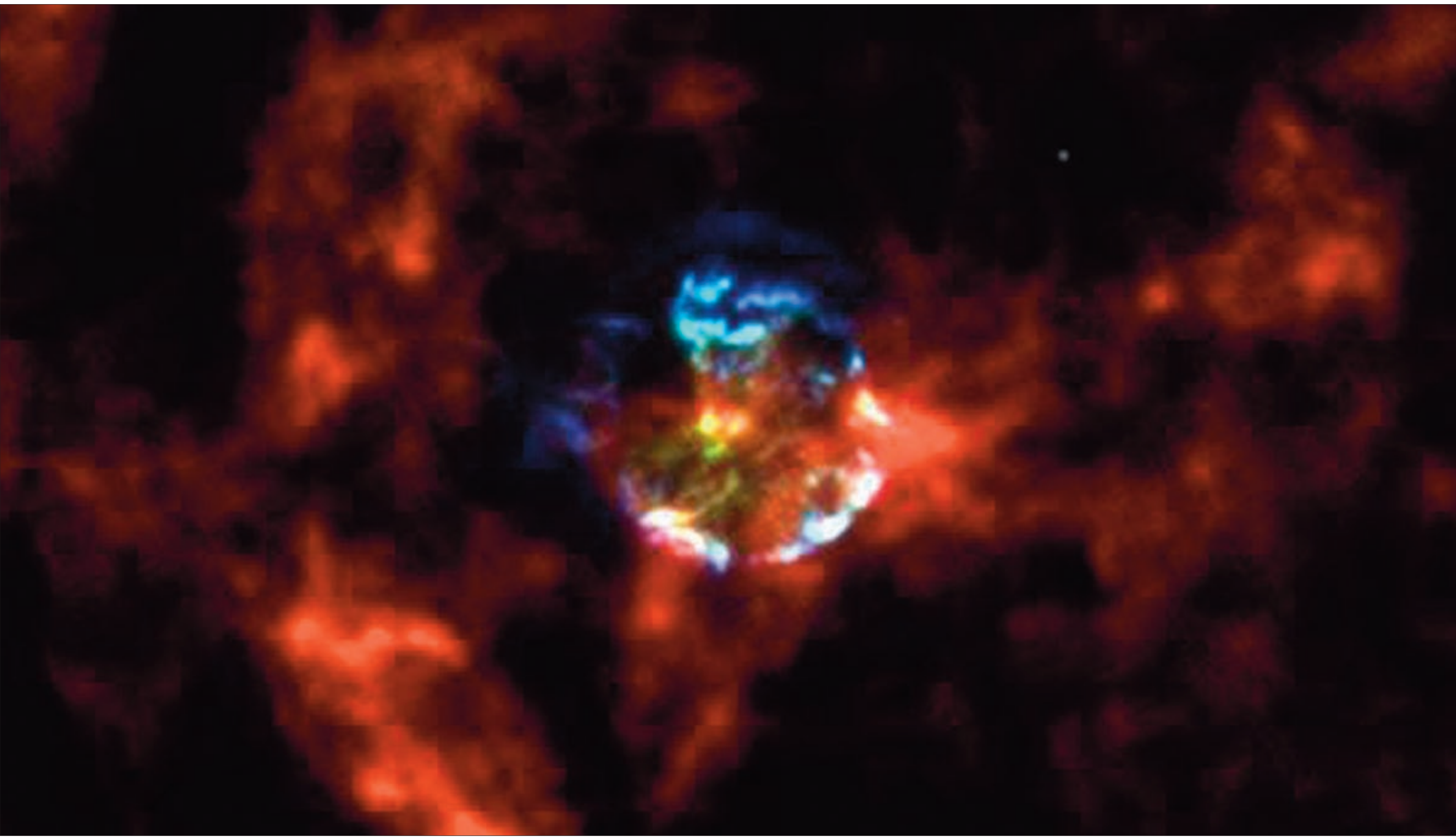
Max Planck Institute for Astronomy

Heidelberg-Königstuhl

Annual Report 2009



MAX-PLANCK-GESELLSCHAFT

Cover Picture:

An early result of the HERSCHEL mission.

The galactic supernova remnant Cassiopeia A is shown as a composite from PACS images at the three wavelengths 70 micrometers (coded blue), 100 micrometers (green) and 160 micrometers (red). The “warm“ dust within the remnant appears bluish-white, while the colder interstellar dust throughout the surrounding glows in red color. The new data answer an old question: How much dust is formed within a supernova remnant? The answer: only 0,07 solar masses! See the details on pages 34 – 39 (Chapter II.4).

Credits: Oliver Krause et al. / MPIA / PACS / ESA

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Max Planck Institute for Astronomy

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Staff: By the end of 2009, a staff of 344 was employed at MPIA (including externally funded positions). This includes 230 scientists, of which 56 were junior and visiting scientists, and 91 were PhD students.

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Preface

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

The year 2009 has brought a rich scientific harvest on topics ranging from the structure of the universe to exoplanets.

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

A special highlight was the flawless start of the Herschel mission and the smooth start of operation of the Pacs instrument.

On October 13, a festive groundbreaking ceremony marked the beginning of the construction phase of the "Haus der Astronomie", the new education and public outreach facility being erected on the Königstuhl.

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

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

Thomas Henning, Hans-Walter Rix

Heidelberg, August 2010

I. General

I.1 Scientific Goals

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

The research at the MPIA is organized within two scientific departments: Galaxies and Cosmology, and Planet and Star Formation. In addition to the staff in these departments, the Institute has seven independent Junior Research Groups (three Emmy Noether groups supported by the German Science Foundation DFG, and four groups supported by the Max Planck Society). Over the course of the year 2009, there were a total of 56 postdoctoral stipend holders, 91 PhD students, and 17 diploma and master's students and student assistants working at the institute. Strong ties exist between the Institute and the University of Heidelberg, with its Center for Astronomy (ZAH), both in teaching and research, for example through the International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics.

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

Galaxies and Cosmology

The "Realm of Galaxies"

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

Fig. I.1: The main building of the MPIA on the Königstuhl.

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

This means that the “realm of galaxies”, as Hubble called it, shows a high degree of order. How this order developed from the random mass fluctuations existing after the Big Bang is a fundamental question of galaxy formation and a central issue of cosmology.

There are three broad lines of explanation for the limited variety in the zoo of galaxies: Either, observed galaxies represent the only stable configurations. Alternatively, the cosmological initial conditions only permit the formation of the galaxies we see. Or, the overall process of galaxy formation results in a limited set of outcomes because it is very much self-regulating.

What questions would we like to answer?

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

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

What do we do to find the answers?

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

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

Planet and Star Formation

The link between stars and galaxies

The formation of stars is a fundamental process in the Universe, shaping the structure of entire galaxies and determining their chemical state. The formation of individual stars can be best studied in nearby molecular clouds. The study of star formation in other galaxies allows us to understand this process under physical conditions which can be very different from those in the Milky Way. Our studies of star formation in the

Magellanic Clouds allow an investigation of the effect of metallicity on the star formation process, which is certainly an important factor in understanding star formation in the early Universe.

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

Looking behind the curtain…

The earliest phases of star formation are obscured by enormous amounts of dust and gas and can only be detected by sensitive far-infrared and (sub-) millimeter observations. At later evolutionary stages, the objects "glow" at near- and mid-infrared wavelengths, and finally become visible at optical wavelengths. Our observing programs cover a wide range of wavelengths with a special emphasis on infrared and (sub-) millimeter observations.

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

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

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

The formation of planetary systems and the search for other planets

With the detection of the first extrasolar 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 submillimeter observations, numerical (magneto-) hydrodynamical simulations, and radiative transfer studies. Imaging with the Hubble Space Telescope and the wealth of data from the Spitzer Telescope is providing new insights into the earliest stages of planet formation. Improved spatial resolution from our adaptive optics program, infrared interferometry with large telescopes and long baselines, and the use of millimeter interferometers provide insights into disk structure and evolution on spatial scales relevant to planet formation. Gas evolution in disks is studied by high-resolution infrared spectroscopy and the accretion behaviour by multi-object spectroscopy

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

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

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

I.2 Observatories, Telescopes, and Instruments

The MPIA has been a key driver and partner in the construction and operation of two large ground-based observatories. During the 1970s and 1980s the construction of the Calar Alto Observatory, still the largest observatory on the European continent, had been the central focus of the MPIA, and the 2.2 and 3.5 m telescopes are scheduled for competitive observing programs. Since 2004 the observatory is jointly operated as Centro Astronomico Hispano Aleman (CAHA) by the Max Planck Society, represented by the MPIA, and the Consejo Superior de Investigaciones Científicas (CSIC), represented by the Instituto de Astrofísica de Andalucía (IAA), as an organization of Spanish law. Since 1997, the MPIA has been the coordinating institute for the German participation in the Large Binocular Telescope (LBT) on Mt. Graham near Tucson, Arizona. By the end of 2007, the second prime-focus camera was installed. The camera is now used for regular science programs. The year 2008 has seen the installation and the beginning of the commissioning of the LUCIFER instrument, jointly built by the State Observatory in Heidelberg, the MPIA, the MPE, the Ruhr University in Bochum and Fachhochschule in Mannheim. Science demonstration observations with this near-infrared multi-object spectrometer have commenced in December 2009. The MPIA also uses its 2.2 m telescope on La Silla, Chile, operated by the European Southern Observatory (ESO). As of April 1st 2009 in a new agreement between the MPG and ESO, the amount of time available at this telescope for MPG researchers has been increased from 25 to 75 percent.

The MPIA has a prominent and successful tradition of developing and building instruments for ground-based and space-based astronomical observations. Such observations are, almost by necessity, complementary. Ground-based telescopes usually have larger mirrors and there-

Fig. I.2: Aereal view of the Calar Alto Observatory.

fore more light-gathering power than space telescopes. By using cutting-edge techniques such as adaptive optics and interferometry – which the MPIA has played a leading role in developing – they can also achieve higher angular resolution. Space telescopes, on the other hand, are the only way to carry out observations in wavelength regions where our atmosphere absorbs the radiation or generates a bright background, as is the case, for example, in wide regions of the infrared spectral regime.

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

At the end of 2009 Herschel has provided the first data obtained within a number of key science programs with MPIA participation. The quality of the data is excellent and will provide the basis for the first scientific publications arising from Herschel to be published in a dedicated Astronomy & Astrophysics special issue scheduled for summer 2010.

The new generation of instruments for 8 m-class telescopes and space missions are too large and expensive to be built by a single group, such as the MPIA. At present, the Institute is therefore participating in, or leading a number of international collaborations for building scientific instruments for new large telescopes, thereby gaining access to the world's most important observatories. An example in the southern hemisphere is the Eso Very Large Telescope (VLT) in Chile, with its four 8m telescopes that can be linked to form a powerful interferometer. In the northern hemisphere, the MPIA is participating in the Large Binocular Telescope (LBT) in Arizona. This extraordinary telescope is equipped with two mirrors of 8.4 m diameter each, fixed on a common mount, making it the world's largest single telescope. With the current routine scientific use of the two prime focus cameras and the beginning of science demonstration observations with the near-infrared multi-object spetrograph Lucifer 1 in December 2009, the LBT has become a productive world-class observatory. In 2007, MPIA became the University of Hawaii's largest Partner in the international Pan-Starrs1 (PS1) project, which grants full access rights to the data from a 1.8 m wide-field telescope on Haleakala/Maui (Hawaii). The 1.4 Gigapixel camera – the largest digital camera ever built – was installed in August 2007 at this telescope.

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

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

Instrumentation for Ground-based Astronomy

The currrent activities of the MPIA in the area of ground-based instrumentation concentrate on interferometric instruments for the Eso VLT Interferometer (VLTI), high-fidelity imaging instruments for the LBT and the VLT, and survey instruments for Calar Alto. The MPIA is also involved in studies for future instruments for the European ELT (E-ELT).

VLTI instrumentation

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

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

Gravity is the successor of Prima. Like Matisse it will combine four VLT 8.2 m telescopes, but in the near-infrared. The Gravity consortium is led by MPE Garching; the partners include MPIA, l'Observatoire de Paris, and the University of Cologne. Assisted by a high-performance adaptive optics system, Gravity will provide precision narrow-angle astrometry and phase referenced imaging of faint objects over a field of view of 2″. This will permit astronomers to study motions to within a few times the event horizon size of the massive black hole in the Galactic Center, and potentially test General Relativity in its strong field limit. Other applications are the direct detection of intermediate mass black holes in the Galaxy, dynamical mass determinations of extrasolar planets, the origin of protostellar jets, and the imaging of stars and gas in obscured regions of AGNs, star forming regions, or protoplanetary disks.

High-resolution cameras

After its integration at MPIA, Lucifer 1, the first of two identical mid-infrared cryogenic imaging cameras and multi-object spectrographs for the LBT, was shipped to Mt. Graham in August 2008, followed by phases of installation and commissioning. This instrument built together with the Landessternwarte Heidelberg, the MPE Garching, the University of Bochum, and the Fachhochschule for Technology and Design in Mannheim, has become ready for scientific exploitation in December 2009. It provides a $4' \times 4'$ field-of-view in seeing limited mode. Once the adaptive secondary mirrors have been installed at the LBT, diffraction-limited performance can be expected for the two Lucifer instruments over a field of about $0\overset{'}{.}5 \times 0\overset{'}{.}5$. Adaptive optics will also permit users to achieve spectral resolving powers of several tens of thousands. Scientific applications for the multi-mode Lucifer instruments are many, including studies of star formation in nearby galaxies.

The largest instrumentation project at the MPIA is the near-infrared beam combiner Linc-Nirvana for the LBT, which presently is being assembled at the institute. As the PI institute, the MPIA leads a consortium with the Italian Observatories (Inaf), the MPIfR Bonn, and the University of Cologne. Linc-Nirvana is currently undertaking integration and testing at the MPIA as the various subsystems provided by the different project partners are being delivered. By coherent combination of the two LBT primary mirrors via Fizeau interferometry, Linc-Nirvana will provide diffraction-limited imaging over a $10\overset{''}{.}5 \times 10\overset{''}{.}5$ field of view in the 1 – 2.4 μm regime, with the spatial resolution of a 23 m-telescope. Multi-conjugated adaptive optics with up to 20 natural guide stars will ensure large sky coverage. Due to the panoramic high-resolution imaging and astrometric capabilities of Linc-Nirvana, scientific applications range from supernova cosmology, galaxy formation, and extragalactic stellar populations and star formation, to extrasolar planets, stellar multiplicity, the structure of circumstellar disks, and the imaging of solar-system planets and their atmospheres.

As Co-PI institute in a consortium with the Laboratoire d'Astrophysique de l'Observatoire in Grenoble, the Laboratoire d'Astrophysique in Marseille, ETH Zürich and the University of Amsterdam, the MPIA coleads the development of Sphere, a VLT instrument specialized for the imaging of Jupiter-like extrasolar planets. To overcome the huge brightness contrast between the planet and its host star, Sphere will use eXtreme Adaptive

Fig. I.4: The building of the Large Binocular Telescope (LBT) on Mt. Graham, Arizona. (LBTO).

Optics (XAO), coronography, and three differential imaging-capable focal plane subinstruments that will, respectively, employ polarimetry in the visual, dual imagery in the near-infrared, and integral field J-band spectroscopy.

Survey instrumentation

The current workhorse for MPIAs survey efforts is the OMEGA2000 near-infrared imager, in operation at the prime focus of the Calar Alto 3.5 m telescope since 2003. It provides a field of view of $15\farcm5 \times 15\farcm4$, and z to K-band sensitivity.

The successor of OMEGA2000 will be PANIC, the Panoramic Near-infrared Camera, which is a wide-field general purpose instrument for the Calar Alto 2.2 m telescope. PANIC is a joint development of the MPIA and the Instituto de Astrofísica de Andalucía. With four HAWAII2-RG detectors, it will provide a field of view of $30' \times 30'$. Surveys of extragalactic, galactic, and solar system objects will be possible as well. Some of the numerous possible science cases are gamma-ray burst hosts, supernovae, distance scales, high-redshift quasars, accretion disks, post AGB-stars, and X-ray binary counterparts.

MPIA has also build LAIWO, the Large Area Imager for the Wise Observatory (Israel). It is an optical camera that was re-installed at the observatory's 1m telescope in fall 2008. A mosaic of four CCD detectors with 4K × 4K pixels each provides a field of view of one square degree. The main scientific application is the photometric search for transiting extra-solar planets of Jupiter size.

