Adaptive Optics
Wolfgang Brandner, Alessandro Berton, David Butler, Fulvio De Bonis, Markus Feldt, Dimitrios Gouliermis, Stefan Hippler, Felix Hormuth, Stefan Kellner, Elena Masciadri, Micaela Stumpf

Emmy-Noether-Group I: »The Evolution of Circumstellar Disks to Planetary Systems«
Sebastian Wolf, Kacper Kornet, Alexander Schegerer

Emmy-Noether-Group II: »Properties and Formation of Substellar Objects«
Coryn Bailer-Jones, Steve Boudreault, Paola Re Fiorentin

Emmy-Noether-Group III: »The Formation of Massive Stars«
Hendrik Beuther

Department »Galaxies and Cosmology«
Director: Hans-Walter Rix

Structur and Dynamics of Galaxies and in the Milky Way System
Hans-Walter Rix, Eva Schinnerer, Knud Jahnke, Matthew Coleman, Ignacio Trujillo, Carl Jakob Walcher, Richard D'Souza, Sebastian Haan, Nadine Neumaier, Dan Zucker, David Butler, Jelte de Jong, Domenico Tamburro, Rainer Klement

Stellar Populations and Star Formation
Fabian Walter, Thomas Herbst, John Cannon, Kirsten Kraiberg Knudsen, Hélène Roussel, Frank Bigiel, Sami Dib, Dominik Riechers

Evolution of Galaxies and Cosmology
Eric Bell, Klaus Meisenheimer, Hans-Walter Rix, Marco Barden, Dörte Mehlert, Catherine Heymans, Siegfried Falter, Zuzana Györyva, Isabel Franco, Anna Pasquali, Sergey Koposov

Active Galactic Nuclei
Klaus Meisenheimer, Nadine Neumaier, Almudena Prieto, Hélène Nicol, Marc Schartmann, Konrad Tristram, Michael Zatloukal, Vernesa Smolcic, Christian Fendt

Deep Surveys
Klaus Meisenheimer, Hermann-Josef Röser, Hans Hippelein, Irini Sakelliou, Zoltan Kovacs, Siegfried Falter, Boris Häußler, Knud Jahnke

Theory – Formation of Galaxies and Large Scale Structure
Rachel Somerville, Akimi Fujita, Jorge Penarrubia, Frank van den Bosch

Instrumental Developments
Thomas Herbst, Hermann-Josef Röser, Josef Fried, Wolfgang Gäßler, Lucas Labadie, Martin Kürster, Stefan Hanke, Roberto Soci, Sebastian Egner, Eva Meyer

Cooperation with Industrial Firms

4D electronic, Bretten
ABB, Alzenau/Heidelberg
Adolf Pfeiffer, Mannheim
ADR, Paris
Agilent Technologies, Böblingen
Almet-AMB, Mannheim
Althen, Kelkheim
America II, Mönchengladbach
Amphenol-Tuchel Electronics, Heilbronn
Angst+Pfister, Mörfelden
APE Elektronik, Kuppenheim
API Portescap Deutschland, Pforzheim
Arthur Henninger, Karlsruhe
asknet AG
Auer Paul GmbH, Mannheim
August Krempel Soehne GmbH, Vaihingen/Enz
AVNET EMG, Braunschweig
bacuplast GmbH
Baier, Digitaldruck, Heidelberg
Barth, Leimen
Bectronic GmbH, Derschen
Best Power Technology, Erlangen
Best Ventil und Fitting GmbH, Karlsruhe
Beta Layout, Arbergen
Bieri Engineering GmbH, Winterthur
Binder Elektronik, Sinsheim
Binder Magnete, Villingen-Schwenningen
Blaessinger, Stuttgart
BOC Edwards GmbH, Kirchheim/München
Bohnenstiel, Heidelberg
Böllhoff GmbH, Winnenden
Börsig, Neckarsulm
Brüel & Kjaer Vibro, Darmstadt
Bubenzer Bremsen, Kirchen-Wehrbach
Bürklin OHG, München
C&K Components, Neuried b. München
CAP CNC + Coating Technik, Zell. a. H.
CAB, Karlsruhe
Cadillac-Plastic, Viernheim
CAMCenter GmbH
Carl Roth, Karlsruhe
Carl Zeiss, Oberkochen
Caspar Gleidlager GmbH
CEF, Heidelberg
Cherry Mikroschalter, Auerbach
Christiani, Konstanz
Coating-Plast, Schriesheim
Com Pro, Stuttgart
Compumess Electronik, Unterschleissheim
Comtronic, Heiligkreuzsteinach
Conrad Electronic, Hirschau
Cryophysics, Darmstadt
Dannewitz, Linsengericht
Dastex Reinraumzubehör GmbH, Muggensturm
Datel, München
db electronic Daniel Böck GmbH, Waldshut-Tiengen
Dell-Computer GmbH
Delta-V, Wuppertal
Deltron Components GmbH, Neuried b. München
Deti, Meckesheim
Digi-Key, Enschede
Dicronite UTE Pohl GmbH
DMG-Service, Pfronten
DPV Elektronik, Eppingen
Dr. Johannes Heidenhain, Traunreut
Dürkes & Obermayer, Heidelberg
Dyna Systems NCH, Mörfelden-Walldorf
Ebara Pumpen, Dietzenbach
EBJ, Ladenburg
EBV-Elektronik, Frankfurt/M.
EBV-Elektronik, Leonberg
EBV-Elektronik. Wiesbaden-Nordenstadt
EC Motion, Mönchengladbach
EC-Motion, Erkelenz
Edsyn Europa, Kreuzwertheim
EFH, Neidenstein
Eldon, Büttelborn
electronic sensor+resistor, Ottobrunn
Elna Transformatoren, Sandhausen
elspec, Geretsried
ELV Electronik, Leer
Erni, Adelberg
eurodis Enatechnik, Quickborn
Europa-Lehrmittel, Verlag
EWF, Eppingen
Faber Industrietechnik GmbH, Mannheim
Fairchild Imaging, USA-Milpitas
Farben Specht, Bammental
Farnell in One, Deisenhofen
Farnell Electronic Services, Möglingen
FCT Electronic, München
Fels Spedition, Heidelberg
Fisba, St. Gallen
Fischer Elektronik, Lüdenscheid
Fluke Deutschland, Fellbach
FPS-Werkzeugmaschinen GmbH, Otterfing
Frank GmbH
Franke, Aalen
Fresemann Andreas
Fritz Faulhaber, Schönaich
Future Electronics Deutschland, Unterföhring
GAD GmbH
Ganter, Walldorf
Garlock GmbH, Neuss
Geier Metall-u. Stahlhandel, Mannheim
Genoma Normteile, Hameln
Gerwah Päzision GmbH
GGP-Schaltungen, Osterode am Harz
Glenair Electric, Oberursel
GLT, Pforzheim
Göbel, Horst, Ludwigshafen
Goodfellow
Gould Nicolet Meßtechnik, Dietzenbach
Grandpair, Heidelberg
Gresham Powertrade, Landsberg
Grulms-Pneumatik, Grünstadt
GRW, Würzburg
Gudeco Elektronik, Neu-Anspach
Gummi Körner, Eppelheim
Gummi-Plast Schild, Gernsheim
Gutekunst, Pfalzgrafenweiler
Häcker, Weinsberg
Häfele Leiterplattentechnik, Schrießheim
Hahn u. Kolb GmbH
Hans Buerklin Dr., München
Harting Elektronik, Minden
HCK-Messzubehör, Essen
Heidenhain Dr. Johannes GmbH, Traunreut
Helukabel GmbH, Hemmingen
Hilger und Kern, Mannheim
HKi GmbH, Weinheim
Hilma-Römheld GmbH, Hilchenbach
Helukabel, Hemmingen
Hema, Mannheim
Heräus, Hanau
Herz, Leister Geräte, Neuwied
Hewlett-Packard Direkt, Böblingen
Hitex Development Tools, Karlsruhe
HM Industrieservice, Waghäusel
Hommel-Hercules Werkzeughandel, Viernheim
Hormuth, Heidelberg
Horst Göbel, Ludwigshafen
Horst Pfau, Mannheim
Hoschar Systemelektronik, Karlsruhe