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

Instruments for next generation telescopes

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

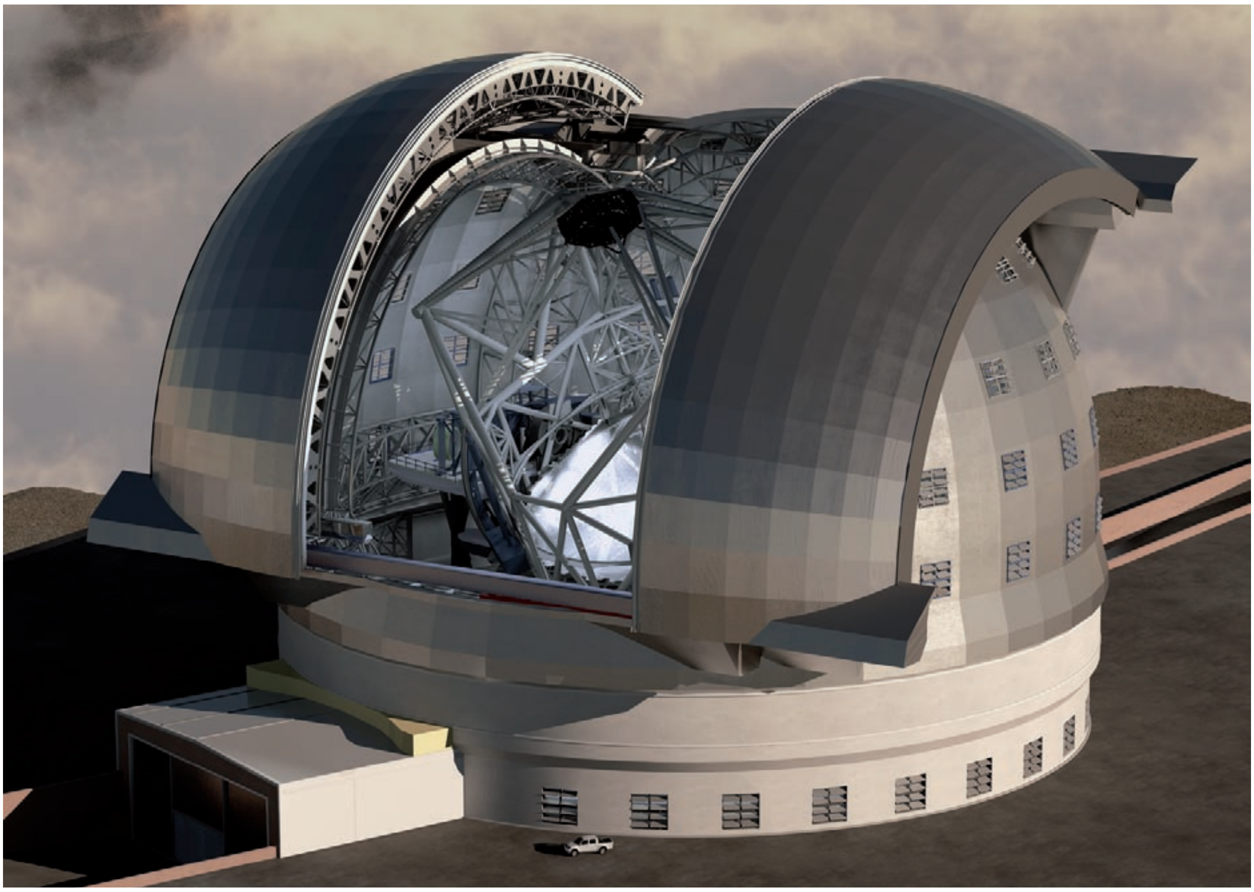
In December 2008, several concepts of the MICADO study were evaluated and down-selected for a phase A study. MICADO is a near-infrared imaging camera with multi-conjugated adaptive optics that will provide a spatial resolution exceeding that of the James Webb Space Telescope (JWST) by a factor of 6 to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

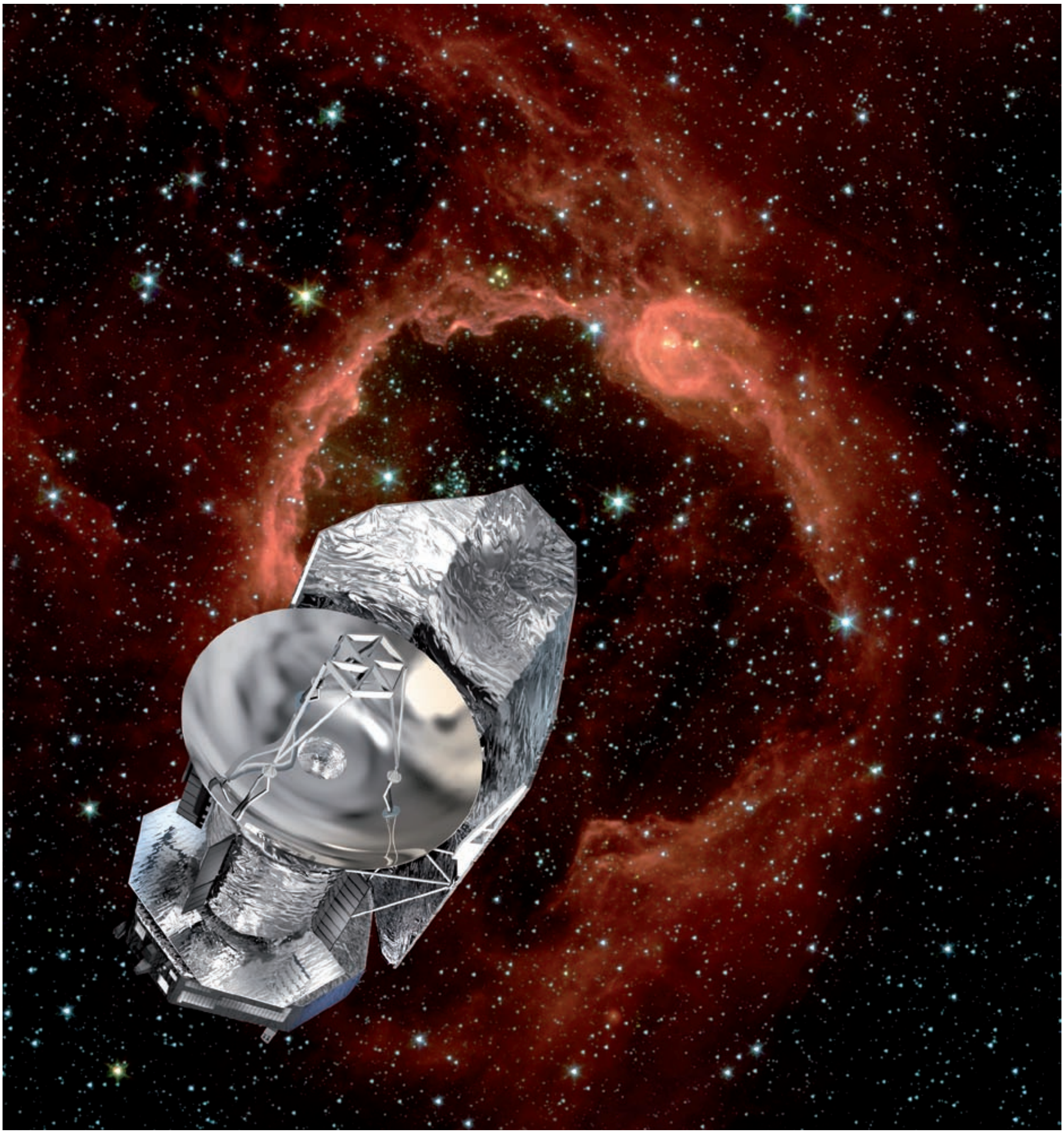
Instrumentation for Space-based Astronomy

Europe's new far infrared and submillimetre space observatory HERSCHEL has started its four year long mission with a picture-perfect launch aboard an ARIANE-5 rocket on 14th May 2009. The MPIA has been one of the major partners in the development of the PACS instrument which will enable imaging and spectroscopy in the wavelength range from 60 to 210 μm with unprecedented sensitivity and spatial resolution. The MPIA has been responsible for delivering the PACS focal plane chopper and for characterizing the large Ge:Ga spectrometer cameras and their – 270 °C readout electronics.

After successful delivery and check-out of the PACS hardware contributions, MPIA has been heavily involved in many PACS Instrument Control Center tasks. The Instrument Control Centre (ICC), located at the PI institute MPE in Garching, has the responsibility for operations, calibration and data reduction of the PACS instrument. MPIA is one of four institutes of the PACS consortium which are main manpower contributors to the PACS ICC. MPIA has coordinated a large number of tasks for the calibration of the PACS instrument and has been responsible for establishing the PACS performance verification phase plan and the central PACS calibration document. In particular, the MPIA team has exclusively carried out the detailed mission planning of all PACS performance verification phase operational days, utilizing dedicated software tools, and has delivered the observational data bases to the HERSCHEL Science Center at ESAC in Villafranca (Spain) and the Mission Operations Center at ESOC in Darmstadt (Germany). Currently, the MPIA

Fig. I.5: The European Extremely Large Telescope, E-ELT. (ESO).





team is building up a corresponding calibration plan for Herschel's routine phase. The MPIA team also ensured the optimum inflight setup of the Ge:Ga spectrometer detector arrays following a procedure developed in the MPIA space laboratory.

The MPIA is the leading institute in Germany for the development of instrumentation for the James Webb Space Telescope (JWST, Fig. I.7), to be launched in 2014 as the successor to the Hubble Space Telescope. JWST will be equipped with a folding primary mirror with a diameter of 6.5 m and four science instruments. As a member of a European consortium, MPIA is responsible for the development of the cryogenic wheel mechanisms required for precise and reliable positioning of the optical components in JWST's mid-infrared instrument Miri and is also leading the electrical system engineering of this instrument. Miri is designed for the wavelength range from 5 to 28 micron, and consists of a high-resolution imager and a spectrometer of medium resolving power.

Fig. I.6: On May 14th, 2009, after more than ten years of development, Herschel was liftet into space to start its mission. In chapter II.4 members of the Pacs team at MPIA present first scientific result.

In 2009 the flight model of the filter wheel mechanism was delivered for integration into the imager section of the MIRI instrument.

The MPIA also provides critical components for the second JWST instrument mainly developed in Europe, the near-infrared multi-object spectrograph NIRSPEC. This contribution, as well as our participation in the NIRSPEC science team, will provide the astronomers at MPIA with further excellent opportunities for powerful infrared observations. For the development of the precision optics of MIRI and NIRSPEC, the MPIA is closely cooperating with Carl Zeiss Optronics, Oberkochen, and Astrium GmbH, Ottobrunn and Friedrichshafen.

The MPIA is also leading a major data analysis aspect of ESA's GAIA project, a space observatory scheduled for launch in 2012. GAIA will be the successor to the HIPPARCOS astrometry satellite, exceeding the latter's sensitivity by several orders of magnitude. The satellite will measure positions, magnitudes, and radial velocities of one billion stars, in addition to numerous galaxies, quasars and asteroids. The telescope will provide photometric data in 15 spectral bands as well as spectra in a selected spectral range. Unlike HIPPARCOS, GAIA does not need to be provided with an input catalogue, but will measure systematically all accessible objects. Automatic object classification will thus be of major importance for data analysis. At present, concepts for coping with this demanding task are being developed at the MPIA (supported by a grant from DLR).

MPIA is involved in the mission studies within the ESA Cosmic Vision program. EUCLID has the goal of mapping the geometry of the dark Universe by studying the distance-redshift relationship and the evolution of cosmic structures. To this end, the shapes and redshifts of galaxies and galaxy clusters will be measured out to redshifts $z \sim 2$, that is, to a look-back time of 10 billion years, thereby covering the entire period over which dark energy played a significant role in accelerating the expansion of the Universe. The observing strategy of EUCLID will be based on baryonic acoustic oscillations measurements and weak gravitational lensing, two complementary methods to probe dark energy. The Euclid survey will produce 20 000 deg^2 visible and near-infrared images of the extragalactic sky at a spatial resolution of 0.″30. It will also yield medium resolution ($R \sim 400$) spectra of about a third of all galaxies brighter than 22 mag in the same survey area.

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

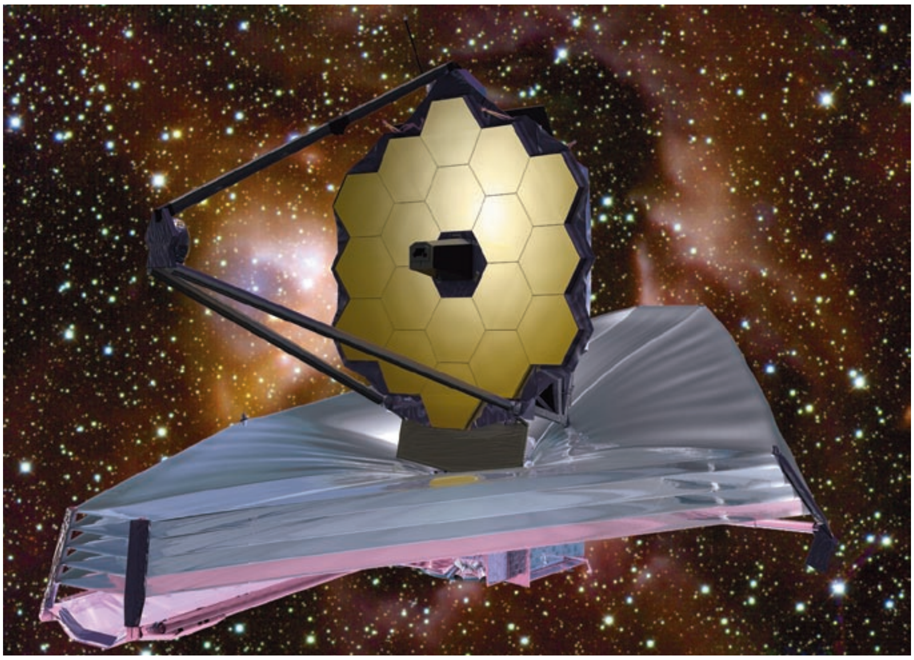


Fig. I.7: Design model of the James Webb Space Telescope (JWST), with its large segmented primary mirror and characteristic sun shield.

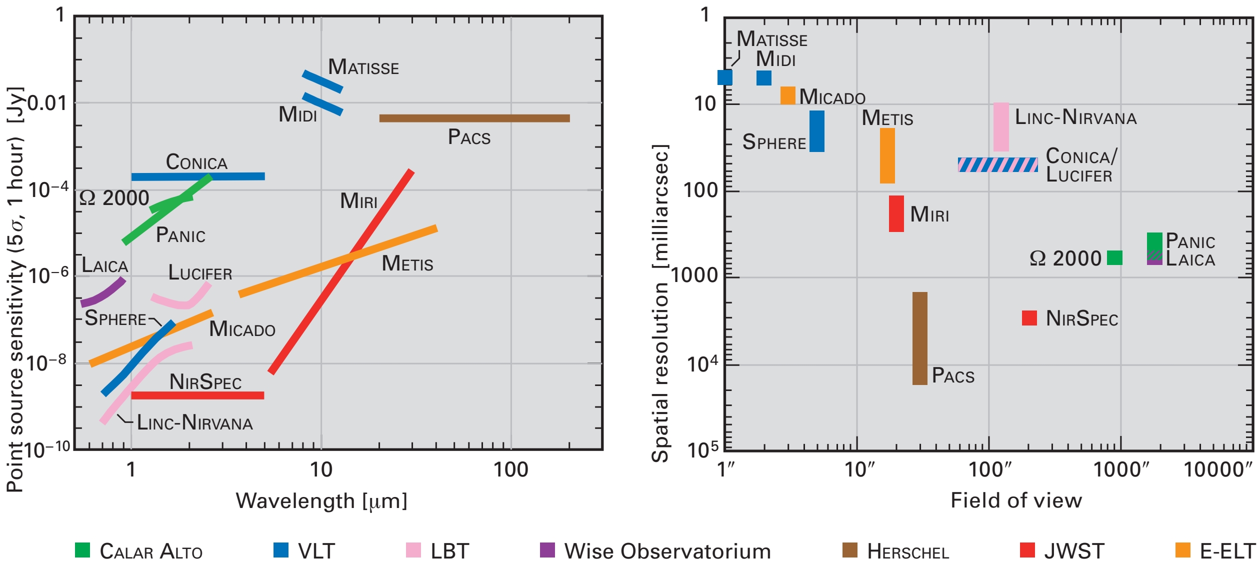


Fig. I.8: Capabilities of MPIA's major instruments. *Left:* sensitivity as a function of wavelength. *Right:* spatial resolution as a function of field of view.

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

Fig. I.8 gives an overview of the major instruments which are already working or are about to be put into operation. Sensitivity is shown as a function of wavelength (left), and spatial resolution as a function of the size of the field of view (right).

I.3 National and International Collaborations

MPIA is strategically well-placed: Heidelberg has become one of Germany's foremost centers of astronomical research. Cooperation with the High-energy Astrophysics Department of the MPI für Kernphysik, and with the institutes of the Center for Astronomy Heidelberg (ZAH), established in 2005, is manifold: the ZAH consists of the Landessternwarte, the Astronomisches Recheninstitut, and the Institut für Theoretische Astrophysik at the University. Also, the "International Max Planck Research School" for Astronomy and Cosmic Physics (IMPRS, see Section I.4) is run jointly by the Max Planck Institutes and the University.

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

The establishment of the German Center for Interferometry (Frontiers of Interferometry in Germany, or FrInGe), located at the MPIA, also emphasizes the Institute's prominent role in Germany in this innovative astronomical technique. The goal is to coordinate efforts made by German institutes in this field and to accomodate the interests of the German astronomical community in the European Interferometric Initiative. Another

Fig. I.9: Distribution of the partner institutes of the MPIA in Germany.

specific goal is the preparation of the next generation of interferometric instruments. This includes the preparation of second-generation instruments for VLTI, such as Matisse – an imaging interferometer consisting of four telescopes – and Gravity. Further tasks are: participation in the definition of new imaging capabilities of the VLT interferometer. FrInGe, together with other interferometric centers in Europe, is partaking in the establishment of the European Interferometry Initiative. The long-term perspective is to establish a European interferometric center for the optical and infrared wavelength region. In addition to MPIA, the following institutes are participating in FrInGe: the Astrophysikalisches Institut Potsdam, the Astrophysikalisches Institut der Universität Jena, the Kiepenheuer Institut für Sonnenphysik in Freiburg, the MPI für Extraterrestrische Physik in Garching, the MPI für Radioastronomie in Bonn, the University of Hamburg, the I. Physikalisches Institut der Universität Köln, and the Universities of Kiel and Munich.

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

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

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

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

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

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

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

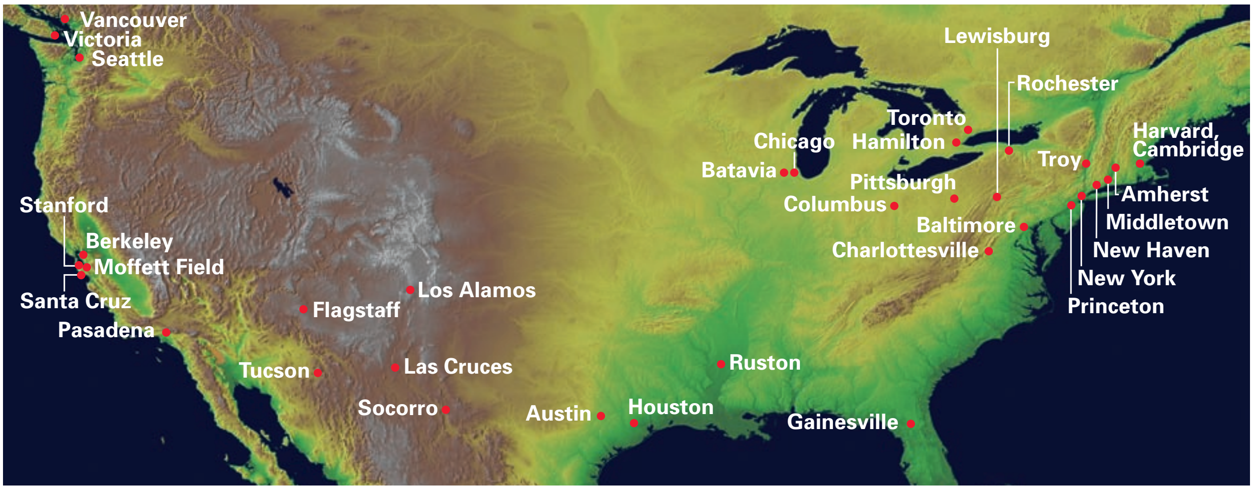
Elixir, an EU network dedicated to exploit the unprecedented capabilities of the NirSpec instrument on the JWST space mission, scheduled for launch in 2014.

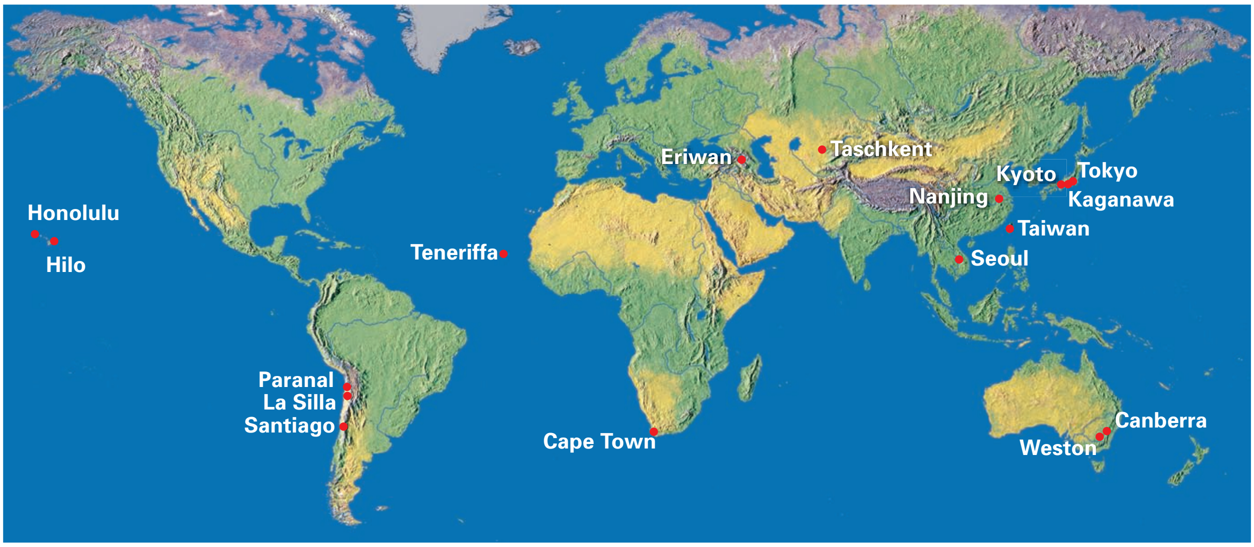
SDSS, the Sloan Digital Sky Survey, has revolutionized wide-field surveying at optical wavelengths. It is the most extensive imaging and spectroscopy sky survey to date, imaging about a quarter of the entire sky in five filters. The final catalogue will provide positions, magnitudes, and colors of an estimated one hundred million celestial objects as well as redshifts of about one million galaxies and quasars. The observations are made with a 2.5 m telescope specially built for this purpose at Apache Point Observatory, New Mexico. The project is conducted by an international consortium of US, Japanese and German institutes. The MPIA was the first of what is now twelve European partner institutes in SDSS and the only one to participate since the inception of surveying. In exchange for material and financial contributions to the SDSS, a team of scientists at the MPIA receives full access to the data. In 2005, the "original" SDSS was completed, but an extension, SDSS-II/Segue, focusing on Milky Way structure, was completed in mid 2008.

MPIA is a partner in Pan-Starrs1 (PS1), the most ambitious sky survey project since the SDSS, as part of the Pan-Starrs1 Science Consortium (PS1SC), using a dedicated 1.8 m telescope and the record-breaking 1.4-Gigapixel Camera (GPC1) with a 7-square-degree field of view. PS1SC is an international collaboration, involving the University of Hawaii, the MPE, Johns

Fig. I.10: Distribution of MPIA's international partner institutes.


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


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


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

Hopkins University, the Harvard-Smithsonian Center for Astrophysics/Las Cumbres Observatory Global Telescope, the Universities of Durham, Edinburgh and Belfast, and Taiwan's National Central University. It will operate the PS1 telescope during 2009 – 2012 to carry out multiple time-domain imaging surveys in its g, r, i, z, y filter set: the "3pi" survey of all of the sky visible from its location on Haleakala (Hawaii), a medium-deep supernova survey, as well as a dedicated survey of the Andromeda galaxy and a search for transiting planets. Including this planet search, MPIA scientists are leading four out of twelve key science projects within PS1SC, covering in addition the search for the most distant quasars and the coolest stars, as well as a comprehensive study of the Local Group's structure.

Within the Herschel Space Observatory project, MPIA is the largest Co-I instute in the Pacs instrument consortium, which consists of partners from 6 European countries. Herschel was successfully launched on May 14th , 2009. The institute leads two Herschel Guaranteed Time Key Programs on "The earliest phases of star formation" and "The Dusty Young Universe: Photometry and Spectroscopy of Quasars at $z \approx 2$" and participates in nine other Herschel Open and Guaranteed Time Key Programs. All these observing programs are large international collaborations.

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

Training the next generation of scientists and communicating astronomy to the public has a longstandig tradition on the Königstuhl. The “Haus der Astronomie”, a new center for education and public outreach, whose establishment had been decided in December 2008, is presently being erected on the Campus of the MPIA. The new institution will amplify and strengthen the efforts of all Heidelberg astronomers directed to this goal.

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

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

The International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics, which was established by the Max Planck Society and the University of Heidelberg, started in 2005. In 2009, the

Fig. I.11: On October 13, 2009 the construction site of the “Haus der Astronomie” on the MPIA campus was inaugurated with a festive groundbreaking ceremony. *From left to right:* Kurt Roth, Prorector of the University of Heidelberg, Manfred Bernhardt, Architekten Bernhardt + Partner, Darmstadt, Beate Spiegel, Office Manager of the Klaus Tschira Foundation, Thomas Henning, MPIA, Herbert Jäckle, Vice-president of the Max Planck Society, Eckart Würzner, Lord Major of the City of Heidelberg.

school offered 66 PhD students from all over the world a three-years education under excellent conditions in experimental and theoretical research in the field of astronomy and cosmic physics. It is supported by the five astronomical research institutes in Heidelberg.

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

Our initiative for the general public, a series of eight "Public Lectures on Sunday Morning", which was in its fourth year in 2009, always leads to a sold-out auditorium at the MPIA. Also, as in previous years, the one week long practical course which was offered to interested schoolchildren (BOGy), was immediately booked out – applicants came from all-over the country. And again, the MPIA participated in the Girls' Day, an annual nationwide campaign intended to encourage schoolgirls to learn about professions that are still mainly male-dominated. At various stations throughout the MPIA, about 60 schoolgirls got a general idea of the work at an astronomical institute.

On the occasion of the International Year of Astronomy 2009, during the winter term 2008 – 2009 we organized, in collaboration with the University, a series of 14 public lectures about "Galilei's first look through a telescope and its consequences today", which were given by renowned scholars from Heidelberg and abroad. The lectures regularly attracted an audience of more than 400 people to the central auditorium of the University. And on May 17, we had again an Open Day, with more than 4000 people from Heidelberg and surroundings, who came to visit "our astronomers on the Königstuhl".

Finally, the monthly magazine "Sterne und Weltraum" (Stars and Space, SuW) is published at the MPIA. This journal is intended for the general public and offers a lively forum both for professional astronomers and for the large community of amateurs in the field. A significant fraction of our readers are teachers and pupils. In parallel to SuW, didactic material is produced monthly within our successful project "Science to schools!", which helps teachers to treat interesting themes of current astronomical research during regular classes in physics and natural sciences. The project "Science to schools!" was sponsored by the Klaus Tschira Foundation from 2005 to 2009, and is now continued in the "Haus der Astronomie". The didactic material is made freely available through the web and is widely used in german-speaking countries.

The "Haus der Astronomie" – a Center for Education and Public Outreach

The "Haus der Astronomie", which was founded in December 2008, is presently being erected on the campus of the MPIA. In this facility, the educational and public outreach activities of all astronomers in Heidelberg will be concentrated and developed further. Information for the media and the general public, the development of didactic material, simulations and visualizations, and the training of university students and teachers of physics, astronomy and natural sciences will play a major role. The Klaus Tschira Foundation is financing the building and its technical equipment, and the Max Planck Society is operating the facility. In addition to these Institutions, the City of Heidelberg, the State of Baden-Württemberg, the University of Heidelberg are contributing to the personnel costs, and the astronomers at the MPIA and at the University's Center for Astronomy will also bring in activities related to public and educational outreach. During 2009, the center's core team was assembled, and construction work was started on October 13 with a festive groundbreaking ceremony.

II. Highlights

II.1 In which molecular clouds are stars formed?

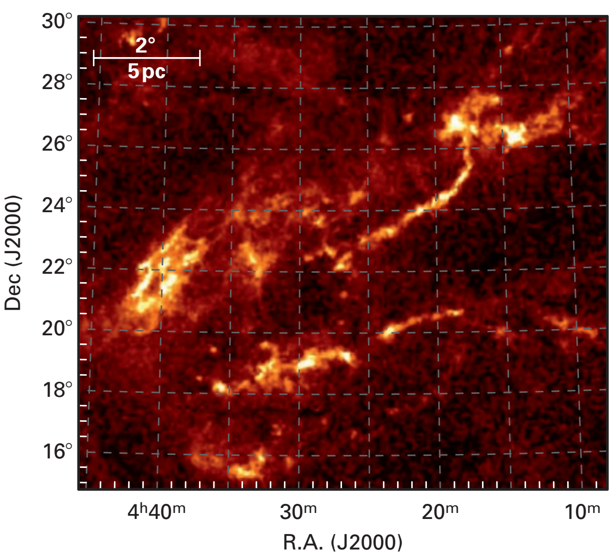
How is it possible to tell whether the large molecular clouds in our galactic neighborhood are already in the process of forming new stars deep down inside or will do so in the relatively near future? How do their internal structures differ?

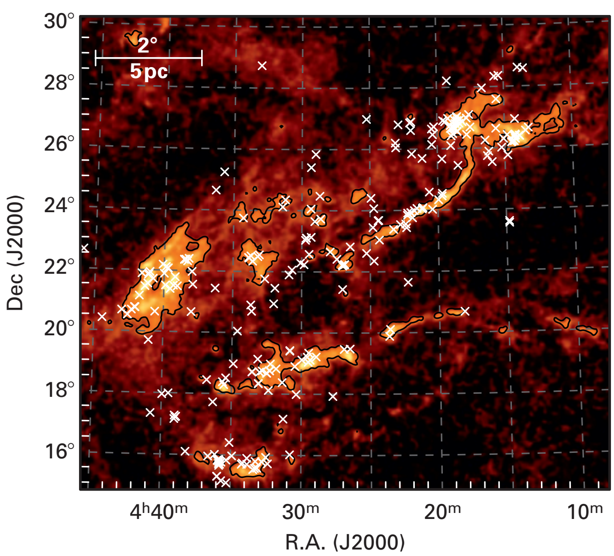
Stars are formed in molecular clouds – in their densest cores, to be precise. The internal structure of molecular clouds, and thus the presence of these dense cores as well, is determined by three factors: turbulent flows, the intrinsic gravitation of the gas itself, and magnetic fields that permeate the cloud. The question regarding the relative importance of these factors is an important topic of ongoing research.

Numerical model calculations show that turbulent flows in the interior of the molecular clouds lead to the formation of local density enhancements, thus generating a special probability distribution of the density values occurring in a given volume: Where the medium is isothermal and turbulent, and self-gravity can be neglected, a Gaussian normal distribution of the density values is to be expected. This probability distribution plays a key role in current star formation theories – it can be used to derive the initial mass distribution of the newly formed stars and the efficiency of the star formation in the molecular clouds.

What does the probability distribution of the density values in molecular clouds look like in reality? Is it possible to determine how the internal structure of starforming molecular clouds differs from that of clouds that are currently not forming any stars? Any Gaussian normal distribution of the density values which may be present thus remains even when the column density is observed instead of the spatial density – that is, the spatial density integrated along the line of sight through a molecular cloud. The usual way of determining the column density is to measure the line emission of the CO molecules or the thermal emission of the dust (the dust is intermixed with the gas and in a fixed ratio; the spatial density of the dust particles can therefore be considered to be an indicator of the gas density). The column density derived in this way depends strongly on the assumed temperature distribution in the cloud, however, and the method can only be applied if the column density is within a narrow interval.

Fig. II.1.1: *Left* – Extinction chart of the molecular cloud complex in the constellation of Taurus. The angular resolution is 2.4 arc minutes. *Right* – the regions of low extinction are emphasized in this logarithmic representation. The contour lines added correspond to a visual extinction of $A_V = 4$ mag: Within these contour lines (at higher extinction values) the probability distribution of the extinction values deviates from the normal distribution (see Fig. II.1.2). The crosses mark the positions of the known (young) stars embedded in the cloud.



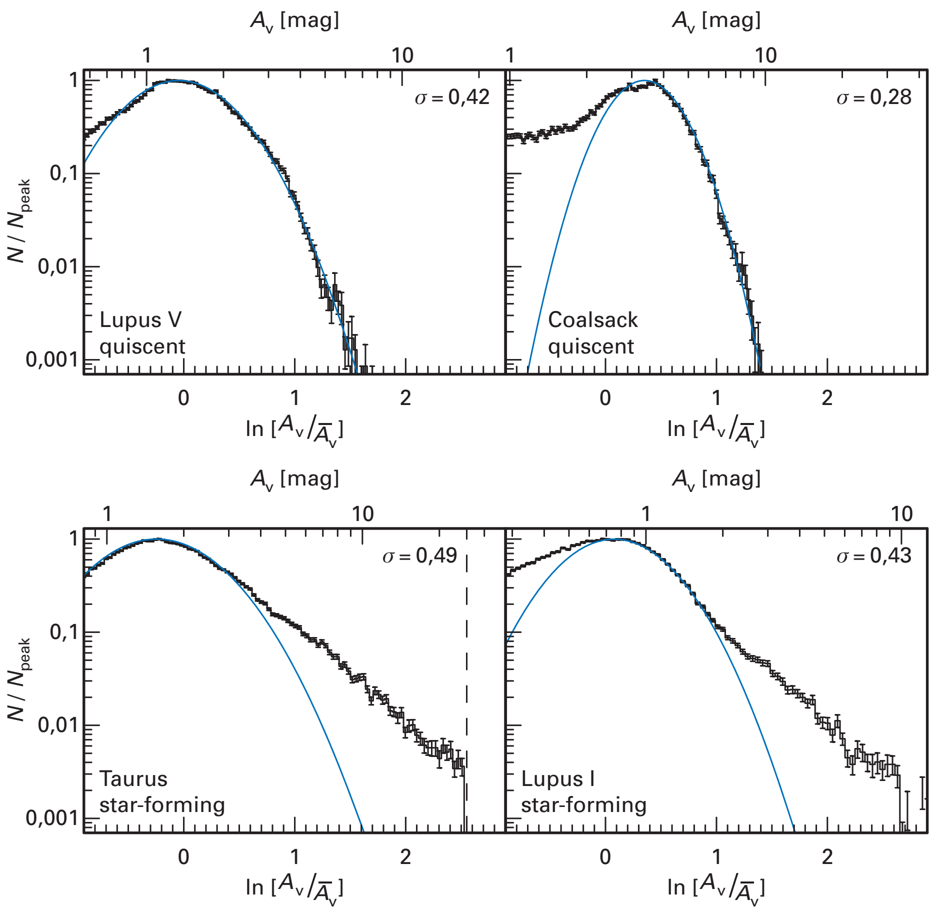


In the molecular clouds closest to us, the measurement of the dust extinction (the attenuation and discoloration of the light from stars located behind a molecular cloud by the dust present in the cloud) in the near infrared provides reliable column densities where the densities vary by a factor of 50 or so. The broad range of application of this method and the fact that it is independent of the temperature of the interstellar dust make it suitable for determining the column density in extended molecular clouds of low and medium density – even in cases where the method of CO line emission already fails because the gas densities are too high and the molecules then freeze onto the dust particles and are no longer able to be detected.

To investigate the internal structure of star-forming and non-starforming molecular clouds, the column density of all molecular clouds within 200 parsecs of the sun, which are larger than 4 parsecs or whose mass is more than 1000 solar masses, was charted at the MPIA using the method of dust extinction measurement. These amount to a total of 18 clouds, of which 13 contain young stellar objects and are therefore obviously in an active phase of star formation, and five clouds which display no signs of star-formation activity whatsoever. To derive the extinction in the clouds along the line of sight in the direction of the stars behind them, the colors of these stars in the J, H and K_S infrared bands were taken from the 2MASS catalog and compared to the colors of neighbouring stars that are located adjacent to the molecular clouds from our point of view. The extinction contribution of the cloud thus derived was used to derive the column density within the cloud for every line of sight to a star located behind the cloud, and was used to construct the column density chart or extinction chart of the molecular cloud. The data were smoothed to give a uniform resolution of 0.1 parsec (corresponding to 2 arc minutes at a distance of 170 parsecs). This corresponds to the Jeans length of a cloud core which has a temperature of 15 Kelvin and a gas density of 50 000 molecules per cubic centimeter (if the cloud core is compressed by external influences to below its Jeans length, its self-gravity dominates and its star-forming collapse starts).

Fig. II.1.1 shows the extinction chart of the Taurus complex as an example. The probability distribution of the extinction values was derived from such charts for all of the cloud complexes investigated. Two examples of each of these distributions are shown in Fig. II.1.2

Fig. II.1.2: Normalized probability distribution of the extinction values in the non-star-forming cloud complexes Lupus V and Coalsack (*top*) and in the star-forming cloud complexes Taurus and Lupus. I (*bottom*). The excess of high extinction values or column densities in the star-forming cloud complexes is conspicuous.



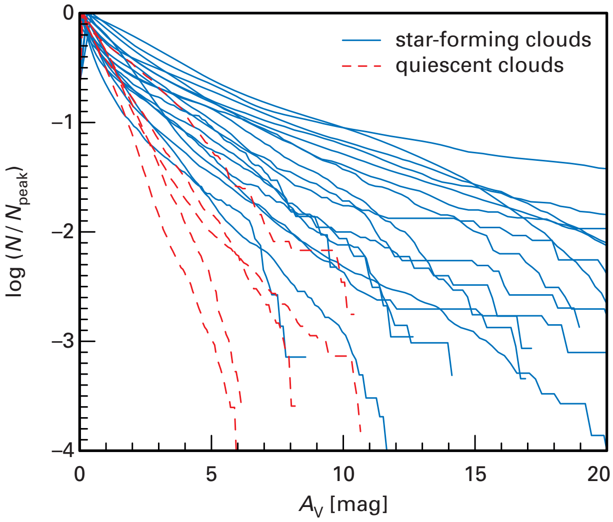


Fig. II.1.3: Cumulative representation of the probability distributions of all molecular clouds investigated. This representation shows which fraction of the mass of a molecular cloud is in columns that correspond to an extinction which is higher than a certain value shown on the abscissa. Obviously the mass in star-forming clouds is distributed over denser regions than in non-star-forming clouds.

for non-starforming cloud complexes (Lupus V and Coalsack) and for starforming cloud complexes (Taurus and Lupus I). Close to their maximum, the distributions show the characteristic, theoretically expected shape of a Gaussian normal distribution, which turns into a power law towards higher extinction values. This excess of higher extinction values is strongly developed in the starforming clouds and absent completely in the non-starforming clouds.

The cumulative representation of the probability distributions in Fig. II.1.3 is also interesting. It shows which fraction of the mass of the molecular clouds is present at column densities or extinction values that are higher than the value which corresponds to a specified extinction. There is also a clear distinction between starforming and non-starforming molecular clouds. In the former, a significantly higher fraction of the total mass is to be found in regions of higher density. Starforming clouds thus have around ten times as much matter in columns with $A_V > 5$ mag, for example, and one thousand times more in columns with $A_V > 15$ mag, compared to non-starforming clouds.

Theoretically, it is to be expected that turbulence in molecular clouds leads to the formation of density enhancements whose mass spectrum follows a Gaussian normal distribution. The excess of intrinsic gravitation, in contrast, leads to strong deviations from this distribution as soon as extinction values of $A_V > 5$ mag are present. The results of this study fit in well with the idea that the internal structure of the molecular clouds is fundamentally characterized by turbulent motions at the beginning of their development. In this phase, the mass spectrum of the density enhancements in their interiors follows a Gaussian normal distribution, as is actually the case in non-starforming cloud complexes. In the course of time the intrinsic gravitation becomes dominant in the most massive density enhancements in the interior of the clouds and concentrates an ever-increasing fraction of the cloud gas in increasingly denser structures. This is where new stars soon begin to form.