HOT Electronic, Taufkirchen
HTF Elektro, Mannheim
Huber + Suhner, Taufkirchen
IBF Mikroelektronik, Oldenburg
Infrared Labs, Tucson, USA
Inkos, Reute/Breisgau
Invent GmbH
iSystem, Dachau
Jacobi Eloxal, Altlussheim
Jarmyn, Limburg
Jngenieurbüro Steinbach, Jena
Joisten+Kettenbaum, Bergisch Gladbach
Kaiser + Kraft GmbH
Kaufmann, Crailsheim
Kerb-Konus-Vertriebs-GmbH, Amberg
Kniel, Karlsruhe
Knürr, München
Kremer Pigmente, Aichstetten
Kurt Norr & Co
KVT Canespa, Langenhagen
Laflo Reinraumtechnik GmbH
Lambda Electronics, Achern
Laser Components
Layher, Güglingen
Lemo Electronik, München
Leybold Vacuum GmbH, Köln
Linde AG, Wiesbaden
Lineartechnik Korb, Korb
LPKF CAD/CAM Systeme, Garbsen
LWS-Technik GmbH & Co.
Machery-Nagel, Düren
Macrotron, München
Mädler, Stuttgart
Mankiewicz, Hamburg
Martor KG, Solingen
Matsuo Electronics Europe, Eschborn
Matsushita Automation, Holzkirchen
Maxim Ges. f. elektronische integrierte Bausteine, Planegg
Menges electronic, Dortmund
Mentor, Erkrath
Metrofunkkabel-Union, Berlin
Micro Epsilon, Ortenburg
Mitsubishi-Electric, Weiterstadt
Mitutoyo Messgeräte, Neuss
Möller-Wedel Optical, Wedel
Moll, Bleche und Verarbeitung, Hirschberg
Mönninghoff, Bochum
MSC Vertriebs-GmbH, Stutensee
MTS Systemtechnik GmbH, Mertingen
MTI, Baden-Baden
Munz, Lohmar
Nanotec, Finsing
Newport, Darmstadt
Nickel Schalt- und Meßgeräte, Villingen-Schwenningen
Niedergesess, Sandhausen
Nies Electronic, Frankfurt
Noor, Viernheim
Oberhausen, Ketsch
Olympus, Hamburg
Otto Faber, Mannheim
Otto Ganter, Furtwangen
Orglmeister
Parametric Technology, Muenchen
Parcom, CH-Flurlingen
pbe Electronic, Elmshorn
PCE Group oHG
Pfeiffer Adolf GmbH, Mannheim
Pfeiffer Vacuum GmbH, Asslar
Pfister Büro
Phoenix Contact GmbH & Co, Blomberg
Physik Instrumente, Waldbronn
Phytec Messtechnik, Mainz
Phytron-Elektronik, Gröbenzell
Pink Vakuumtechnik GmbH, Wertheim
Plastipol & Co., Runkel
Prout Services+Handware GmbH
PSI Tronix, Tulare, California, USA
Pühl A. GmbH
Radiall, Rödermark
Rala, Ludwigshafen
Rau-Meßtechnik, Kelkheim
Räder Gangl, München
Reeg, Wiesloch
Regional Electronic Distribution, Rodgau-Jügesheim
Reichelt Elektronik, Sande
Reinhold Halbeck, Offenhausen
Reith, Mannheim
Retronic, Ronneburg
Rexel Deutschland HTF, Mannheim
Rexim, Maulbronn
Riegler & Co. kG
Riekert & Sprenger, Wertheim
Rittal + Co., Herborn
Roland Häfele Leiterplattentechnik, Schriesheim
Roth Carl GmbH, Karlsruhe
RRG Industrietechnik GmbH, Mülheim
RS Components, Mörfelden-Walldorf
RSP-GmbH, Mannheim
Rudolf, Heidelberg
Rufenach Vertriebs-GmbH, Heidelberg
Rütgers, Mannheim
Rufenach Vertriebs-GmbH, Heidelberg
Sasco Holz, Dreieich
Sauter-Cumulus GmbH
Sartorius, Ratingen
Sasco, Putzbrunn
Scantec, Germering
Scantec, Planegg
Schaffner Elektronik, Karlsruhe
Schlossmacher Ingenieurbüro
Schrauben-Jäger AG
Schwab Holz-Zentrum
Schulz Bürozentrum GmbH
Schuricht, Fellbach-Schmiden
Schweizer Elektroisolierungsstoffe, Mannheim
SCT Servo Control Technology, Taunusstein
SE Spezial-Electronic, Bückeburg
Seifert mtm Systems, Ennepetal
Senior Berghöfer, Kassel
Siemens IC-Center, Mannheim
Sinus Elektronik, Untereisesheim
SolidLine AG
Spaeter, Viernheim
Spindler & Hoyer, Göttingen
Spoerle Electronic, Dreieich
Stahlschlüssel Wegst GmbH
Steinbach M. Ingenieurbüro
Straschu Leiterplatten, Oldenburg
Suco-Scheuffele, Bietigheim-Bissingen
Tafelmaier, Rosenheim
Tautz GmbH
Tandler, Brauen
Teldix GmbH
Telemeter Electronic, Donauwörth
THK, Düsseldorf
Thorlabs, Gruenberg
ThyssenKrupp Schulte
TMS Test- und Meßsysteme, Herxheim/Hayna
Tower Electronic Components, Schriesheim
Trivit AG
TS-Optoelectronic, München
TWK-Elektronik, Karlsruhe
Vacuumschmelze, Hanau
VBE Baustoff+Eisen, Heidelberg
Varian Deutschland GmbH, Darmstadt
Vereinigte Baustoff-und Eisen GmbH
Vero Electronics, Bremen
Vision Engineering, Emmering
W. & W. Schenk, Maulbronn
Werner Curt GmbH&Co. Heidelberg
Wietholt Heinrich GmbH
Wika, Klingenberg
Witter GmbH, Heidelberg
Wikotec, Bramsche WMM, Andechs
Wilhelm Gassert, Schriesheim
Witzenmann GmbH, Pforzheim
WS CAD Electronik, Berk Kirchen
Würth Elektronik GmbH & CO., Künzelsau
Yamaichi Electronics, München