Jouni Kainulainen, Henrik Beuther, Thomas Henning,
in collaboration with:
René Plume, University of Calgary.

II.2 Where were the cometary crystals baked?

Science has long pondered over the question as to how small silicate crystals, whose formation requires a burning hot environment, found their way into the interior of ice-cold comets which were formed far away in the freezing cold outer reaches of the solar system. These crystals should originally have existed as amorphous silicate particles in the dense cloud of gas and dust, which later gave birth to the solar system. This mystery has now been solved by researchers from Heidelberg, Budapest and Leiden with the aid of infrared observations with the SPITZER space telescope.

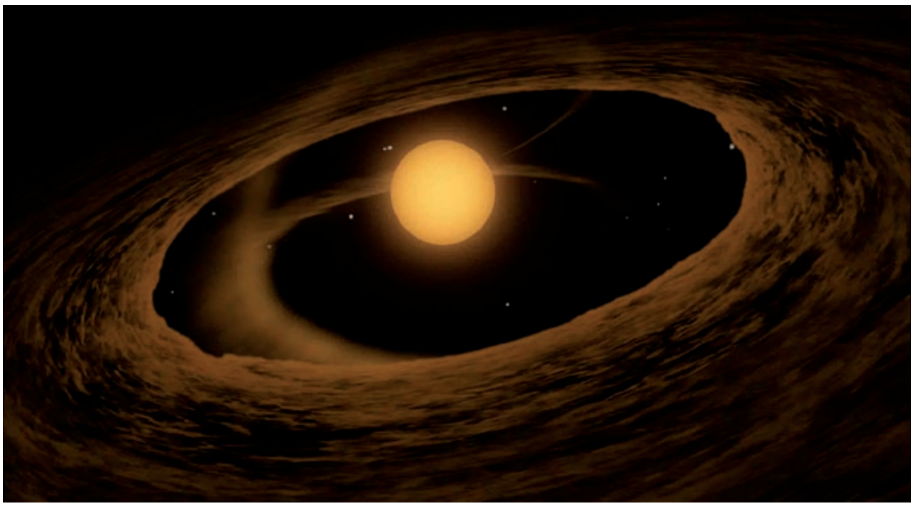
EX Lupi is a young star that is very similar to our Sun as it was four and a half billion years ago. The star has two characteristic features that are typical of very young stars: on the one hand, it is encircled by a dense disk of dust and gas where, according to our present thinking, its system of planets is currently being formed. On the other hand, every four to five years or so it experiences a brightness outburst that lasts between one and several months, and during which its brightness increases five- to tenfold. Such outbursts are triggered when the circumstellar disk becomes unstable and larger quantities of its matter collapse into the star (Figs. II.2.1 and II.2.2); and every 50 years or so there is a particularly intense outburst. The sun probably also went through such an active phase with irregular brightness outbursts of variable intensity in its earliest infancy.

Fig. II.2.1: A gravitational instability in the circumstellar disk causes larger quantities of gas and dust to collapse onto the central star.

The astronomers had already recorded an infrared spectrum of EX Lupi with SPITZER in 2005, while the star was in a quiescent phase. This spectrum (Fig. II.2.3b) shows the emission typical of the amorphous silicate particles of the interstellar dust (Fig. II.2.3a) and contains no indication of the presence of crystalline silicates. However, on April 21, 2008 researchers caught the star during one of its brightness outbursts. Although the outburst had already passed its peak, the star was still around 30 times its normal brightness. This second spectrum (Fig. II.2.3c) is significantly different from the first – it shows that at this point in time not only the amorphous silicates but also a crystalline form was present, namely forsterite, a mineral that is observed in the circumstellar disks of young stars, as well as in comets in our solar system (see Fig. II.2.3d). The temperature of the crystals at the time of observation was significantly higher than the temperature of the disk during the quiescence of the star.

This result means that the astronomers probably became the first witnesses to the crystallization process: it appears that the crystals are formed by the heating and annealing of the silicate particles near the surface of the thick, inner disk of dust and gas during the brightness outbursts of EX Lupi. During the annealing the material is heated to a temperature where its chemical bonds are broken open and new, different types are formed (Fig. II.2.4): This causes the physical properties of the particles to change as well.

These findings offer a completely new approach to understanding the formation of cometary crystals. Immediately after they are created in the optically thick disk, the crystals impress their characteristic feature on-



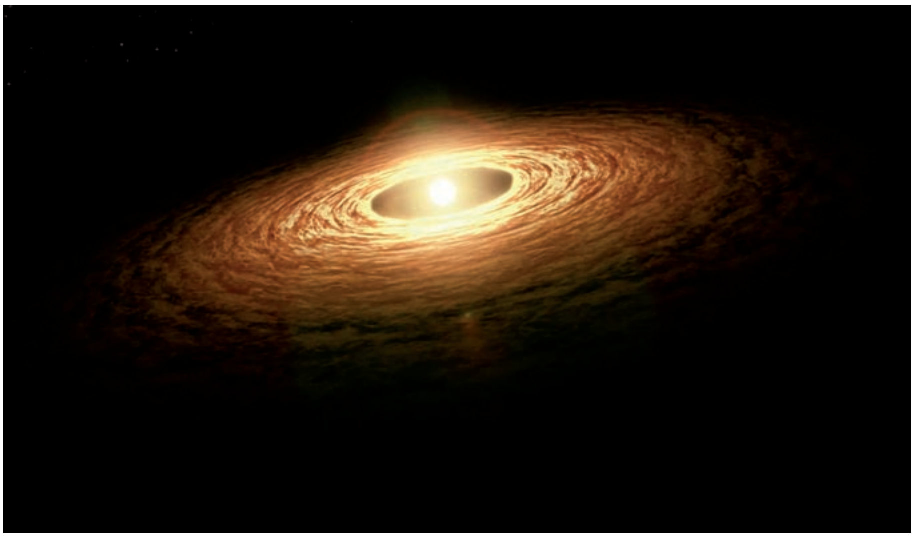
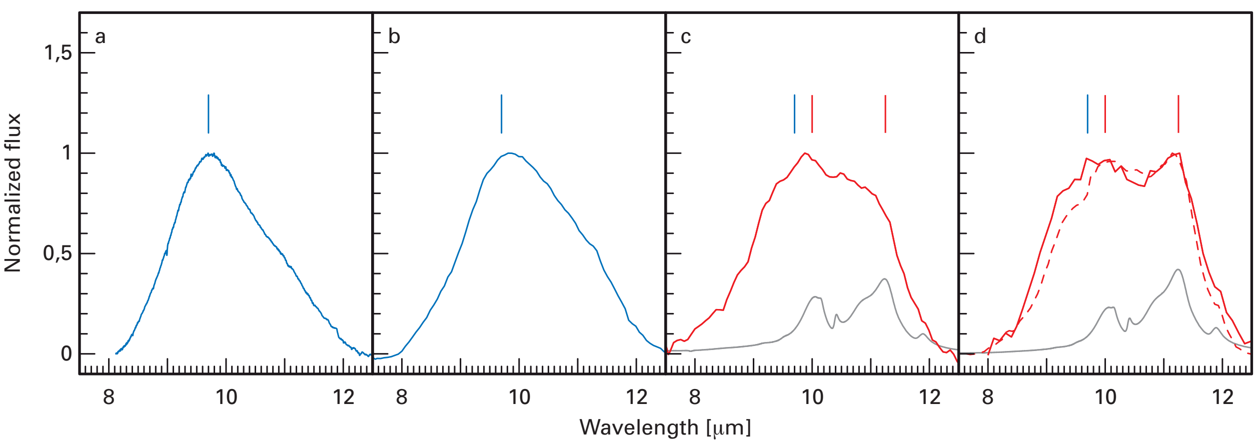


Fig. II.2.2: The collapse of gas and dust masses onto the central star brings about a brightness outburst of the central star and causes the layers of the disk close to the surface to heat up.

to the observed spectrum as long as they remain concentrated on its surface. Later they mix with material that is further towards the center; therefore, every outburst of the central star increasingly enriches it with crystalline silicates. As long as the system is very young, the crystalline silicates can only be observed during the outbursts when they are concentrated on the surface of the optically thick disk.

Up until now, the researchers had considered two other ways in which annealing could form the crystalline silicates observed in comets and circumstellar disks: either the material in the innermost region of the disk is heated over a longer period of time by the radiation of the young star – however, this contradicts the finding that the spectrum acquired in the normal state of the star contains no indication of crystalline silicates. Or a larger body, a juvenile planet, for example, triggers a shockwave within the disk which transfers a lot of energy onto the dust particles in a short period of time. They are thus heated up to the temperature required for the crystallization and subsequently cool down at a similar rate. The high tem-

Fig. II.2.3: Normalized spectra of the silicate emission in the wavelength range between 8 µm and 12 µm. *a)* Emission of amorphous silicate particles of the interstellar medium; *b)* Spectrum of EX Lupi in a quiescent phase, measured with the SPITZER spectrograph on March 18, 2005; *c)* The same, taken during an outburst of EX Lupi on April 21, 2008; *d)* Spectra of the comets Halley (*red, solid*) and 9P Tempel 1 (*red, broken*) measured from the ground. In all images the blue vertical lines mark the position of the maximum for amorphous silicate measured in the laboratory; the grey curves in Figs. *c)* and *d)* show the emissivity of pure forsterite measured in the laboratory at temperatures of 1250 K and 300 K. The red vertical lines in Figs. *c)* and *d)* mark the maxima of these spectra.



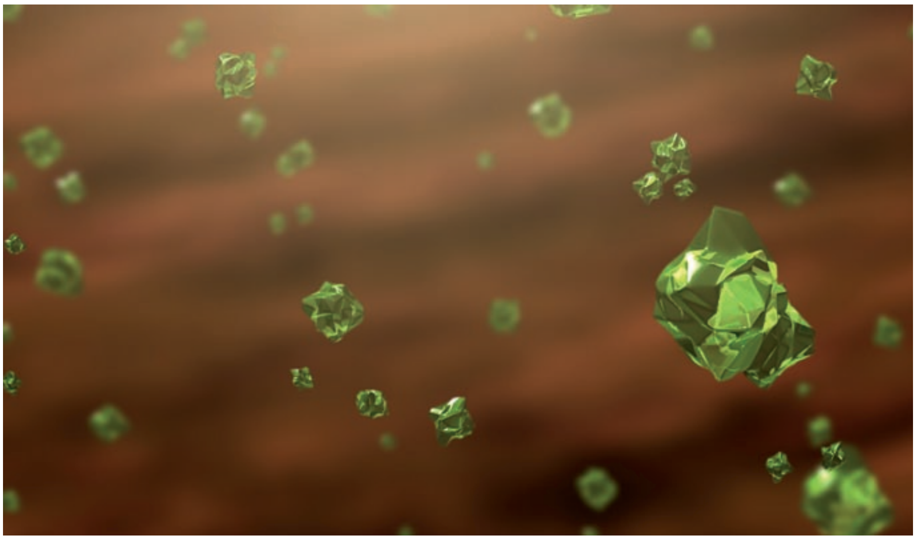
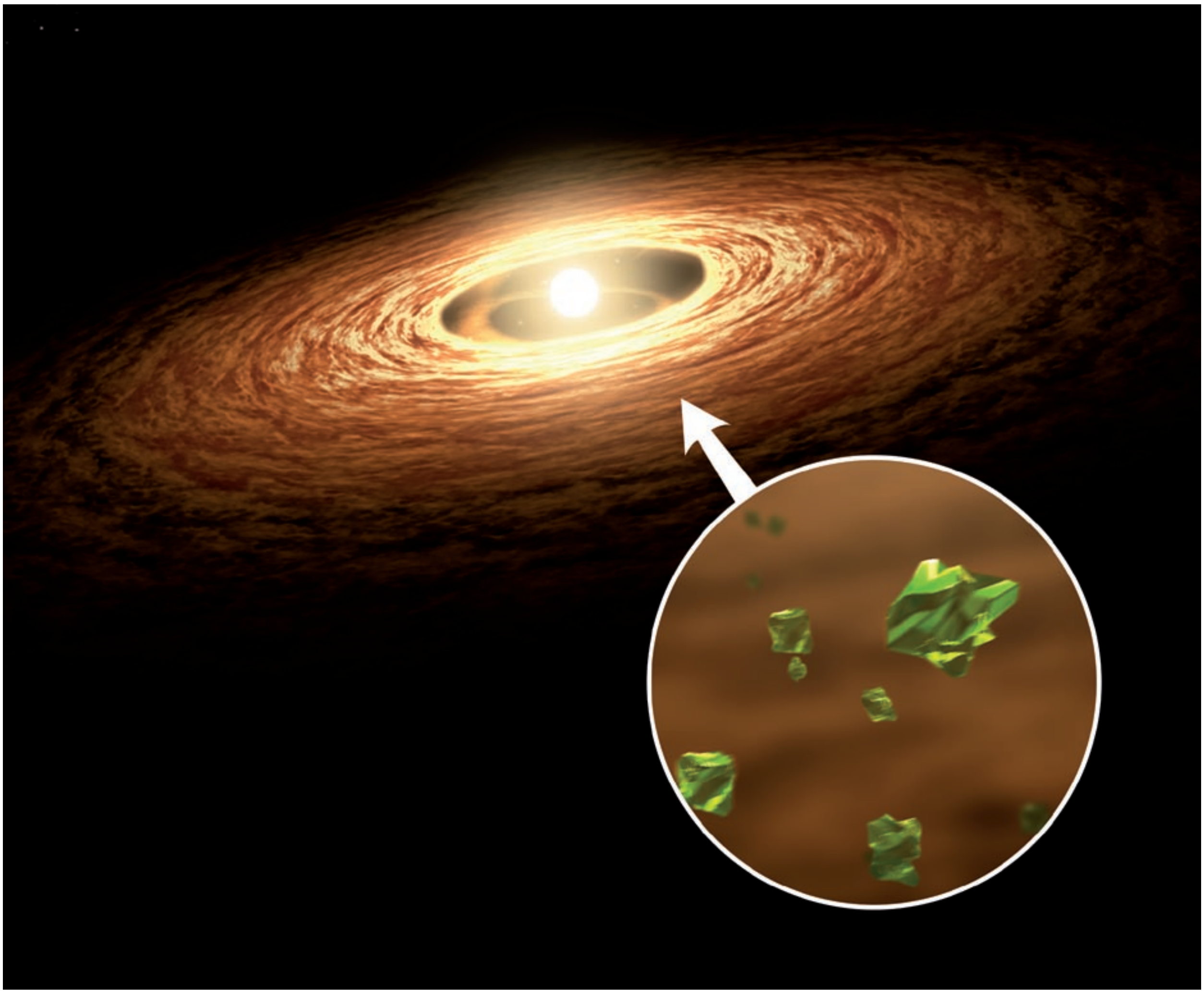


Fig. II.2.4: (*top*) The amorphous dust particles in the layer of the disk close to the surface are heated, then cool again and thus take on the crystalline structure and the green color of forsterite.

Fig. II.2.5: (*bottom*) Repeated brightness outbursts of the young central star cause the enrichment of the forsterite crystals in the circumstellar disk. They then become part of the comets. (All pictures: NASA/JPL/Caltech/MPIA)



perature of the crystal, which can be observed during the relatively long outburst, contradicts this second model; however, because one would expect that, immediately after the shock, the temperature of the silicate particles rapidly drops back to its normal value.

The observations of Juhász and colleagues therefore do not fit into either of the two previous scenarios. The authors of this study therefore conclude that a third process not considered thus far affects the crystallization by annealing – that is, the heating of the amorphous silicates by the brightness outburst of the central star. During the active phase of the young stars, which is characterized by many outbursts, the crystalline silicates accumulate in their circumstellar disks and then become part of the comet nuclei which are forming (Fig. II.2.5).

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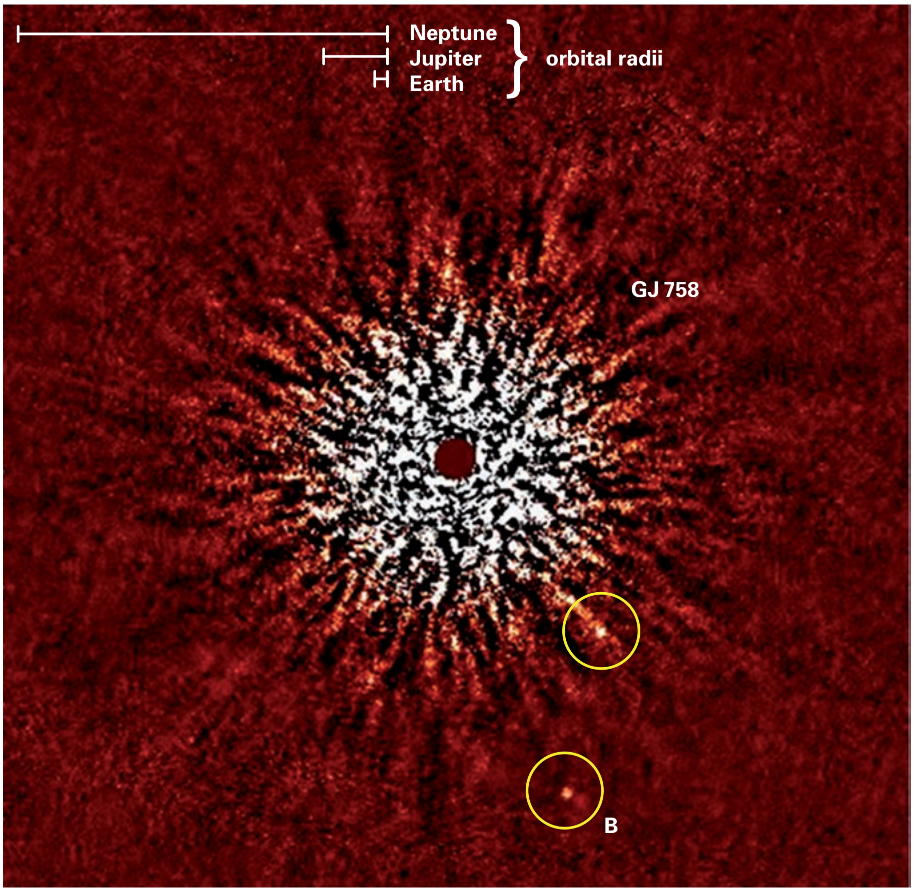
II.3 First direct image of a cool planet orbiting a sun-like star

The very first observations with HiCiao, the world's newest instrument in the search for extrasolar planets, have led to the discovery of G 758 B, the low-brightness companion of the star GJ 758. This is possibly the first direct observation of a cool extrasolar planet orbiting a Sun-like star. The mass of GJ 758 B is estimated to be between 10 and 40 Jupiter masses. It is therefore either a giant planet or a low-mass brown dwarf. Its distance from the central star is of the same order of magnitude as the distance of the planet Neptune from the sun. The temperature of GJ 758 B – 600 Kelvin (330 degrees Celsius) – makes it the coldest companion of a Sun-like star ever to be imaged directly, and thus the companion most similar to the planets of the solar system.