Teaching Activities

Winter Term 2004/2005

J. Fried: Galaxies (lecture, with B. Fuchs, ARI)

Th. Henning: Protostellar Disks (lecture), Physics of Star Formation (seminar)

K. Meisenheimer: Radio Galaxies and Quasars (seminar, with J. G. Kirk, MPIK, and S. Wagner, LSW)

Ch. Leinert, H.–J. Röser: Introduction to Astronomy and Astrophysics, I (lecture)

D. Lemke: Introduction to Astronomy and Astrophysics, III (seminar, with M. Bartelmann, H.-P. Gail, ITA, and J. Heidt, LSW)

Sommer Term 2005

C. Bailer-Jones, Th. Henning: From Brown Dwarfs to Giant Planets (lecture); Physics of Star Formation (seminar)

Th. Henning, S Wolf: Protostellar Discs (lecture), Physics of Star Formation (seminar)

R. Mundt: Introduction to Astronomy and Astrophysics, III (seminar, with M. Bartelmann, ITA, and J. Krautter, LSW)

Ch. Leinert, H.–J. Röser: Introduction to Astronomy and Astrophysics, II (lecture)

H.–W. Rix: Evolution of Galaxies, Stellar Dynamics, Interstellar Matter (seminar, with A. Just, R. Spurzem, ARI, H.-P. Gail, ITA); Gravitational Lenses (seminar, with M. Bartelmann, ITA, J. Wambsganss, ARI)

Winter Term 2005/2006

C. Dullemond: The Formation of Stars and Planets (lecture)

M. Fendt, K. Meisenheimer, H.–W. Rix: Current Research Topics in Astrophysics (IMPRS-Seminar, with W. Duschl, ITA)

J. Fried: Galaxies (lecture and exercises, with B. Fuchs, ARI)

H.–W. Rix: Introduction to Astronomy and Astrophysics I/II (IMPRS-lecture and exercises, with A. Just, R. Spurzem, ARI)

H.–J. Röser, M. Stickel: Introduction to Astronomie und Astrophysik, III (seminar, with J. Wambsganss, ARI)

S. Wolf, Th. Henning: Protoplanetary Disks (lecture)

Conferences, Scientific and Popular Talks

Conferences Organized

Conferences Organized at the Institute

C. Afonso: Microlensing Workshop, November 5–6

C. A. L. Bailer-Jones: GAIA »Data Analysis Coordination Committee« meeting, MPIA, October 6–7

H. Dannerbauer, U. Klaas, J. Schreiber: PACS Instrument Control Centre Team Meeting # 22, MPIA Heidelberg, July 25–26

Ch. Fendt: MPIA Internal Symposium, December 8–9

W. Gässler, T. Herbst: Ringberg Workshop »Instrumentation for Extremely Large Telescopes«, Ringberg Castle, July 25–29

R. Gredel: NEON Summer School, Calar Alto, August 7–20

K. Jäger: Colloquium »From T Tauri Stars to the Edge of the Universe«, in Honour of Prof. Immo Appenzeller, Heidelberg, June 30–July 1 (with Jochen Heidt); Kuratoriums-Kolloquium, Heidelberg, September 15; Colloquium »Frontiers of Infrared Astronomy« in Honour of Prof. Dietrich Lemke and Prof. Christoph Leinert, Heidelberg, Dezember 1

H.–J. Röser: Ringberg Workshop »Distant Clusters of Galaxies«, October 23–28

S. Wolf: Wilhelm und Else Heraeus Physics School »Extrasolar Planetary Systems«,

Bad Honnef, October 17–21; 2nd Annual Internal MPIA Symposium (December 8–9)

J. Setiawan: PSF Group Workshop, Buchenbach/Schwarzwald, May (LOC, with A. Schegerer, D. Peter; SOC: T. Khanzadyan, J. Rodmann, B. Goldman); MPIA External Retreat, Schloss Hirschhorn, April 25–26

N. Neumayer und Micaela Stumpf: Second MPIA Student Workshop, Oberau, March 5–9

Other Conferences Organized

Ch. Fendt: »Ultra-Relativistic Jets in Astrophsyics – Observations, Theory, Simulations«, Banff, Canada, July 11–15 (SOC member)

W. Gässler: Project meetings for LINC-NIRVANA, T-OWL, ONERICA, FP6–ELT-DS Novel Concpets in AO for ELT

Roland Gredel: Jornadas de Astronomia de Almeria, June 6–10; »25 anos mirando al cielo«, El Ejido, Spain, November 7–20

M. Kürster: LINC-NIRVANA Final Design Review, July 21–22; LINC-NIRVANA team visit to LBT, Nov. 28–Dec. 1

Th. Henning: European Interferometry Initiative Meeting, Prag, September 9

Eva Schinnerer: Meeting on LINC/NIRVANA science cases, Bonn, December 7

S. Wolf, Th. Henning: Heraeus Physics School »Extrasolar Planetary Systems«, Bad Honnef, October 17–21;

Conferences and Meetings Attended, Scientific Talks and Poster Contributions

C. Afonso: Launch Conference of the International Year of Phyiscs, Paris, UNESCO Headquarters, January 13–15; PSF Workshop, Buchenbach, May 30–June 2 (talk); XVENAA Conference, Lisbon, Portugal, June 28–July 3 (talk); IAU Colloquium 200, »Direct Imaging of Exoplanets«, Nice, October 3–7 (poster) ; Protostars and Planets, V, Hawaii, October 24–28 (poster); Microlensing Workshop, MPIA, November 5–6 (talk)

C. A. L. Bailer-Jones: Brown dwarfs and the Gaia Galactic survey mission, University of Erlangen-Nürnberg, Januar (invited talk); GAIA Science Team meeting, ESTEC (Netherlands), April 13–14; GAIA Classification working group meeting, Barcelona, April 27–28; Brown dwarfs and the GAIA Galactic survey mission, University of Potsdam, May (invited talk); Mapping the universe in six dimensions, Astronomisches Institut der Universitaet Basel, Switzerland, July (invited talk); GAIA Data Analysis Coordination Committee meeting, MPIA, October 6–7; The impact of GAIA on the future of astrophysics, University of Potsdam, October (invited talk); The GAIA challenge, Strasbourg Astronomical Observatory, France, November (invited talk);

M. Barden: Ringberg meeting »The Role of Wide and Deep Multi-wavelength Surveys in Understanding Galaxy Evolution«, March 29–April 1st (invited talk); Symposium »The Origin of the HUBBLE Sequence«, Vulcano Island, Italy, June 6–12 (invited talk)

A. Berton: Workshop on Adaptive Optics-assisted Integral-Field Spectroscopy, La Palma, Spain, May 9–11 (contributed talk); IAU Colloquium 200 »Direct Imaging of Exoplanets: Science and Techniques«; Villefranche sur Mer, France, October 3–7 (Poster); IAU Symposium 232 »The Scientific Requirements for Extremely Large Telescopes, Cape Town, November 14–18 (talk); Heraeus Physics School »Extrasolar Planetary Systems«, Bad Honnef, October 17–21

S. Birkmann: IAU Symposium 227 »Massive Star Birth: A Crossroads of Astrophysics«, Catania, May 16–20 (poster)

W. Brandner: IAU Symposium 227 »Massive Star Formation«, Catania, May (Poster); 2nd NAHUAL Workshop, Segovia, June (contributed talk); »From T Tauri Stars to the Edge of the Universe«, Heidelberg, June; »Protostars and Planets, V«, Hawaii, October 24–28 (Poster); Brown Dwarf Workshop, Hawaii, October

J. M. Cannon: AAS Meeting 205, San Diego, CA, January (poster); STScI Mini-Workshop »Galactic Flows: The Galaxy/IGM Ecosystem«, Baltimore, MD, March (poster); IAU Symposium 227 »Massive Star Birth: A Crossroads of Astrophysics«, Acireale, Italy, May (poster); AAS Meeting 206, Minneapolis, MN, May; »Infrared Diagnostics of Galaxy Evolution«, SPITZER Science Center conference, Pasadena, CA, November

A. Carmona Gonzalez: »Photochimie des disques protoplanetaires et la interaction gas-poussière«, Laboratoire d'Astrophysique de Marseille, January (poster); Kobe International School of Planetary Sciences »Origin of Planetary Systems«, Hawaii, July 11–17 (poster); First External PSF Group Meeting, Buchenbach, May, 30-June 2 (poster); Workshop in Planet Formation, Kobe, July 18-19 (talk); IRAM Summer School »Millimeter Wavelengths Techniques and Applications«, Pradollano, Spain, September 30–October 7 (poster); »Protostars and Planets, V«, Hawaii, October 24–28 (poster)

H. Dannerbauer: Workshop »The role of wide and deep multi-wavelength surveys in understanding galaxy evolution«, Ringberg, March 29–April 1 (talk); Annual Meeting of the Astronomische Gesellschaft, Köln, September 29-30 (poster); The SPITZER Science Center 2005 Conference: Infrared Diagnostics of Galaxy Evolution, Pasadena, November 14-16 (talk)

R. Gredel: Colloquium, Jena University, February 4; Colloquium, MPI for Solar System Research, Katlenburg-Lindau, May, 4; Colloquium, Universidad de Chile, June 13; IAU Symposium 232, »The scientific requirements of ELTs«, Capetown, November 14–18

C. Dullemond: Meeting »From Disks to Planets«, Pasadena, March 2005 (invited review); meeting »Star Formation«, NASA-Ames, July 2005 (invited talk); conference »Protostars and Planets, V«, Hawaii, October (invited review, with Hollenbach, Kamp, and D'Alessio)

S. Falter: 2. MPIA Students Worshop (talk); Ringberg Workshop »Distant Clusters of Galaxies«, October 24–28 (talk)

Ch. Fendt: Workshop »JETSET-kickoff meeting, node Heidelberg«, Heidelberg, March 2 (talk); Colloquium at the Institute for Theoretical Astrophysics, Heidelberg, June 8 (talk); International Conference »Ultra-Relativistic jets in Astrophsyics – Observations, theory, simulations«, Banff, Canada, July 11–15 (Invited conference Summary; two Posters); Workshop »JETSET-kickoff meeting, node Grenoble«, Grenoble, France, July, 17–20, (talk); Workshop »PPV review team meeting«, Copenhagen, Denmark, August, 21–23; Conference »Protostars and Planets, V«, Hawaii, October 24–28 (Review talk team member; poster); MPIA Internal Symposium, Heidelberg, December 8–9 (talk)

M. Fernandez: Conference »Protostars and planets, V«, Hawaii, October 24–28 (poster)

W. Gässler: Conference on Multiconjugated Adaptive Optics, Paris, March 13–16 (invited talk)

D. Gouliermis: IAU Symposium 227, »Massive Star Birth: A Crossroads of Astrophysics«, Acireale, May 16-20 (poster); Planet and Star Formation Group Workshop, Buchenbach, May 30–June 2 (talk); IAU Symposium 232 »The Scientific Requirements for Extremely LargeTelescopes«, Cape Town, South Africa, November 14–18, (talk); »Stellar Associations of the Large Magellanic Cloud – A laboratory for the Initial Mass Function«, Potsdam, Astrophysical Institute, September 21 (invited seminar)

S. Hanke: MPIA Student Workshop, Oberau, Austria, March (talk)

B. Häußler: Winter school »Surveying the Universe – Spectroscopic and Imaging Surveys for Cosmology«, Obergurgl, February 12–19 (poster); GEMS meeting, Baltimore, March 17–19 (talk); conference »The Role of Wide and Deep Multi-wavelength Surveys in Understanding Galaxy Evolution«, Ringberg, March 29–April 1 (poster); SISCO meeting, Edinburgh, September 14–17; GEMS meeting, Heidelberg, November 7–11 (2 talks)

Th. Henning: Meeting »MIRI Consortium Science Team«, Zürich, Januar 6 (invited talk); Braunschweig University, February 1 (Physics colloquium talk); Tübingen Universität, February 2 (Physics colloquium talk); Meeting »From Young Disks to Planets: New Observations, Models and Theories«, Pasadena, March 7–10 (invited talk); meeting »The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation«, Garching, April 4–8 (invited talk); »8th Conference on Electromagnetic and Light Scattering by Nonspherical Particles«, Salobreña, Granada, May 16–20 (invited talk); Oort Workshop on Protoplanetary Disk Evolution, Leiden, July 7–8 (invited talk); Sapporo Universiity, August 6–10 (Astronomical colloquium); IAU Symposium 231 »Astrochemistry throughout the Universe: Recent Successes and Current Challenges«, Asilomar, USA, August 29–September 9 (invited talk); Heraeus Physics School »Extrasolar Planetary Systems«, Bad Honnef, October 17–21 (two invited talks); Conference »Protostars and Planets, V«, Hawaii, October 24–28 (invited talk); »Planets Network Meeting«, Leiden, November 14–18 (invited talk).