More than 450 exoplanets (planets orbiting a star other than the Sun) are currently known. Most of them have been detected indirectly, by observing how they affect the movement or the brightness of their central star. Much more difficult is the direct imaging of an exoplanet, as the central stars are very much brighter than their planets – such a venture is like trying to photograph a glowworm sitting right next to a floodlight from a distance of a kilometer. However, when one does succeed in directly imaging an extrasolar planet, the scientific benefit is always considerable, as the images provide valuable information on the orbit of the planet and on the temperature and chemical composition of its atmosphere.

With the aid of the 8-meter Subaru telescope on Mauna Kea (Hawaii) scientists have now thus succeeded in discovering a new, as yet unknown planet candidate which orbits the star GJ 758 in the Lyra constellation and has been given the designation GJ 758 B. The latest adaptive optics was used to remove the blur caused

Fig. II.3.1: This image of GJ 758, taken in August 2009 at the Subaru telescope with the HiCiao instrument in the near-infrared, shows the discovered companion GJ 758 B. The second circle marks a background star. Without the special technology of "angular differential imaging" used here, the light of the central star would hopelessly eclipse the images of both planetary candidates. (Photo: MPIA/NAOJ).



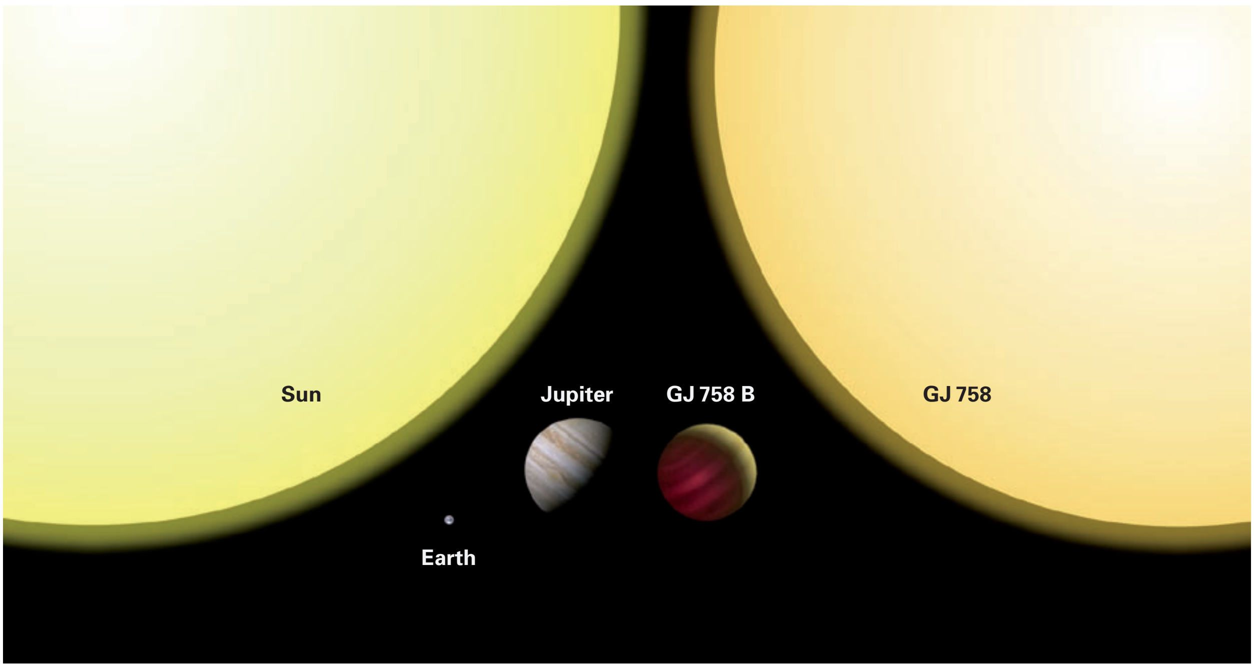
by turbulences of the Earth's atmosphere. Although the planet's tiny signal is drowned out by the residual halo of the central star on every single image, the clever combination of time sequences of individual images, so-called "Angular Differential Imaging" (ADI), enabled the astronomers to suppress the halo of the central star to such an extent that the weak glow of the companion GJ 758 B became visible in the final image (Fig. II.3.1).

Before this discovery, only ten possible exoplanets had been imaged directly; however, in all of these cases the systems were very different from our solar system: either the companion orbits its central star at a great distance (several hundred times greater than the distance Earth-Sun), or its temperature is higher than 1000 Kelvin (and thus corresponds more to that of a star than a planet); or the central star is very dissimilar to the Sun. Compared to these other candidates, GJ 758 B has much more in common with the planets in our own solar system: it orbits a Sun-like star at a distance that corresponds to those of the outer planets of the solar system – projected into the sky, its distance to its central star is roughly the same as the distance between Neptune and the sun. With the data available to date, it has only been possible to estimate the true size of its orbit; most probable is an average distance from the central star of 59 astronomical units (compared to 39 astronomical units for Pluto's orbit).

Especially interesting is the temperature of the planet, which is low compared to the exoplanets successfully imaged so far, yet nevertheless 550 to 640 Kelvin or 280 to 370 degrees Celsius – this corresponds to the temperature of a domestic oven or the temperature on the side of the planet Mercury, which is turned towards the Sun! GJ 758 B is therefore the coldest companion of a sun-like star ever to be imaged directly. The remotest planet of our solar system, Neptune, receives only about 1/900 of the sunlight which reaches Earth, and has a surface temperature of only around 70 K (–200 °C). GJ 758 B is at least the same distance from its central star as Neptune. Its significantly higher temperature points to this body still being in the contraction phase, during which the young, massive gas planets convert their gravitational energy into heat. The temperature, age and mass of such a contracting body are related: the more mass it has, the longer it takes for it to radiate its surplus heat into space and achieve its equilibrium temperature. This also explains why the mass of GJ 758 B cannot be determined more accurately: its measured infrared brightness corresponds either to that of a 700 million-year-old planet with 10 Jupiter masses or that of an 8700 million-year-old companion with 40 Jupiter masses. Since the central stars are formed at the same time as their planets, an accurate determination of the central star's age would remove this uncertainty; the observation data available to date, however, do not yet allow such an age determination.

GJ 758 B was detected during two independent observation runs in May and August 2009. The images clearly show that it is no mere coincidence that GJ 758 B and the star GJ 758 are close to each other in the sky. Just like numerous other close stars, GJ 758 has a so-

Fig. II.3.2: Size comparison between (*from left to right*) the Sun, Earth, Jupiter, the exo-planet GJ 758 B and its central star GJ 758. At a temperature of between 550 and 640 Kelvin, GJ 758 B glows in the near-infrared, and can therefore be seen in this spectral range on its night-side facing away from the central star, too. (Photo: MPIA/C. Thalmann)



called "proper motion" – it changes its position, albeit only very slowly. The images show that GJ 758 B moves exactly as one would expect if it were gravitationally bound to its central star: its motion in the night sky is a superimposition of the proper motion of GJ 758 and its own orbital motion about the central star.

The image taken in August, shown in Fig. II.3.1., is of a somewhat higher quality and shows a further object slightly closer to the central star. It could be a second companion, which would then be designated GJ 758 C. However, a further observation at a later time has shown that this object does not participate in the common proper motion of the system, and therefore it must be an object located in the background.

The discovery of GJ 758 B, an exoplanet or brown dwarf orbiting a Sun-like star, provides the astronomers with insight into the variety of substellar objects which can be formed in the vicinity of Sun-like stars. This variety, however, points towards our own solar system with conditions that lead to the creation of life being only one scenario among the many which can result during the formation of planets or brown dwarfs in the vicinity of Sun-like stars.

The HiCiao instrument is now being used in the five-year, systematic Seeds survey project for a comprehensive search for extrasolar planets and circumstellar disks. The spectacular discovery of GJ 758 B during its start up promises great things for this demanding project and shows that the instrument is admirably suited for the task envisaged for it.

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Markus Janson, Miwa Goto,
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in collaboration with:
College of Charleston, University of Toronto,
Princeton University, Subaru Telescope,
National Astronomical Observatory of Japan,
Institute for Astronomy, University of Hawaii.

II.4 First Results from Herschel mission

It was a picture-perfect launch and clearly the highlight for infrared space astronomy in 2009: At exactly 15:12:02 CEST on May 14, Europe's new space observatory Herschel lifted off into space aboard an Ariane 5 rocket (Fig. II.4.1). This very moment was the culmination of more than one decade of challenging technical developments across Europe and marked the transition into the phase of exciting scientfic discoveries which has just begun.

With its 3.5-m-mirror, Herschel is the largest space telescope ever launched. Working at far-infrared and submillimetre wavelengths between 70 and 500 µm – much longer than the wavelength of visible light – it can observe the cool universe, from the cold bodies of the solar system like comets and Kuiper-Belt-objects to the dust between the stars, and clouds of gas and dust were new stars are forming, up to distant galaxies and their infrared light, redshifted due to cosmic expansion. Herschel carries a suite of three powerful scientific instruments (Pacs, Spire, and Hifi) of which the first two contain cameras and of which all three enable spectroscopic observations such as the detection of individual absorption and emission lines from atoms and molecules. All instruments are cryogenically cooled to operating temperatures close to absolute zero (–273 °C) using 2300 litres of liquid helium carried within the Herschel cryostat.

MPIA was one of the major partners in the development of one of these instrument, the Photodetector Array Camera & Spectrometer Pacs, and responsible for important hardware contributions such as the focal-plane chopper. Everyone in the team was relieved when the initial switch-on of the instrument in space, 10 days after launch, confirmed that all subsystems were operating nominally.

Before obtaining the first scientific observations, Herschel had to undergo an extensive program of initial operation, systematic characterization, optimization and

Fig. II.4.1: Launch of the Herschel and Planck satellites on board an Ariane 5 ECA rocket from Europe's Spaceport Kourou in French Guayana.

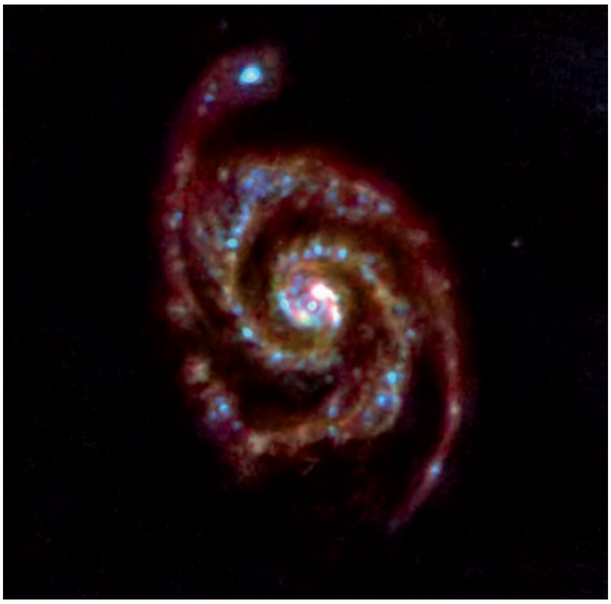


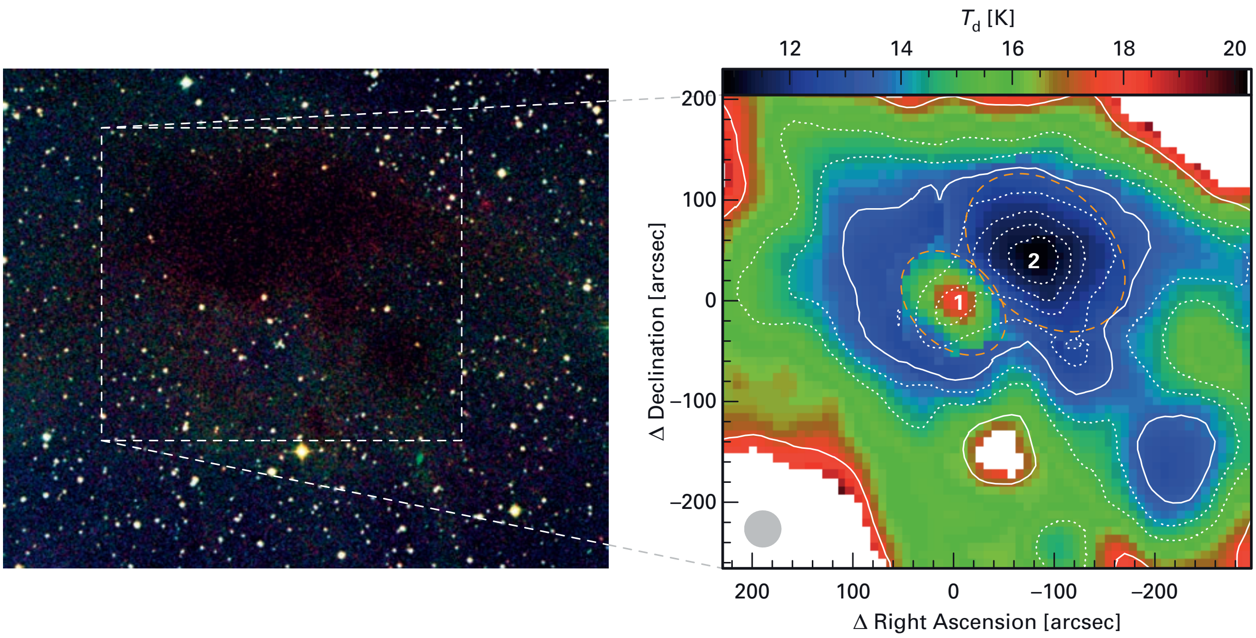
Fig. II.4.2: Colour composite image of the spiral galaxy M 51 ("Whirlpool Galaxy") obtained at wavelengths of 70 µm (*blue*), 100 µm (*green*) and 160 µm (*red*) with the PACS instrument.

calibration of the complex instrument and its interaction with the satellite. This activity started already during the 5 weeks long flight of HERSCHEL into its final destination, a large halo orbit around the Lagrangian point L2 at a distance of 1.5 Mio. km from Earth. During this phase our institute played in important role by performing the overall planning and scheduling of this calibration observations. All 16 operational days for the initial operation of the PACS instrument during mid-June to mid-July – including the first light images of HERSCHEL – as well as the 64 operational days for the characterization of the instrument and the HERSCHEL telescope pointing performance verification (PACS has the highest resolution), lasting from mid July until end of November, were coordinated and scheduled by the MPIA ICC team, which also maintained the overall PV Plan.

The first images (Fig. II.4.2) were obtained exactly one month after launch with the PACS instrument, immediately after the cover of the cryostat was opened and light from space could enter the instruments for the first time. The objective of these test observations of the famous "Whirlpool Galaxy" M 51 was the determination of the pointing accuracy and the stray light/background level of the still relatively warm telescope. Although meant as a very early image that gives a glimpse of things to come, the result was already exceeding all expectations: The galaxy was nearly perfectly pointed and in focus, demonstrating diffraction-limited resolution at all wavelengths.

By the fall of 2009, the effort was rewarded by an instrument that fulfilled all requirements in terms of scientific performance. During the following Science Demonstration Phase a wealth of data could be obtained, both, in photometry and in spectroscopy, from objects ranging from nearby, young stars to galaxies at cosmological distances. These observations were obtained within large observing programs in guaranteed observing time which has been granted to the instrument builders for their efforts in providing HERSCHEL's instruments. MPIA's share of guaranteed observing time is 285 hours.

Fig. II.4.3: (*left*) Optical image of the CB 244 globule region showing background stars and the cold, dense globule material in the centre. (*right*) Dust temperature and column density of the CB 244 cold, dense material based on the HERSCHEL emission maps. Object 1 is a young stellar object and object 2 is a prestellar core that is likely to form a star.



The following examples highlight some of our initial HERSCHEL results and were presented during a workshop in Madrid in December 2009.

Measuring the temperature and density distribution of a prestellar core

In the observing program EPOS ("Earliest Phases of Starformation") led by the MPIA HERSCHEL PACS and SPIRE maps obtained at wavelengths between 70 and 500 µm are used to construct spatially resolved spectral energy distributions of low- to high-mass star forming cores and protostars, covering the full peak of thermal dust emission. The unrivalled ability of ESA's HERSCHEL infrared space observatory to discern detail in such celestial objects has been used to take the temperature across a starforming cloud (Fig. II.4.3).

HERSCHEL has revealed two regions inside the cloud where individual stars will form. In the first, which has a temperature of –255° C, HERSCHEL pinpointed the nascent star. The second region is so young that there is not even a star yet, just a collapsing core of gas and dust. Eventually, this too will become a hot star but at present its temperature is just –262° C. The temperature map has allowed astronomers to calculate the amount of matter inside the cloud. The young star contains 1.6 times

Fig. II.4.4: Infrared image of the star-forming region IsoSS J22164 + 6003: High-mass stars are detected during early phase of their evolution. Several protostars are still deeply embedded in cold gas and dust having temperatures as low as –255° C and became only visible in the far infrared. Composite image of HERSCHEL observations at 70, 100 and 160 µm (*red/yellow structures*) and near-infrared frames obtained at the Calar-Alto-Observatory.

the mass of the Sun, the collapsing region contains between 3 and 7 times the Sun's mass. Overall, the cloud is between 10 and 20 times the Sun's mass, meaning that almost half of its mass is involved in forming these two stars. The observation also reveals that the temperature of the cloud rises towards the outer edges. This shows where the light from the surrounding stars is heating the outer faces. It is very difficult to measure these low temperatures from the ground because the atmosphere blocks emission at these submillimetre wavelengths while HERSCHEL with its sensitive heat cameras is poised perfectly in space and designed to investigate these coldest regions of the Universe.

Of particular interest in the EPOS observing program are high-mass star forming regions. Understanding the initial conditions that lead to the formation of massive stars remains one of the key questions in high-mass star formation research. High-mass stars ($M > 8$ solar masses) are rare and are only found at large average distances. The combination of HERSCHEL's high spatial resolution and wavelength coverage is therefore essential to study the population of embedded protostars in such regions as shown in Fig. II.4.4 and to conclude on their formation scenarios.

Dust formation in supernovae – The case of Cassiopeia A

Dust plays a significant role in the universe as it constitutes the raw material from which stars and planets continually form. The solid particles can only form, however, when heavy elements, carbon in particular, are present. According to current cosmology, only the light, volatile elements hydrogen and helium as well as small amounts of lithium and beryllium were created in the big bang. All heavier elements up to iron were synthesized later by nuclear reactions within the interiors of stars and subsequently blown into interstellar space by supernova explosions or stellar winds. Also dust can form in these environments. While in the latter case the process can take up to several billion years, supernovae may produce dust in much less time, in only a few 10 million years. However, the exact dust yields are much under debate.

Only when the interstellar medium had been enriched in this way with heavy elements, dust could also form and only then the prerequisites for planet formation were given. As observations made over the last two years have shown, large quantities of dust already existed no later than 700 million years after the big bang. About one hundred million solar masses of dust were detected in the vicinity of the most distant quasars as for example in SDSS J1148 + 5251 described above. How could these enormous amounts of dust have been created in such a short period of time?