T. Herbst: JENAM 2005 »Distant Worlds«, Liege, July 4–7; »Instrumentation for Extremely Large Telescopes«, Schloss Ringberg, July 25–29; »The Scientific Requirements for Extremely Large Telescopes«, Cape Town, November 14–18; DOME C Meeting, MPIA, April 11, JENAM 2005, Liege, July 7 (invited talk); MPIA Kuratorium, September 15 (instrumentation progress report); LINC-NIRVANA Post-FDR Update, Presentation to LBT Observatory Staff, September 29; LINC-NIRVANA Project Overview and LBT Issues, Presentation to LN Consortium Meeting, October 27; LBT Telescope and Instrument Status Report, LBTB Meeting (presented by K. Jäger), November 15; LINC-NIRVANA Update of the Science Case, Presentation to LN Consortium Meeting, November 15; LINC-NIRVANA Project Overview, Presentation to LBT Observatory Staff, November 28; LINC-NIRVANA Update of the Science Case, Presentation at LN Science Team Meeting, December 7.

S. Hippler: Design Review Meeting »Rayleigh laser beacon for the 4.2m William HERSCHEL Telescope« of the Isaac Newton Group on La Palma, Spain, January 27–28; invited Colloquium »Adaptive Optics in Astronomy – Current trends and future prospects« at the Institute for Technical Physics, DLR, Stuttgart, September 14; OWL conceptual design review meeting, ESO, Garching, November 2

R. Hofferbert: European Space Mechanisms and Tribology Symposium, Luzern, September 21–23 (talk)

K. Jäger: Dritte Münchener Runde der CPTS, München, Juli 11-12; Annual Meeting of the Astronomische Gesellschaft, Köln, 26. September 26–October 1

A. Johansen: meeting »Principles of Magnetohydrodynamics«, Leiden, March (invited talk); »Pencil Code Workshop«, Copenhagen, June (talk); conference »Protostars and Planets, V«, Hawaii, October 24–28 (two posters); PLANET network meeting, Leiden, November (talk)

J. de Jong: SDSS collaboration meeting, Portsmouth, June 18–21; Universitätssternwarte München, October 11 (invited colloquium); Institut für Astrophysik, Universität Göttingen, November 10 (invited colloquium); Kapteyn Astronomical Institute, University of Groningen, December, 19 (invited colloquium)

K. Kornet: IAU Colloquium 200, »Direct Imaging of Exoplanets: Science and Techniques« (talk); 79th Annual Scientific Meeting of the Astronomische Gesellschaft, Splinter Meeting: Formation of brown dwarfs (talk); PLANET School and Network meeting, Leiden (talk); Nicolaus Copernicus Astronomical Center, Warsaw (colloquium)

H. Klahr: Bad Honnef, Heraeus Sommerschule (lecture); Annual Meting of the AG (talk); »Disks to Planets« meeting in Pasadena (talk); Aspen Conference on Planet Formation and Detection (talk); Protostars and Planets, V, Hawaii (seven posters); Protoplanetary disk evolution in Leiden (invited talk)

U. Klaas: »FIR Spectroscopy – 10 Years After«, Abingdon, Oxon U.K., October 10–11

K. Kraiberg Knudsen: Workshop »Legacy Surveys with the James Clerk Maxwell Telescope«, Leiden, January 24–26; Kapteyn Institute, Groningen, February 7 (colloquium); Laboratoire d'Astrophysique de Marseille OAMP, February 18 (colloquium); Workshop »The role of wide and deep multi-wavelength surveys in understanding galaxy evolution«, Ringberg, March 29–April 1 (talk); Workshop »Science Requirements for a Far-Infrared Mission«, Leiden, October 17–19; Workshop »The study of Near-IR selected high redshift galaxies«, Leiden, November 2–4 (talk); »The SPITZER Science Center 2005 Conference: Infrared Diagnostics of Galaxy Evolution«, Pasadena, CA, November 14–16 (poster)

E. Krmpotic: Annual Meeting of the Astronomische Gesellschaft, Köln, September 26–30 (poster); Summer School »Millimeter Wave Observing Techniques and Applications«, Pradollano, Spain, September 30–October 7 (talk)

J. Kurk: meeting »Open Questions in Cosmology: the First Billion Years«, Garching, August 22–26; meeting »IR Diagnostics of Galaxy Evolution«, SPITZER Science Center, Pasadena, CA, November 14–16 (talk)

M. Kürster: »From T Tauri stars to the Edge of the Universe«, June 30–July 1; MPIA Internal Symposium, December 8–9, (talk)

Ch. Leinert: Workshop »The power of optical/infrared interferometry: recent results and 2nd generation instruments«, ESO, Garching, April (talk); »Protostars and Planets, V«, Hawaii, October (invited talk, co-author)

D. Lemke: JWST-MIRI Science Team Meeting, ETH Zürich, January 6; Colloquium at the Technical University Dresden, January 10–12 (invited talk); Moon Workshop, Bremen, March 22–24 (talk); SPIE Conference »Remote Sensing«, San Diego, August 1–5 (talk); Symposium »To Moon and Beyond«, Bremen, September 15–16 (talk); Annual Meeting of the Astronomische Gesellschaft, Köln, September 26-30 (talk)

R. Lenzen: LUCIFER progress meeting, MPE, Garching; January 26; ESO TOWL, Garching, March 10 (invited talk); PILOT meeting (Antarctica), Heidelberg, April 11; NAHUAL, Segovia, June 16/17; Ringberg meeting on Extremely Large Telescopes, June 25–29 (invited talk); ELT Small Studies kick-off meeting, Leiden, 21. September 21; IAU Symposium 232, Capetown, November 14–18 (talk)

H. Linz: IAU Symposium 227 »Massive Star Birth: A Crossroads of Astrophysics«, Acireale, Italy, May 16–20 (poster)

E. Masciadri: Site Workshop III, Vancouver, June (invited talk); Site testing workshop TMT III, Vancouver, July (talk); Arcetri Specialistic Seminar (invited talk); IAU Colloquium »Direct imaging of exoplanets: science and techniques«, Nice, October (talk)

K. Meisenheimer: Workshop »The power of optical/NIR Interferometry«, ESO Garching, April 4–8 (invited talk); »Relativistic Astrophysics and Cosmology – Einsteins Legacy«, München, November 7–11 (talk)

N. Neumayer: Japanese-German Symposium, Regensburg, July 18–22 (contributed talk)

A. Pasquali: meeting »The Study of Near-IR Selected High Redshift Galaxies«, Leiden, October 31–November 4 (invited talk)

S. P. Quanz: ESO Workshop »The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation«, Garching, April 4–8 (talk); conference »Protostars and Planets, V«, Hawaii, October 24–28 (poster); PLANET Network Meeting, Leiden, November 14–18 (talk)

Th. Ratzka: ESO Workshop »The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation«, April (poster); Annual meeting of the Astronomical Society, Köln, September (talk)

H.–W. Rix: NIRSPEC IST-Meeting, Florence, February 8–9 (invited talk); GEMS Workshop, Baltimore, March 17–19; Ringberg Workshop »The Role of Wide and Deep Multi-Wavelength Surveys in Understanding Galaxy Evolution«, March 28–April 1; New York University, April 28–29 (two colloquium talks); 2005 SPITZER Lectures, Princeton University, May 1–13 (five lectures); ESO OPC-Meeting, May 30 (talk); JWST SWG-Meeting, Edinburgh, UK, June 14–15 (talk); SDSS-Meeting, Portsmouth, UK, Juni 18–20 (talk); Symposium »From T Tauri Stars to the Edge of the Universe«, Landessternwarte Heidelberg, June 30–July 1 (talk); Ringberg Workshop »Instrumentation for Extremely Large Telescopes«, July 25–29; Lawrence Berkeley National Laboratory, Berkeley, August 9 (colloquium talk); Conference »Nearly Normal Galaxies in a ΛCDM Universe«, UC Santa Cruz, August 8–12 (invited talk); ESF Exploratory Workshop »Modelling the Galaxy«, Oxford, September 6–9 (talk) Crafoord Prize Symposium »Structure of the Universe and the Future of Cosmology«, Stockholm, September 20–21 (invited talk); FIRES Workshop »The study of Near-IR selected high redshift galaxies«, Leiden, Oktober 31–November 4 (talk)

F. Rodler: MPIA Student Workshop, Oberau (Austria), March (talk); PSF Meeting, Buchenbach, June (talk); Astrodynamical Seminar, Vienna, June (talk)

H.–J. Röser: NEON Summerschool at Calar Alto, August (talk)

H. Roussel: meeting »Infrared Diagnostics of Galaxy Evolution«, SPITZER Science Center, Pasadena, 14–16 November (poster); Institut d'Astrophysique de Paris, December (invited talk); Service d'Astrophysique, CEA, Saclay, December (invited talk)

M. Schartmann: Annual Meeting of the Astronomische Gesellschaft, Köln, September 26–October 1; Meeting »Relativistic Astrophysics and Cosmology – Einstein‘s Legacy«, München, November 7–11

E. Schinnerer: 205th Meeting of the American Astronomical Society, San Diego, CA, January (talk); SISCO winterschool »Surveying the Universe«, Obergurgl, Austria, February 12–19 (lecture); MPIA Ringberg meeting, March 29–April 1 (invited talk); Colloquium at the USM München, May 9; COSMOS team meeting, Kyoto, May 22–27; AG Tagung, Cologne, September 25–29 (talk); Workshop »Infrared diagnostics of Galaxy Evolution«, Pasadena, CA, November 14–16 (poster)

D. Semenov: MPIA Mini-workshop »Magnetic Fields in Disks«, Heidelberg, January 25 (talk); Sterrewacht Leiden, January 27 (invited colloquium talk); First External PSF Group Meeting, Buchenbach, May, 30–June 2 (talk); »Interstellar Reactions: From Gas Phase to Solids«, Pillnitz bei Dresden, June 5–9 (contributed talk); IAU Symposium 231 »Astrochemistry throughout the Universe: Recent Successes and Current Challenges«, Asilomar, USA, August 29–September 3 (three posters); Protostars and Planets, V, Hawaii, October 24–28 (poster); PLANET network meeting, SPITZER School, Leiden, November 14–18 (talk); MPIA Internal Symposium, December 8–9 (talk)

O. Schütz: Cerro Tololo International Observatory, La Serena, Chile, February 25 (invited talk)

J. Setiawan: Workshop »The Power of optical/IR Interferometry«, Garching, April 4–8 (poster, with R. Launhardt); PSF group Workshop, Buchenbach/Schwarzwald, May (talk); Workshop »Stellar Pulsation and Evolutions«, Rome, June 19–24 (talk); Kiepenheuer-Institut für Sonnenphysik, Freiburg, July 7 (invited talk); Asia Pacific Regional IAU Meeting, Bali, July 26–29 (talk); International Conference on Instrumentation, Communication and Information Technology, Bandung, Indonesia, August 3–5 (invited talk)

A. Sicilia Aguilar: PLANET Network Meeting, Leiden, November 14–18 (talk)

J. Staude: MNU-Tagung in der Pädagogischen Hochschule, Freiburg, 25. November (invited talk)

J. Stegmaier: Alpbach Summerschool, Alpbach, July 19–28 (talk); Annual Meeting of the Astonomische Gesellschaft, Köln, September 26–30 (talk); Frontiers in Astroparticle Physics, Vienna, November 25–27

J. Steinacker: Workshop Series »Grand Challenge Problems in Computational Astrophysics«, 4th IPAM Workshop »Transfer Phenomena«, Los Angeles, May 18; Protostars and Planets, V, Hawaii, October 24–28 (poster)

M. Stickel: ADASS XV, El Escorial, Spain, October 2–5 (talk); Annual Meeting of the Astonomische Gesellschaft, Köln, September 26–30 (talks, poster); EXTRA-HOT, Workshop on the Preparation of HERSCHEL Open-Time Key Projects, Leiden, October 20–21; AIRUB Bochum, November 2005 (invited talk)

M. Stumpf: 2005 Aspen Winter Conference on Astrophysics »Planet Formation and Detection«, Aspen, February 5–11 (poster); Protostars and Planets V, Hawaii, October 23–28 (poster); PPV Brown Dwarf Workshop, Hawaii, Oktober 29 (poster)

M. Swain: meeting in Nice/Villefranche on »Astronomy in Antarctica« (poster)

Ch. Tapken: Japanese-German Symposium »The Formation and Co-Evolution of Black Holes and Galaxies«, Regensburg, July 18–22 (talk); Ringberg Workshop »The role of wide and deep multi-wavelength surveys in understanding galaxy evolution«, Ringberg Castle, March 29–April 1

Roy Van Boekel: »From disks to planets«, Pasadena, March 7–10 (talk); Protostars and Planets, V, Hawaii October 24–28 (poster); Spitzer School/PLANET Network Meeting, Leiden, November 14–18 (invited talk); MPI für Radioastronomie, Bonn, June 22 (colloquium)

F. Van den Bosch: Workshop on Dark Matter Substructure, Massachusetts Institute of Technology, Cambridge, USA, November 14–18 (invited talk); Massachusetts Institute of Technology, November 18 (invited talk); University of Massachusetts, Amherst, USA (invited talk)