The mystery soon seemed to be solved: In 2004 a team of astronomers claimed to have detected enormous amounts (between 2 and 4 solar masses) of cold dust in the Cassiopeia A (Cas A) supernova remnant from ground based observations at submillimetre wavelengths. The scientists concluded from this that core collapse supernovae were the first to produce dust in the universe. However, when astronomers at MPIA followed up this issue they came to a different conclusion: The dust detected at Cas A has nothing to do with the supernova remnant but actually belongs to an extended dust complex lying between Earth and Cas A.

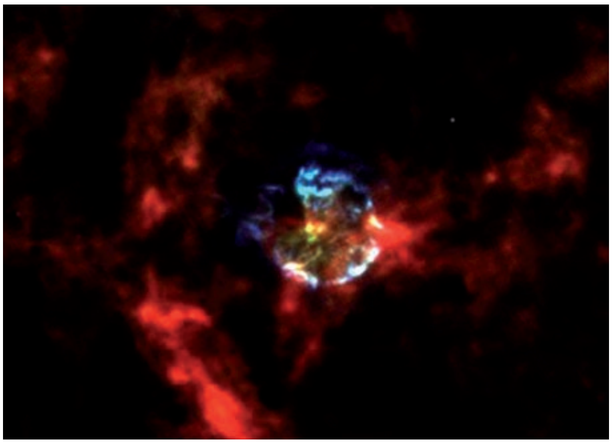


Fig. II.4.5: Composite image of the galactic supernovae remnant Cassiopeia A obtained with the PACS instrument at wavelengths of 70 µm (*blue*), 100 µm (*green*) and 160 µm (*red*).Warm dust within the supernova remnant is visible in blue colour tones, while the more extended and cooler dust component of the unrelated interstellar medium is seen in red colour.

New observations with HERSCHEL have now finally confirmed the interstellar nature of the cold far-infrared and submillimeter emission towards Cas A. Fig. II.4.5 shows the infrared emission towards Cas A in the three PACS bands between 70 and 160 µm. Dust grains of different temperatures emit most of their radiation at slightly varying wavelengths. The proper spectral sampling of the HERSCHEL data and fast mapping speed enable to disentangle the dust properties across the supernova remnant and its surroundings. While warm dust within the outer shock boundary supernova remnant is visible in blue colors, the more extended and cooler dust component of the unrelated interstellar medium can be seen in red. The total amount of dust that has newly formed in the Cas A supernova and derived from the HERSCHEL observations is only 0.07 solar masses.

Revealing the Metamorphosis of the colliding Antennae Galaxies

70 million light years away from our Milky Way and its 2.5 million light years distant sister, the Andromeda galaxy, two similar spiral galaxies have approached

each other 100 times more closely, so that a collision became unavoidable. This twin galaxy system, in the constellation of Corvus, is being made up of the galaxies NGC 4038 and NGC 4039, also called "the Antennae".

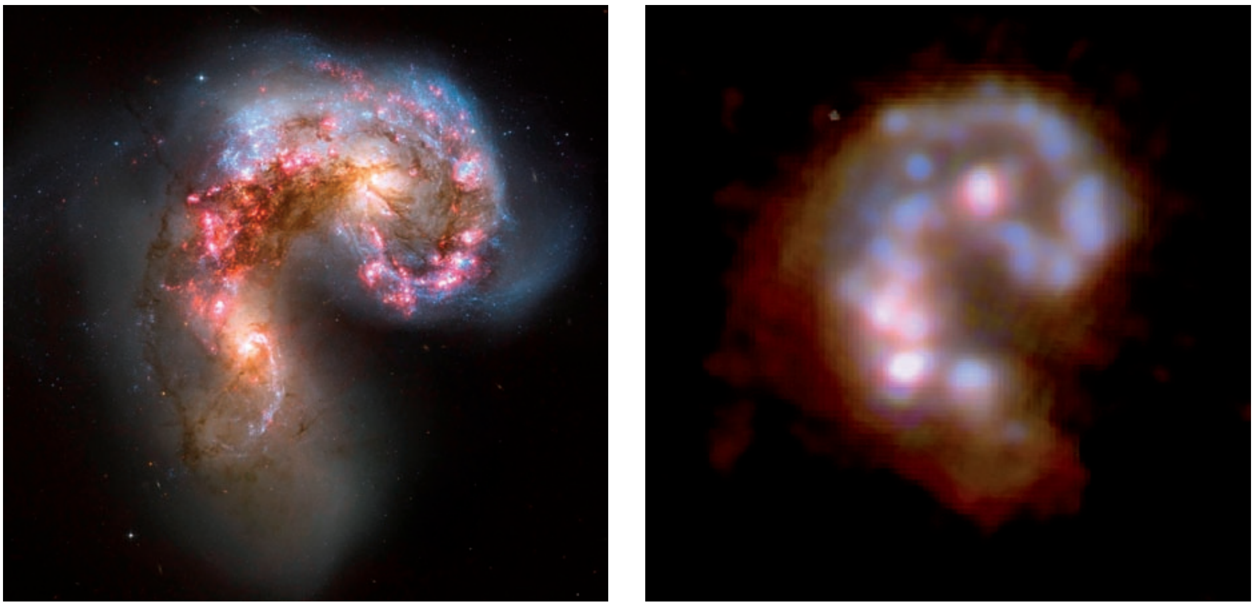
When two galaxies actually collide, their mutual gravitational forces interact very strongly, therefore they are also called interacting galaxies. The stars of these two galaxy systems will not be destroyed (direct crashes between individual stars are very unlikely), however the gravitational forces expel many of them from their current orbits and catapult them on extreme orbits outlining very long and narrow tidal tails. The system of NGC 4038 and NGC 4039 has formed such tails whose shape provides its nickname "the Antennae" (Fig. II.4.6 left). It is one of the most spectacular nearby interacting galaxy systems.

The many hundreds of million solar masses of interstellar material in the form of gas and dust, however, undergo a much more furious fate. They are also pulled towards the gravity centres, tidal waves pass through the material and clouds crash inelastically into each other causing huge shock fronts to propagate, leading to compression of the cloud material and consequently fragmentation into smaller units. Finally the self-gravitation of the fragments becomes so large, that new stars with a rate of at least 5 times more than in our Milky Way are being born out of this material. A large amount of dust first hides these sites of the most recent star formation, however far-infrared waves as collected by the HERSCHEL telescope and analysed by the PACS instrument tell us the full story of this star formation event.

The optical heritage image of the HUBBLE Space Telescope (Fig.II.4.6 left) shows still two distinct galaxy disks with a lung-shaped appearance. The two nuclei are indicated by the yellowish regions, NGC 4038 being the northern (upper) one, NGC 4039 the southern (lower) one. The two galaxy disks appear to be clamped (glued?) by a net of brownish dust streamers which cover a large fraction of the so-called overlap region. Young bluish stars and reddish HII regions around the most massive young stars outline star formation triggered already some time ago in the prominent northern spiral arm and at the rims of the dust streamers.

The new HERSCHEL-PACS image (Fig. II.4.6 right) taken by a MPIA-team shows now a very different morphology: The Antennae appears like a single system with two spiral arms emerging from the northern nucleus of NGC 4038. However, the prominent optical spiral arm in the north is relatively faint, whereas the dominant emission comes from a chain of knots along an arc connecting the northern (NGC 4038) and southern (NGC 4039) nuclei and coinciding with the net of dust streamers in the optical. In this picture, the southern nucleus only appears as a kind of outermost appendix of this "southern arm". The two neighbouring knots are considerably brighter in the FIR, and they are actually also brighter than the northern nucleus. Hence, the PACS image shows the sites of the currently most furious star formation, still hidden in the optical, reveals the metamorphosis and unveils the future appearance of this merging galaxy system, once the 100 millions of young stars being formed inside the bright FIR emission regions will destroy their surrounding dust clouds by their radiation.

Fig. II.4.6: (*left*) Optical image of the Antennae galaxies (NGC 4038/4039) obtained with the ACS instrument aboard the HUBBLE Space Telescope. The system is located at a distance of 70 million light years (21 Mpc). The projected separation of the two nuclei: is ~ 23 000 light years (7.15 kpc). (*right*) Colour composite image of the Antennae obtained with the PACS instrument at wavelengths of 70 µm (*blue*), 100 µm (*green*) and 160 µm (*red*).



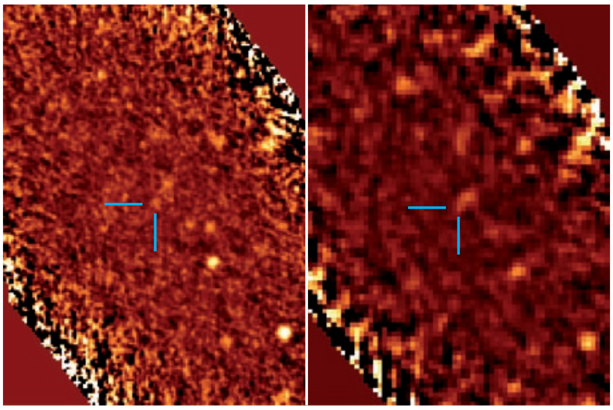


Fig. II.4.7: (*left*) Deep Pacs scan map of SDSS J1148 + 5251 at a wavelength of 100 µm. The source is clearly detected (*right*). The same area observed with Pacs at a wavelength of 160 µm, where the source is still detected. To the northwest of it a companion source can be also seen.

Pacs observation of high-redshift Quasars

The detection of a significant fraction of the highest redshift quasars ($z > 5$) in the (sub)millimetre wavelength range indicates that a substantial amount of dust has been synthesized already during the first billion year since the Big Bang. Recent 24 µm observations with Spitzer have shown that very hot dust is present close to the QSO core in most $z > 5$ quasars. However, both the (sub-) mm and mid infrared observations can only catch tails of the dust emission spectrum, at $\lambda_{\rm rest} > 200$ µm, and at $\lambda_{\rm rest} < 5$ µm, respectively. Measuring the peak of the dust emission has been beyond the capabilities of Fir satellites or ground-based sub-mm telescopes. Thus, critical properties, such as Fir luminosity, dust temperatures and mass, remain unconstrained.

The first Pacs observations of two luminous sources at the edge of the universe, the most distant known quasar SDSS J1148 + 5251 at $z = 6.42$ and the mm-loud quasar BR 1202-0725 at $z = 4.69$, by the MPIA-led 164 hours Guaranteed Time Key Program "The Dusty Young Universe" have clearly detected the sources (Fig. II.4.7). In both cases the Pacs photometry indicates a very continuous distribution of dust temperatures between $T \sim 1000$ K and $T \sim 50$ K.

Outlook

MPIA's technical expertise with Pacs and the scientific interests of the institute led to a successful involvement in eleven Herschel key observing programs. The wide distribution of these programs in galactic (Epos, Digit, Mess, Dunes, Gould Belt, Cold Cores, Hops) and extragalactic astronomy (Dusty Young Universe, Kingfish, Shining, Hercules) – reflects the significance of Herschel for the core science fields of our institute. The total observing time granted to these Herschel programs is 2600 hours, the MPIA being responsible for many key areas of data reduction and analysis. All of these observing programs produce data of very high quality and many scientists at the institute are now involved in the detailed scientific analysis of these measurements. The first science results published in a referred journal will appear in a dedicated A&A Herschel special issue in July 2010.

According to current estimations based on mass measurements of the liquid helium the Herschel mission may last until end of February 2013 when its coolant will be fully evaporated. The uncertainty on the exact date is still of order plus or minus a few months. Direct liquid helium content measurements in which a heat pulse is inserted into the helium bath will enable a more accurate prediction of the mission lifetime and it is expected that in November 2010 the remaining observing time can be determined with much higher accuracy.

It took almost 30 years from the first ideas of this ambitious mission until it was launched and we are now seeing the data for the first time. The mission is working absolutely wonderful, far better than one could have imagined. It has been worth well being waiting to see and enjoy now the outstanding results from Herschel.

Oliver Krause, Ulrich Klaas, Markus Nielbock, Jürgen Schreiber, Zoltan Balog, Jeroen Bouwman, Ulrich Grözinger, Hendrik Linz, Jutta Stegmaier, Thomas Henning,Christian Leipski, Amelia Stutz, Martin Hennemann, Helmut Dannerbauer, Ralf Launhardt, Marc-Andre Besel, Jan Pitann, Dietrich Lemke, Ralph Hofferbert, Klaus Meisenheimer, in collaboration with the partner institutes of the Pacs instrument consortium and the programm consortia of Mess, Epos and Shining key.

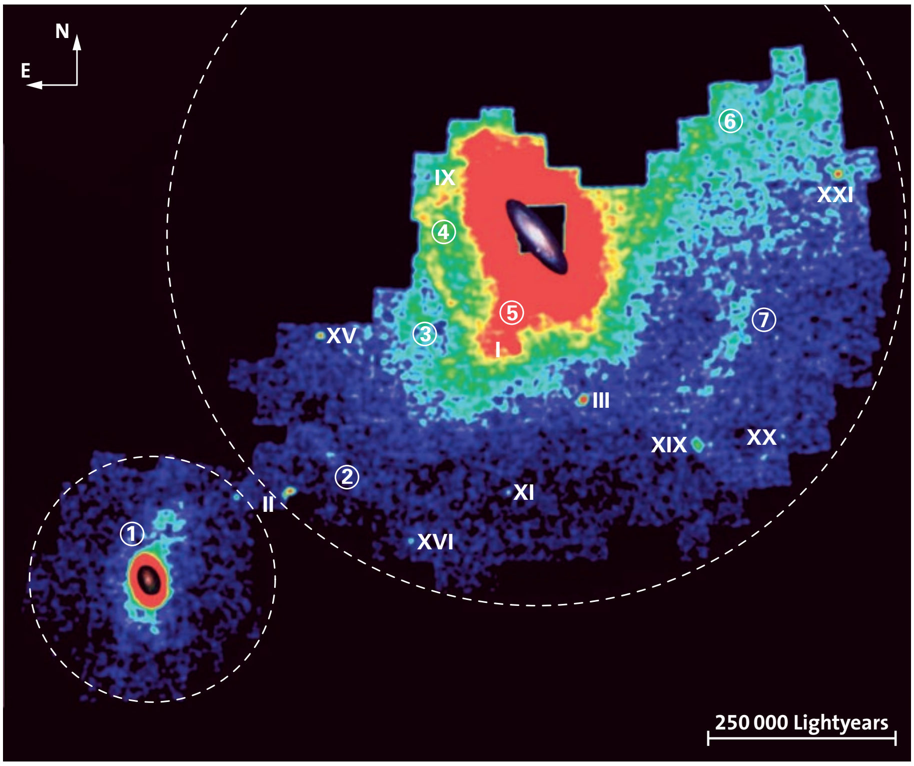
II.5 Galactic cannibalism: Stellar streams around the Andromeda Galaxy

According to the idea of a hierarchical evolution of galaxies developed in recent years, the larger and more massive galaxies continue to grow by devouring their smaller satellites. The small satellites break up in the gravitational field of the large ones, leading to the formation of loosely bound stellar streams slightly further out. The PandAS project, a thorough survey of the Andromeda Galaxy and its environs in which the MPIA is involved, has provided the most complete and most detailed picture so far of such fusion processes.

It is only during the last five years that astronomers have been able to detect traces of such acts of galactic cannibalism in both our home galaxy, the Milky Way, and also in galaxies further away: stellar streams – elongated accretions of thousands of stars which orbit the galaxies concerned as if in formation flight. Compared with the large number of stars in the disk of our galaxy, for example, these stellar streams shine only very weakly and are correspondingly difficult to detect. New findings from the international PAndAS project (abbreviation for »Pan-Andromeda Archaeological Survey«) provide the most complete and most detailed picture so far of such stellar streams in the vicinity of a galaxy (Fig. II.5.1). The PAndAS survey runs from 2008 to 2011 at the Canada-France-Hawaii Telescope (CFHT) on Mauna Kea in Hawaii; it is being carried out in the colors g (414 – 560 nm) and i (702 – 853 nm), the corresponding limiting magnitudes are at $g = 26.5$ mag and $i = 25.5$ mag. The project involves the detailed charting of a celestial region with an area of 350 square degrees or so around the Andromeda Galaxy: This area corresponds to 1600 times the apparent size of the disk of the full moon.

The new data form the starting point for modeling the evolution of the Andromeda Galaxy over the last billion years. Although traces of such remnants of dwarf galaxies, which the Andromeda Galaxy devours before our very eyes, had been found earlier, it has only

Fig. II.5.1: PAndAS chart of the environs of the Andromeda Galaxy M 31 (*top*) including the M 33 Triangulum (*bottom left*). The colors stand for different stellar densities: red depicts high stellar density; the stellar density decreases from red to yellow, green, light and dark blue. Conventional images of the Andromeda Galaxy and the Triangulum nebula are inserted into the (*red*) centers of highest density. The radii of the dotted circles around M 31 and M 33 have projected diameters of 150 kpc and 50 kpc respectively. Dwarf galaxies that are visible directly are labeled with Roman numerals. The numbers 1 to 7 in circles mark the stellar streams which stand out at first sight as being sub-structures of the stellar distribution.



now proven possible to draw up such a detailed chart of a stellar stream region. The PAndAS survey shows seven different streams. Two of these are new discoveries: Number 6 in Fig. II.5.1 extends 150 kiloparsecs northwest in the direction of the small axis of the Great Nebula of Andromeda, number 7 is a 40-kiloparsec arc in the south-west, 150 kiloparsecs away from M 31. In the inner halo (within 50 kiloparsecs) such huge structures are stable over several billion years, and at a distance of more than 150 kiloparsecs they are stable at least over the total Hubble time (13 billion years). They will break up in the course of the next billion years and there will be nothing left to indicate that these stars had once been part of other galaxies.

The remaining remnants of the dwarf galaxies orbiting M 31 are visible in Fig. II.5.1 as circular stellar density enhancements; their area density is constant up to a distance of more than 150 kiloparsecs from M 31, and it is possible to estimate that there are around 90 dwarf galaxies, of which only about a quarter are known as yet, in a volume with a radius of 300 kiloparsecs around M 31. This corresponds at most to one tenth of the theoretically expected dark matter halo, however – the "mystery of the missing satellites" thus remains. (But see Section II.7 in this Annual Report.)

The history of the Triangulum nebula, a small companion galaxy of Andromeda, must also be rewritten in the light of the new findings. It had previously been assumed that the Triangulum nebula was simply a companion of Andromeda. We now have convincing indications that the two galaxies were involved in a collision a few billion years ago. This evidence comes from a newly discovered stellar stream of the Triangulum nebula which must have been formed in this collision by the effect of the tidal forces of the Andromeda Galaxy. The slight warp of the Andromeda Nebula's galactic disk is also explained by this scenario.

Nicolas F. Martin
in collaboration with the PAndAS team.
This includes astronomers of Canadian, French, Australian, British, US-American and German institutions;
scientific head is Alan McConnachie from the NRC Herzberg Institute of Astrophysics in Victoria, Canada.

II.6 Maximum star formation in the infant cosmos

Galaxies – our Milky Way and its cosmic relatives – consist of many hundreds of billions of stars. But how were these gigantic star clusters formed billions of years ago? Was there initially a central star-filled region, which grew over time, or did the stars form uniformly over the whole space now occupied by the galaxy? An international team of researchers headed by scientists from the MPIA has now discovered the first direct indications that the star formation begins in a small central region. They established: in the formation phase of the galaxies, the galactic cores produced new stars with maximum possible efficiency.