F. Walter: Meeting of the Bonn/Bochum Graduiertenkolleg, Bad Honneff, January 12–13 (invited talk); Joint Colloquium in Heidelberg, January 25; Colloquium in Basel, February 1; Colloquium in Göttingen, February 10; Winterschool in Obergurgl, February 14–18 (invited lecture); Workshop »Submillimeter Astronomy in the Era of the SMA«, Cambridge, USA, June 13–16 (invited talk); Colloquium at the Department of Astrophysics, American Museum of Natural History, NYC, June 20; Workshop »Open Questions in Cosmology«, Garching, August 22–26 (invited talk); DFG Schwerpunkt meeting, Kloster Irsee September 5; Annual Meeting of the Astronomische Gesellschaft, Köln, September 28–29 (contributed talk); Workshop »FIRM: Far Infrared Mission«, Leiden, October 16–18 (invited talk); Worshop »SPITZER Galaxy Evolution«, Pasadena, November 14–16 (poster with John Cannon)

S. Wolf: Wilhelm und Else Heraeus Physics School »Extrasolar Planetary Systems«, Bad Honnef, October 17–21 (invited talk): IAU Symposium 200, »Direct Imaging of Exoplanets – Science and Techniqes«, October 3–7 (talk); Annual Meeting of the Astronomische Gesellschaft, Cologne, September 29–October 1 (contributed talk); Workshop »Grand Challenge Problems in Computational Astrophysics. IV: Transfer Phenomena«, Institute for Pure and Applied Mathematics (IPAM), University of California at Los Angeles, May 16–20 (invited talk); ESO Workshop »The Power of Optical/Infrared Interferometry: Recent Scientific Results and Second Generation VLTI Instrumentation«, Garching, April 4–8 (talk); 2nd Heidelberg/Tübingen Workshop on Astrophysical Fluid Dynamics, MPIA, Heidelberg, October 24–28; »Protostars and Planets, V«, Hawaii, October 24–28 (posters); »Protostars and Planets, V«, Brown Dwarfs Workshop, Hawaii, October 29 (poster)

Lecture Series

H.–W. Rix gave a five part lecture series about »Observing Galaxy Evolution« on invitation of the Princeton University as »2005 SPITZER Lecturer«.

Popular Talks

A. Carmona Gonzalez: »El Sistema Solar y la formacion de sistemas planetarios«, Universitad Sergio Arboleda, Bogotà, May 12

R. Gredel: Almeria, June 7 (talk); El Ejidio, November 7

B. Häußler: MPIA Open Door’s Day, September 25

M. Hennemann: Arbeitskreis Astronomie, Studium Generale Universität Stuttgart, December 7 (talk »Mikrowellenhintergrund und Topologie«)

T. Herbst: »Building LBT, the Large Binocular Telescope«, Jugend Akademie at MPIA, June 17, and Kinder-Akademie Mannheim, December 13

K. Jäger: »Happy Birthday HUBBLE – 15 Jahre Weltraumteleskop HUBBLE«, Fachhochschule Göttingen, April 28; MPIA Open Door's Day, September 25

K. Kornet: Summer Camp of Almukantarat Astronomy Club (lectures)

D. Lemke: »The Orion Nebula«, Sternfreunde Nordenham, April 28; Are we alone in the Universe?«, Technical University, Darmstadt, June 15

K. Meisenheimer: »Wie es Licht ward im Universum«, Rüsselsheimer Sternfreunde, November 25

S. P. Quanz: »Origin and evolution of the chemical elements«, school teaching at the Anne-Frank-Schule Eschwege, March 21; »Unser Sonnensystem – Eine Reise zu den neun(?) Planeten«, MPIA Open Door's Day, September 25

A. M. Quetz: »Entstehung von Planetensystemen«. Lehrerakademie Donaueschingen, 7.6. »Entstehung von Planetensystemen«, Cinema »Roxy«, Neustadt/Weinstraße, June 28.

H.–W. Rix: Exhibition »Das Halbe Universum unter dem Odeonsplatz«, München, February 22 (opening speech); »100 Jahre Sternwarte Regensburg« Mai 25 (invited talk)

H.–J. Röser: »Die Suche nach den Urgalaxien«, Volkssternwarte Darmstadt, November 26

J. Setiawan: Institute of Indonesian Scientific Agency, Jakarta, August10 (talk); MPIA Open Door's Day, September 25

J. Steinacker: »Das ungelöste Rätsel der Sterngiganten«, MPIA Open Doors' Day, September 25

S. Wolf: Invited Lecture on Planet Formation Studies at the Heinz Maier-Leibnitz Award Ceremony, German Research Foundation, Bad Honnef, June 6

On September 25 the MPIA held an open day with numerous talks (B. Häußler, S. Hippler, K. Jäger, K. Jahnke, H. Klahr, S. P. Quanz, J. Rodmann, J. Setiawan, J. Steinacker)

Service in Committees

C. A. L. Bailer-Jones: Co-chair of the GAIA Data Analysis Coordination Committee; Member of the GAIA Science Team; Leader of the GAIA Classification Working Group; Member of the Scientific Organizing Committee of Commission 45 (Stellar Classification) of the International Astronomical Union

M. Basken: Member of the CAHA program committee

E. Bell: Member of thes ESO Time Allocation Committee

R. Gredel: Member of the Calar Alto Program Committee; Member of the Working Group for a Law against Light Pollution, Junta de Andalucia; Enhancement activities, Padova, May 23–24; Telescope directors review of access office, IAC, August 31; National Observatory of Athens Review, Athens, July and November; Telescope directors forum, Paris, September 14–15; OPTICON Executive Committee meeting, Leiden, September 20; Opticon board meeting, Rome, October 27–28

Th. Henning: member of ESO's Scientific and Technical Committee; member of ESO's Strategic Planning Group; Member of ESA's Astronomy Working Group; member of the SOFIA Science Council; member of the European ALMA Board; Chairman of the German Interferometry Centre FRINGE; President of the Science Council of the European Interferometry Initiative; Chairman of the LBT Beteiligungsgesells chaft; member of the Board of Directors of the LBT Corporation; member of the Executive Committee of the CAHA; member of the finding committee for the C3 Professorship »Theoretical Astrophysics« at the Heidelberg University; member of the DLR review panel »Extraterrestric Basic Research«; Vice chairman of the Scientific Council of the Kiepenheuer Institute for Solar Physics, Freiburg; Co-Investigator of the infrared instruments FIFI-LS (SOFIA), PACS (HERSCHEL), MIRI (JWST), CHEOPS (VLT), PRIMA-DDL (VLTI); member of the Astronomical Society and of the German Physics Society; member of the Deutsche Akademie der Naturforscher Leopoldina

T. Herbst: LBT Science and Technical Committee: Member since 1997, Chair from September 2000 - September 2005; Member of the ESA DARWIN Terrestrial Exoplanet Science Advisory Team; Member of the DARWIN GENIE Team; Member of the ESO Working Group »Instrumentation for ELTs« Member of the MPIA Internal Science Advisory committee; Member of the MPIA Computer Committee; Member of the MPIA PhD Advisory Committee

S. Hippler: member of the Review panel »Rayleigh laser beacon for the 4.2 m William HERSCHEL Telescope (WHT)« of the Isaac Newton Group on La Palma, Spain

K. Jäger: Co-ordinator for PR activities of LBT-B in Germany

U. Klaas: Member of the ISO Active Archive Phase Coordination Committee; Member of the Herschel Calibration Steering Group, member of the MPIA library committee

M. Kürster: Member of IAU Working Group »Extrasolar Planets«

D. Lemke: advisor of the MIRI Steering Committee; member of the LBT Tiger Team for the Evaluation of Financial and Scientific Status of the LBT, Tucson, Arizona, August/September

H.–W. Rix: Chairman of the Scientific Advisory Committee of the Potsdam Astrophysical Institute (AIP); Member of the Board of Trustees of the AIP; member of the Scientific Advisory Board of the Astronomisches Rechen-Institut(ARI) in Heidelberg; Member of the ESO Visiting Committee; Member of the Board of the Large Binocular Telescope Corporation (LBTC) and of the Board of the Large Binocular Telescope Beteiligungsgesellschaft (LBTB); Member of the Board of OPTICON; Member of the HST Time Allocation Committee (TAC); Member of the JWST/NIRSPEC Science Team; Member of the BMBF Referee Committee »Astrophysics and Astroparticke Physics«; Member of the DFG Emmy-Noether Panel; Member of the DFG Fachkollegien

H.–J. Röser: Secretary of the Calar Alto time allocation committee (until spring 2005); allocation of MPG observing time at the ESO/MPG 2.2 m telescope at La Silla (with Rainer Lenzen)

Jakob Staude: member of the Jury in the national contest »Jugend forscht«

Further Activities at the Institute

The Girls' Day at MPIA (April 28) was organized by Eva Schinnerer with the help of Cristina Afonso, Stefan Birkmann, Josef Fried, Stefan Hanke, Stefan Hippler, Ernest Krmpotic, Florian Rodler, Jutta Stegmaier, and Micaela Stumpf

The Undergraduate Research Project (Mini-Forschung) at MPIA was organized by Sebastian Wolf and carried out by Wolfgang Brandner, Dmitry Semenov, and Johny Setiawan

Experiments for the Practical Course for advanced physics students (Physikalisches Fortgeschrittenenpraktikum) where supervised by Stephan Birkmann, Siegfried Falter, Ernest Krmpotic, Sascha P. Quanz, Marc Schartmann, and Konrad Tristram

Practical courses for interested schoolboys and -girls (BOGy) where organized by Klaus Meisenheimer and carried out in the periods January 31–March 4, and October 24–28 with the help of Nadine Neumayer, Marc Schartmann, Jutta Stegmaier, and Stefan Birkmann (MPIA), Michael Biermann and Holger Mandel (LSW), and Ulrich Bastian (ARI)

In the course of the year, a total of 550 visitors in 20 groups were guided throug the MPIA (Axel M. Quetz, Stephan Kellner, Stephan Birkmann and others)

Cornelis Dullemond assisted to M. Bartelmann, ITA during his lecture course »Electrodynamics«

Boris Häussler assisted at the Teachers' continuation training carried out at the LSW, Heidelberg, September 19–23

Eva Schinnerer was the equal opportunity officer at MPIA

Jakob Staude, assisted by Axel M. Quetz, edited the 44. annual volume of the magazine »Sterne und Weltraum«

Jürgen Steinacker was visiting professor at the Observatoire de Bordeaux (June) and (since December) local coordinator of the AstroGrid-D Knot Heidelberg, which includes the institutes ARI, ITA, and MPIA.

Publications

In Journals wirh Referee System:

Abazajian, K., J. K. Adelman-McCarthy, M. A. Agüeros, S. S. Allam, K. S. J. Anderson, S. F. Anderson, J. Annis, N. A. Bahcall, I. K. Baldry, S. Bastian, A. Berlind, M. Bernardi, M. R. Blanton, J. J. Bochanski, Jr. , W. N. Boroski, H. J. Brewington, J. W. Briggs, J. Brinkmann, R. J. Brunner, T. Budavári, L. N. Carey, F. J. Castander, A. J. Connolly, K. R. Covey, I. Csabai, J. J. Dalcanton, M. Doi, F. Dong, D. J. Eisenstein, M. L. Evans, X. Fan, D. P. Finkbeiner, S. D. Friedman, J. A. Frieman, M. Fukugita, B. Gillespie, K. Glazebrook, J. Gray, E. K. Grebel, J. E. Gunn, V. K. Gurbani, P. B. Hall, M. Hamabe, D. Harbeck, F. H. Harris, H. C. Harris, M. Harvanek, S. L. Hawley, J. Hayes, T. M. Heckman, J. S. Hendry, G. S. Hennessy, R. B. Hindsley, C. J. Hogan, D. W. Hogg, D. J. Holmgren, J. A. Holtzman, S.-i. Ichikawa, T. Ichikawa, Z. Ivezic, S. Jester, D. E. Johnston, A. M. Jorgensen, M. Juric, S. M. Kent, S. J. Kleinman, G. R. Knapp, A. Y. Kniazev, R. G. Kron, J. Krzesinski, D. Q. Lamb, H. Lampeitl, B. C. Lee, H. Lin, D. C. Long, J. Loveday, R. H. Lupton, E. Mannery, B. Margon, D. Martínez-Delgado, T. Matsubara, P. M. McGehee, T. A. McKay, A. Meiksin, B. Ménard, J. A. Munn, T. Nash, E. H. Neilsen, Jr. , H. J. Newberg, P. R. Newman, R. C. Nichol, T. Nicinski, M. Nieto-Santisteban, A. Nitta, S. Okamura, W. O'Mullane, R. Owen, N. Padmanabhan, G. Pauls, J. Peoples, J. R. Pier, A. C. Pope, D. Pourbaix, T. R. Quinn, M. J. Raddick, G. T. Richards, M. W. Richmond, H.-W. Rix, C. M. Rockosi, D. J. Schlegel, D. P. Schneider, J. Schroeder, R. Scranton, M. Sekiguchi, E. Sheldon, K. Shimasaku, N. M. Silvestri, J. A. Smith, V. Smolcic, S. A. Snedden, A. Stebbins, C. Stoughton, M. A. Strauss, M. SubbaRao, A. S.

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