The researchers investigated one of the most distant known active galaxies, the quasar with designation J 1148 + 5251. Its light reaches the Earth only after a journey time of 12.8 billion years; current observations thus show this galaxy the way it looked 12.8 billion years ago, less than one billion years after the Big Bang. With the aid of the IRAM interferometer, a Franco-German-Spanish radio telescope, it was possible to prove that, way back then, an extremely high number of stars were formed in the core of J 1148 + 5251 – very close to the limits of what is possible according to the laws of physics. In contrast to previous measurements, they also succeeded in determining the size of the star-forming region, which amounts to a mere 4000 light years or so. Only now that this has been achieved is it possible to estimate the star-formation rate per volume and to compare this with star-formation models.

The result is surprising: In this galaxy, stars with a combined mass of more than 1000 solar masses are formed every year – and this in a region that is really small, in astronomical terms. As a comparison: If the masses of all the stars which are formed in our Milky Way are added together, only one single solar mass is added per year.

Close to the physical limit

Earlier measurements were already able to show that considerable numbers of stars are formed in infant galaxies. The crucial aspect of the new measurements made by Fabian Walter and colleagues is that, in this case, it was also possible to determine the size of the star-forming region. This allows the star-formation rate per volume to be determined, and it is this which enables the comparison with star-formation models, on the one hand, and with particularly active star-forming regions in our own galaxy, on the other.

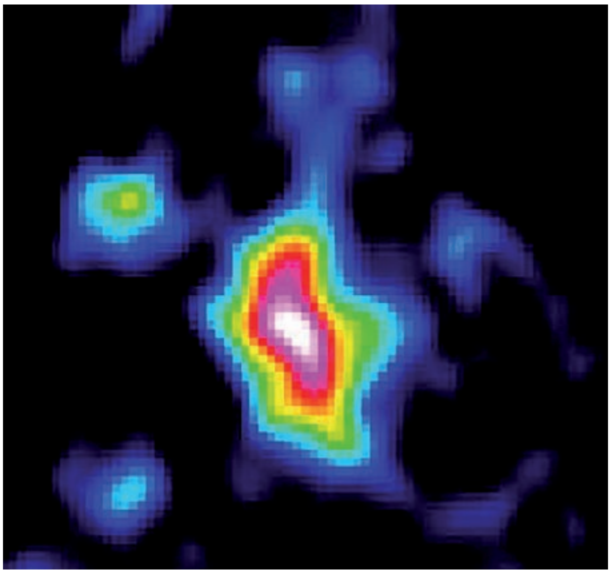


Fig. II.6.1: False-color image of the quasar galaxy J 1148 + 5251, taken by the radio telescopes of the Very Large Array in New Mexico. (NRAO/AUI/NSF).

The activity measured means that the star-forming regions of J 1148 + 5251 (Fig. II.6.1) are at the limits of what is physically allowed. Stars are formed when cosmic clouds of dust and gas collapse under the effect of gravity and heat up in the process. But the radiation released in the process pushes the gas and dust clouds apart and thus impedes a further collapse and the formation of further stars. This results in an upper limit for how many stars can actually form in a given volume of space in a given time.

This upper limit is reached by the observed star regions. In our Milky Way, such extreme circumstances can only be found in distinctly smaller regions, in parts of the Orion nebula, for example (Fig. II.6.2). However, what was observed in J 1148 + 5251 corresponds to a cluster of a hundred million Orion regions.

Star formation occurs from the inside out

Fabian Walter and his colleagues were able to detect such extreme circumstances on galactic scales for the first time – in contradiction to some previous estimates, which arrived at a limit for the maximum star-formation rate in galaxies which was ten times smaller.

So much activity in so small a space is interesting for another reason as well. It shows, namely, that the star

Fig. II.6.2: In the region Orion-KL in the Orion nebula (marked with a square in the picture) the star-forming activity is almost as high as in the central region of J 1148 + 5251 – albeit limited to a volume many hundred million times smaller. (NASA, ESA, M. Robberto (STScI/ESA), Orion Treasury Project Team)

formation in this galaxy obviously occurs from the inside out: In the beginning there is a central core region in which a particularly high number of stars are formed. Only in the course of time does the star-filled central region grow – by collisions and mergers with other galaxies, for example – and reach the far larger size that is characteristic for older galaxies. This finding is of great importance for the theoretical modeling of galaxy evolution.

A one euro coin from a distance of 18 kilometers

The key to determining the star-forming activity and to drawing conclusions about the formation of galaxies is the fact that the researchers succeeded in actually imaging the central region of the distant galaxy. Nature, of course, puts some obstacles in their path. Firstly, the galaxy concerned is almost 13 billion light years away (value of the redshift $z = 6.42$). At this distance, the star-forming region, with its diameter of 4000 light years, has an angular diameter of only 0.27 arcseconds – as large as a one Euro coin viewed from a distance of around 18 kilometers. A further handicap stems from the wave-like nature of electromagnetic radiation: at the wavelength which is suitable for observing the star-forming region – one millimeter or so – it is more than a thousand times more difficult to image fine details than in the visible part of the spectrum.

The fact that the observations described here were nevertheless possible is attributable to a coincidence of favorable circumstances: at one specific frequency at least, which is characteristic of ionized carbon atoms, the star-forming regions outshine the active, very bright core of J 1148 + 5251; thanks to the expansion of the universe (cosmological redshift) this radiation reaches Earth in the form of radio waves that can be detected with suitable telescopes. And thanks to the upgrade of the Franco-German-Spanish Iram interferometer, a compound radio telescope on the Plateau de Bure in the French Alps, the measurements described here shifted to within the bounds of possibility.

As already mentioned, the star-forming region in J 1148 + 5251 appears to us at an angular diameter of only 0.27 arcseconds. In visible light, a structure of this size can just about be recognized with the Hubble space telescope, for example. But J 1148 + 5251 is a quasar – a galaxy in whose core a massive black hole draws in large amounts of the surrounding matter. This releases huge quantities of radiation, which can be used to detect quasars over the greatest distances in the universe. On the other hand, it simply outshines the far weaker radiation of the star-forming regions grouped around the core.

Assistance comes from the cosmic expansion

There is one wavelength where the radiation of the star-forming regions is stronger than that of the quasar, however. In order for the gas and dust clouds to be able to collapse at all, they must radiate a portion of the gravitational energy released by the collapse. However, as far as the radiation is concerned, there are very restrictive rules in the atomic regime – the best known being the fact that an atom can absorb and radiate electromagnetic radiation at only very distinct wavelengths that correspond to its characteristic spectral lines. The clouds we are concerned with here consist mainly of molecular hydrogen, which practically cannot radiate electromagnetic radiation at all under the conditions that prevail. It thus falls to a further constituent of the cloud, singly ionized carbon (i.e. carbon atoms lacking one electron), to radiate a large fraction of the energy released by the collapse at a specific wavelength of 158 micrometers, which is characteristic for these ions. Even if the quasar is also much brighter than the molecular clouds overall, the molecular clouds shine brighter than their competition at this particular wavelength. And since the emission of this special spectral line is linked directly to the cloud collapse and thus with the process of star formation, it is ideally suited for the detection of star-forming regions.

Radiation of this wavelength is completely absorbed by Earth's atmosphere, however. It can be detected with satellite telescopes, but these are not large enough to image structures which appear so small with the spatial resolution that is required here.

The cosmos itself puts things right! The universe is expanding, and thus it is not only the separations between distant galaxies which are changing: the wavelength of electromagnetic radiation propagating through the cosmos is becoming longer and longer (cosmological redshift). When the characteristic infrared radiation of the star-forming regions of J 1148 + 5251 reaches us, its wavelength has increased by a factor of $z + 1 = 7.42$, and it reaches Earth in the form of short-wave radio waves of around one millimeter wavelength. This radiation can be measured from the Earth – at least under favorable atmospheric conditions, as are characteristic for the high-altitude locations of the observatories.

New Technology

It is this that made the observations described here possible: such radio waves can be detected with special radio telescopes. There is, however, always a specific disadvantage with longer wavelengths: In order to image the finer points with the same level of detail, a telescope working at one millimeter wavelength must have a diameter roughly 1000 times larger than one which observes in visible light.

Until the end of 2006 observations at this special wavelength with the required level of detail were simply not possible. Then, however, the six individual antennae of the Iram interferometer, which is located at an altitude of 2550 meters on the Plateau de Bure in the French Alps, received new, improved detectors that can detect this 1-millimeter radiation. With interferometers, the measurements of individual radio telescopes are combined such that the performance corresponds to that of a much larger telescope; the larger the distance between the individual telescopes, the more powerful the resulting combination-telescope. In 2005, the Iram interferometer was extended so much that structures of the size of the star-forming region in J 1148 + 5251 could be imaged with sufficient precision.

The fact that we now know more about the development of stars and galaxies in the early universe is thanks to a favorable coincidence of technological developments – and the evolution of the universe as a whole.

Future telescope

The measurements at the Iram interferometer are also important as a test-case for future telescope projects, in particular for Alma (the Atacama Large Millimeter Array in northern Chile) which is currently being built. The fact that the line of the singly ionized carbon can be used to detect and image the star-forming regions of far distant

Fig. II.6.3: The IRAM interferometer on the Plateau de Bure in the French Alps. (IRAM/Rebus)

galaxies is an important condition for the observation program that will be pursued with ALMA. Researchers were able to use the measurements described here to demonstrate the observation technique in practice for the first time. These measurements open up a new way of characterizing star formation in the early universe. The study of galaxies in the early phase of cosmic evolution, around a billion years after the Big Bang, will be a major field of astronomical research in the coming years.

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California Institute of Technology, Pasadena
Institut de Radio Astronomie Millimetrique, Saint Martin d'Herès,
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National Radio Astronomy Observatory, Socorro.

II.7 Are there enough small galaxies?

The Milky Way and the collection of satellite dwarf galaxies that surround it represent a unique astrophysical laboratory: this is where theories on the formation and evolution of galaxies can be tested. One particular long-standing problem for the otherwise very successful theory of ΛCDM (Λ Cold Dark Matter) is its prediction that a great many dwarf galaxies should be embedded in the halo of our galaxy. Here we report on the solution to this problem.

According to the Λ-CDM scenario, galaxies formed from the tiny density fluctuations of the cosmic primordial soup that are evident in the observed minimal temperature variations in the microwave background radiation. Soon after the Big Bang, the density maxima of these fluctuations formed the initial seeds of the accretion processes that were slowly beginning; the first to accrete was the much more prevalent dark matter, which does not interact with electromagnetic radiation, while the "normal" matter, which was initially ionized at this time, was prevented from accreting by the prevailing background radiation. The objects formed by the accretion of dark matter are called "dark haloes".

With the recombination of protons and neutrons around 370 000 years after the Big Bang, the normal, now neutral matter also decoupled from the radiation field and was able to follow gravity and stream into the already existing dark haloes. These haloes attract each other and so, especially in the early universe where the average density of matter was still significantly higher than it is today, they collided and merged with each other to form larger and larger structures. These consisted primarily of dark matter, with only one seventh in the form of normal matter from which the first stars soon formed in the centers of the dark haloes. In the early universe, this hierarchical growth of the dark haloes, and hence the luminous galaxies embedded in them as well, was very turbulent, and this turbulence continues to this day.

The problem

About ten years ago, the numerical calculations for the modeling of this scenario achieved sufficiently high resolution to show that, according to the Λ-CDM theory, all haloes today should still contain a great many embedded "subhaloes" that have not dissolved into the larger structures. Although the theoretically expected number of subhaloes coincided well with the observations of the largest dark haloes that encompass complete galaxy clusters, the haloes around systems the size of our Milky Way seemed to contain only around one tenth of the subhaloes to be expected according to the theory. At that time, around 40 satellites of the Milky Way were known, whereas the model calculations indicated around 300 satellites were to be expected.

Later, the data collected by the Sloan Digital Sky Survey (SDSS) changed our idea of the Milky Way and its neighborhood quite dramatically. In 2008, a research group headed by S. Koposov used this data to determine the luminosity function of the dwarf galaxies surrounding the Milky Way as satellites within a large section of the sky right down to 100 solar luminosities, and to derive their radial distribution. This now provides researchers with the opportunity to reinvestigate fundamental characteristics of the satellites of the Milky Way, such as their number density, their radial distribution and their mass-luminosity ratio, and to examine whether they are compatible with the current Λ-CDM models and identify the physical processes that have led to the formation of these extremely faint dwarf galaxies.

Models and results

To this end, five researchers at the MPIA teamed up with a colleague from Trieste to reinvestigate the development of four different model haloes the size of the Milky Way (10^{12} solar masses) from an older, extensive simulation, this time with far higher numerical resolution. The haloes selected had not suffered any more significant mergers after $z = 2$ (i.e. in roughly the second half of the period after the Big Bang) and were thus expected to each contain a spiral galaxy of the type and size of the Milky Way in their center. Over the simulated development from $z = 20$ (shortly after the Big Bang) until $z = 0$ (today) 53 snapshots were taken in each case and examined for the number and distribution of their subhaloes. It was thus possible to determine the family trees of the subhaloes still in existence.

In order to be able to model the formation and development of the stellar population in the subhaloes and ultimately compare them with the dwarf galaxies currently in the halo of the Milky Way, it is necessary to simulate not only the pure gravitational force acting on the particles of normal and dark matter but also the astrophysical processes taking place in normal matter which are crucial for star formation. To this end, the authors used three different semi-analytic models which had been developed independently of each other by other working groups. All three take into account the following processes which affect only normal matter: cooling of the atoms by radiation, reionization processes, star formation, supernova explosions, return of the heavy elements produced in the stars into the interstellar medium, dust formation and absorption of radiation by dust.

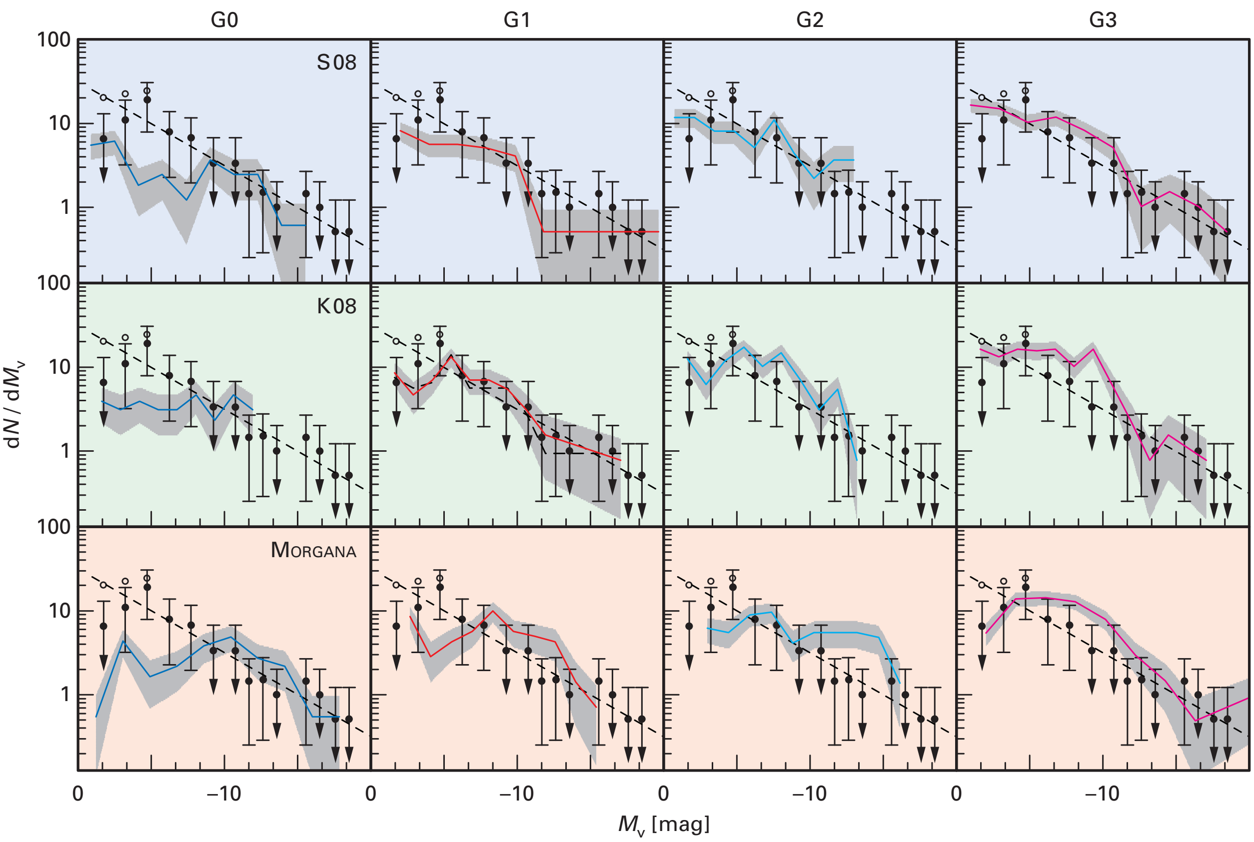
The semi-analytic models used had all been developed and tested with those galaxies in mind that contain stellar components with masses $M_* \geq 10^9\,\mathrm{M}_\odot$ – i.e. far greater than most of the dwarf galaxies considered here. It is not clear from the outset whether these empirical recipes – to describe the star formation or the influence of supernova explosions on their environment, for example – also apply to tiny dwarf galaxies which each formed from a few molecular clouds. It is therefore of considerable interest to examine how these models fare when they are tested with the small dwarf galaxies investigated here.

The luminosity functions of the dwarf galaxies derived from the simulation calculations for the four model haloes in combination with the three different semi-analytic models for the current era were compared with the empirical luminosity functions derived from the data of the Sloan Digital Sky Survey by S. Koposov and colleagues (Fig. II.7.1). The comparison took into account all objects within 280 kiloparsecs around the main galaxy, corresponding to the volume covered by the SDSS data. All models predict that around 100 satellites should be brighter than $M_V = -3$ mag, in good agreement with various recent estimates based on observations

The total number of satellites depends on the mass of the central galaxy. The luminosity function of the least massive model halo (G0 in Fig. II.7.1, its mass is $M = 0.88 \times 10^{12}\,\mathrm{M}_\odot$) is almost flat and contains far fewer low-luminosity satellites than the Milky Way halo. For the most massive halo (G3, with $M = 2.63 \times 10^{12}\,\mathrm{M}_\odot$), however, the semi-analytic models produce more satellites of all luminosities than are observed in the Milky Way. This connection between the mass of the central halo and the luminosity of the dwarf satellites does not depend on the choice of semi-analytic model and shows that the total mass of the central halo is decisive for the shape and the calibration of the luminosity function.

All three semi-analytic models considered here exhibit luminosity functions which are in quite good agreement with the observations. The K09 and S09 semi-analytic models (*top and center* line in Fig. II.7.1) reproduce the observations well across the whole luminosity range -2 mag $\geq M_V \geq -16$ mag; with Morgana (*bottom line*) there is a slight excess in the central region.

Fig. II.7.1: The luminosity function (LF) of dwarf galaxies in the galactic halo. This shows the number of objects per luminosity interval as a function of the absolute luminosity. The solid line represents the results of the model calculations for the four haloes G0 … G3 investigated (*from right to left*) for each of the three semianalytic models used (S 08, K 08 and Morgana, *from top to bottom*). The shaded band indicates the uncertainty in the calculated LF. The measurement points with error bars represent the LF derived from the SDSS.



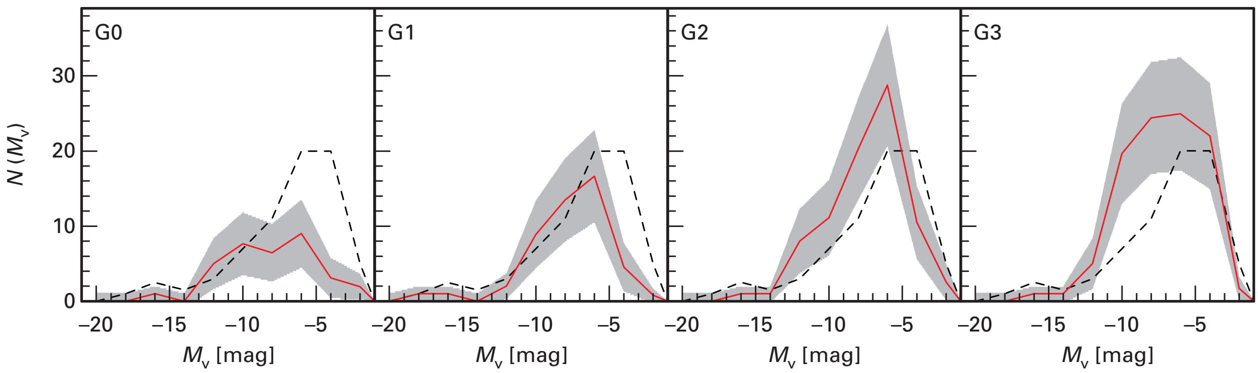


Fig. II.7.2: Comparison of the results of the model calculations modified in accordance with the selective effects of the observation (*red line with shaded error area*) with the raw data from the SDSS (*black dashed line*). The number of dwarf galaxies as a function of their luminosity is depicted for the four model haloes G0 ... G3. The K09 semi-analytic model was used.

The empirical luminosity function of the dwarf galaxies was derived from the SDSS data based on certain assumptions about their radial distributions around the main galaxy. Moreover, a number of selection effects influence the observations, and these must be taken into account when deriving the empirical luminosity function from the raw SDSS data. The comparison between the model calculations and the observations can also be carried out with the model calculations subjected to these same selection effects. The result is then compared directly with the raw data from the SDSS, a method which also tests the validity of the assumed radial distribution of the dwarf galaxies. Such a direct comparison is shown in Fig. II.7.2. It shows again that the semi-analytic models for the haloes G0 ... G2 provide good agreement, while a moderate excess of faint dwarf galaxies occurs with the massive G3 halo.

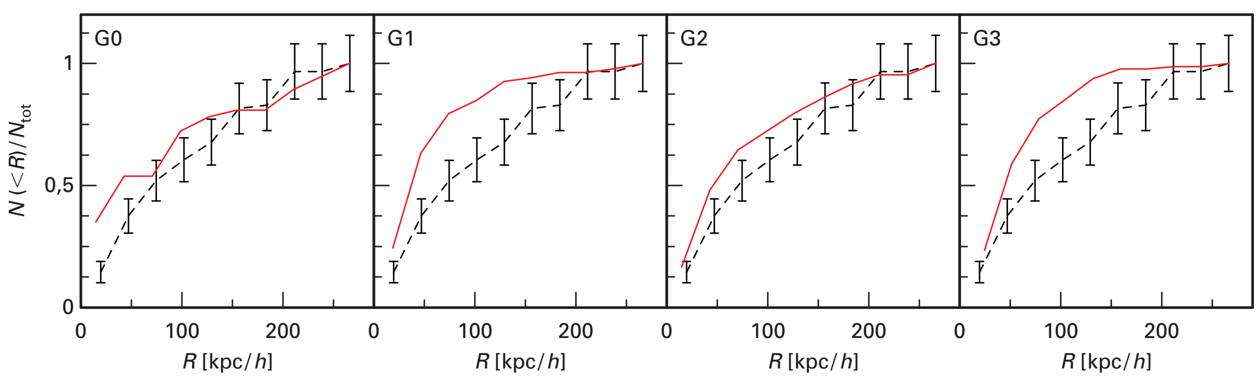
The radial distribution of the dwarf galaxies in the four model haloes compared to the characteristic distribution derived from the SDSS data is shown in Fig. II.7.3. For the model haloes G0 and G2 the simulations obviously reproduce both the gradient and the absolute values of the empirical data well – markedly better than for G1 and G3. The result essentially also confirms the radial distribution of the dwarf galaxies about the Milky Way, which was assumed for the derivation of the empirical luminosity function.

The role of individual processes

What effect do the physical processes taken into account in the semi-analytic models have on the shape and the absolute value of the theoretically calculated luminosity function and, in particular, on the formation of ultra-faint dwarf galaxies? The effects of three processes on the model calculations described here are presented in brief below: 1. Cosmic reionization of the haloes can suppress the accretion of the gas at an early stage; 2. Originally larger subhaloes can be destroyed by tidal forces; 3. Supernova explosions can remove the gas from the haloes and thus prevent further star formation. The importance of the individual processes for the luminosity function can be estimated by varying the corresponding model parameter.

Cosmic reionization. It is still uncertain in which era the flare-up of high-energy radiation sources in the early universe caused cosmic reionization. In addition, reioni-

Fig. II.7.3: The cumulative number of dwarf satellites as a function of their distance from the center of the galaxy. Observations: *Black dashed line with error bars*; K09 semi-analytic model: *Red solid line*.



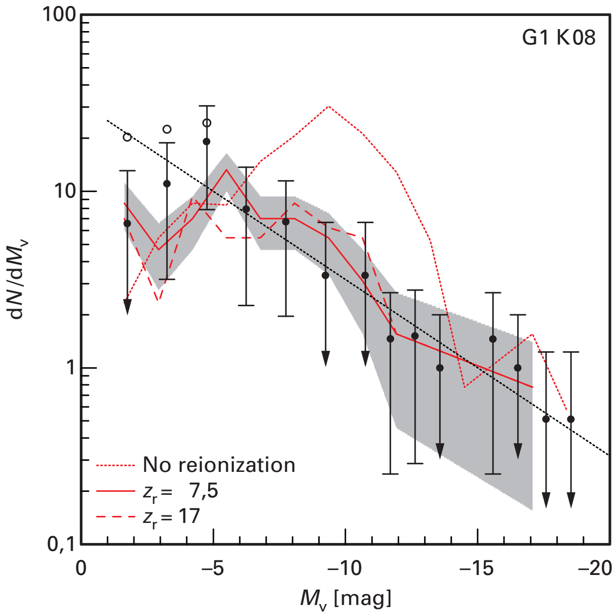


Fig. II.7.4: The luminosity function of the dwarf satellites for halo G1, calculated with the K08 semi-analytic model using three different assumptions for the reionization era. The case $z = 7.5$ was used for all model calculations.

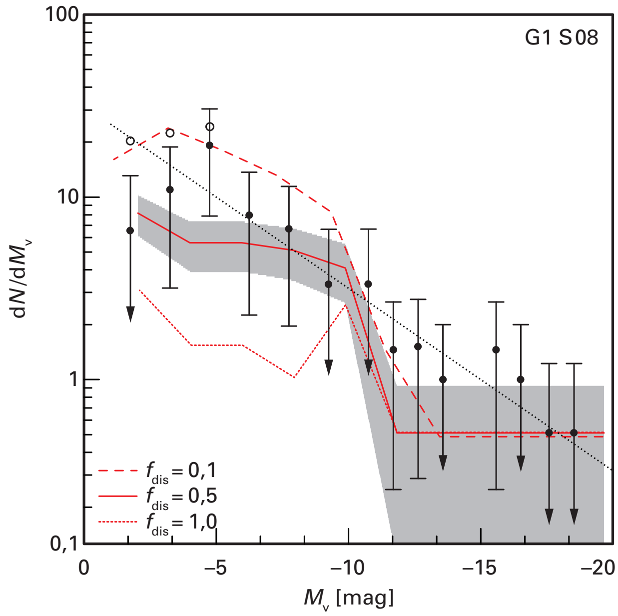


Fig. II.7.5: The influence of the tidal friction on the lower end of the luminosity function is strong, as this calculation for the halo G1 and the S08 semi-analytic model demonstrates. Three different values are assumed for the parameter f_{dis}, which describes the tidal friction.

zation is an inhomogeneous process which could have occurred in the Local Group at a different time compared to the average of the universe as a whole. Three different assumptions concerning the era of reionization were therefore tested here: a) There was no reionization; b) Very early reionization at $z_r = 17$; c) Later reionization at $z_r = 7.5$ – this value was taken for all the model calculations presented above. Without any reionization, the hot gas can cool efficiently by atomic line emission and each subhalo can accrete a lot of gas in a short time. This gas can then be converted into stars before the first supernovae explode, preventing further gas supply and star formation. Many satellites of medium luminosity (–15 mag $M_V < -6$ mag) are formed under this condition. If the reionization is taken into consideration, less gas is available for cooling and star formation, and more low-mass dwarf galaxies and fewer dwarf galaxies of medium mass are formed. Fig. II.7.4 shows the effect of reionization on the luminosity function given the assumptions described using the example of one of the models investigated. The best agreement results for $7.5 < z < 11$.

Tidal friction. The semi-analytic models use the parameter f_{dis} to describe the destruction of the dwarf galaxies due to tidal friction in the halo of the Milky Way. A dark subhalo is considered to be completely destroyed if its mass is less than or equal to the mass which was originally within the radius $f_{dis}\, r_s$, where r_s is the original scale radius of the subhalo. Fig. II.7.5 uses an example to show that the lower end of the luminosity function can vary by a factor of up to 10, depending on the choice of the parameter f_{dis}. The best agreement with the observations is obtained for $f_{dis} = 0.1 \ldots 0.5$ depending on the model.

Supernova explosions have a strong influence on how star formation in dwarf galaxies proceeds. The comparison of model calculations with and without taking supernovae into account shows that, without supernovae, too few faint satellites ($M_V > -5$ mag) are formed, while there is an excess at medium luminosity (-15 mag $< M_V < -10$ mag). The supernovae shift galaxies of medium luminosity to the fainter end of the luminosity function, as also happens with reionization. Overall, the investigation presented here confirms and extends earlier work on the theoretical problem of the »missing satellites«. Its significant progress consists in the way it links evolutionary models of dark haloes with high numerical resolution with semi-analytic models describing the physical processes in normal matter. It has thus been possible to demonstrate that, within the framework of the Λ-CDM scenario, the complex interaction of well-known and well-founded astrophysical processes explains in a natural way the shape of the luminosity function of dwarf galaxies in the halo of our galaxy, which has been derived from observational data over six orders of magnitude in luminosity. The problem of the “missing satellites” no longer exists.

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II.8 The significance of galactic collisions for star formation in the cosmos

When large galaxies come close to one another, the resulting tidal forces initiate intense and large-scale star-forming activity in the systems involved. However, this spectacular process does not play a very important role in the formation of stars in general. In fact, an international study headed by the MPIA has shown that the formation of no more than ten percent of all new stars has been initiated directly by gravitational interaction in mass-rich galaxies during the last eight billion years (at redshifts $z < 1$). This empirical finding is of great significance for the theory of galaxy evolution.

Gravitational interactions and mergers of galaxies can dramatically enhance the star-forming activity in the systems involved. This is exhibited by all investigated cases with redshifts $z < 1$, for which the morphology of the systems is discernible in the visible part of the spectrum. The ultra-luminous infrared galaxies, for example, where the strongest bursts of starforming activity are observed in the near cosmos, are in fact almost exclusively merging pairs of galaxies or multiple systems. These most spectacular cases are of less theoretical interest on an individual basis than they are taken as a whole, however; it is more the *average* increase in the star-forming activity, averaged over all more important cases of interaction or merging within a given population, that is revealing. The strong decrease in the cosmic star formation rate during the last eight billion years in particular has mirrored the decrease in the frequency of close encounters between galaxies. This observation could be naturally explained if a large fraction of the star formation were initiated by such encounters.

It has long been assumed that elliptic and lenticular galaxies are formed by the merging of spiral galaxies, and that such merger processes play an important role in all hierarchical models of galactic evolution. In model calculations, the gravitational interaction of the galaxies causes an increase in the star formation rate and thus plays a key role in the description of the chemical evolution of the stellar populations in galaxies. Therefore, in order to select the correct theoretical description of galaxy evolution, it is necessary to empirically derive the importance of the gravitational interaction between neighbouring galaxies on the star formation rate.

In the study described here, a statistical analysis of the characteristics of a complete, random sample of mass-rich galaxies ($M_* > 2 \times 10^{10}\,M_\odot$) at redshifts in the range $0.4 < z < 0.8$ was performed, taking into account all phases of gravitational interaction between galaxies with stellar components of comparable mass (mass ratio 1 : 1 to 1 : 4). Two key issues were investigated: How large is the average enhancement of the star formation rate as a function of the inverse distance of interacting galaxies? What fraction of the star-forming activity is initiated directly by gravitational interaction and merging of the galaxies?

The random sample and its analysis

The galaxies investigated in this study form a well-defined and, within a given cosmic volume, complete random sample from the photometric survey COMBO-17 that had been conducted earlier at the MPIA, with broad and narrow band images in 17 colors from the UV (350 nm wavelength) through to the near infrared (930 nm) covering a section of the sky the size of a full moon. High-resolution imaging in the COMBO-17 field from the GEMS and STAGE surveys carried out with the HUBBLE Space Telescope were also available. The SPITZER Space Telescope has also observed the field in the mid- and far-infrared.

The redshifts of the galaxies and the masses of their stellar components had already been determined from the COMBO-17 data. It was therefore possible to define a new volume for investigation, chosen to be limited to galaxies with redshifts in the interval $0.4 < z < 0.8$. In order to minimize the influence of the star-forming activity on the composition of this random sample, 2551 galaxies were selected solely on the basis of the mass of their stellar components, bounded on the low side at 20 billion solar masses. To investigate the increase in the star formation rate as a result of gravitational interaction, only pairs of galaxies with similar mass were considered – i.e. those whose mass ratio was in the interval between 1 : 1 and 1 : 4.

The star formation rate of galaxies can be measured by their UV-brightness, as it originates from the stars that are mass-rich, short-lived and therefore newly formed. The dust in large supply around these newly formed stars meanwhile absorbs their UV-radiation and heats up, whereby the thermal radiation of dust is a measure of the UV-radiation absorbed. The star formation rate of the galaxies in this sample was therefore derived from a combination of their UV-brightness and their IR-brightness, based on data from COMBO-17 and SPITZER photometry at 24 μm and 83 μm wavelengths. The UV and infrared brightness in a given galaxy was used to derive the star formation rate on the basis of model calculations by other authors. The possible bias introduced to these results by the thermal emission from dust heated by active galactic nuclei was carefully estimated and neglected, since it contributes 10 percent at most.

An enhancement of the star formation rate can occur in all phases of the gravitational interaction between pairs of galaxies (mutual separation less than 2 arc seconds or 15 kiloparsecs, around 50 000 light years), from the initial close fly-by to the final coalescence. In order to also account for the closest phases of the interaction, data in the COMBO-17 field from the HUBBLE surveys GEMS and STAGES were used for the morphological characterization of the objects, as well as the final determination of the star formation rates. This required a visual classification of these objects. The 2551 galaxies of the random sample were distributed over the three following classes:

1. Objects without discernable signs of gravitational interactions with neighbouring galaxies. This class also includes asymmetric, irregular galaxies with stochastically distributed star-forming activity initiated by internal processes. (A total of 2380 objects.)

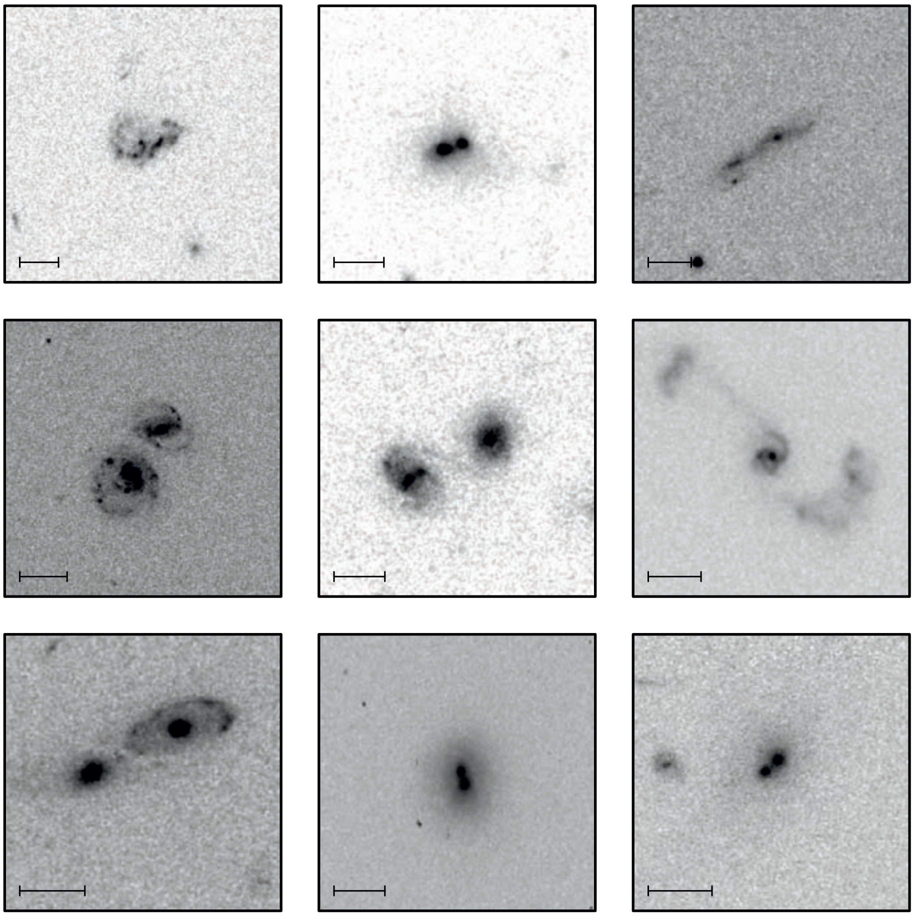
2. Significant close encounters: These are pairs of galaxies which appear spatially separated in HUBBLE images, but not in COMBO-17 images, and whose mass ratio is in the range between 1:1 and 1:4. (A total of 106 objects; examples are shown in Fig. IV.8.1.)

3. Larger merger products: Galaxies whose morphology contains indications of a recent merger of two similar mass-rich galaxies. Typical characteristics are: a highly disturbed morphology, two cores of comparable brightness, or tidal tails of similar length. (A total of 72 objects; examples are shown in Fig. IV.8.2.)

The true distances (not those projected on the sky) of the objects of the first class of the random sample can be derived only statistically, while a mutual separation of 10 kiloparsecs was assigned to the pairs in Class 2 and a distance of zero kiloparsecs to the merger products of Class 3.

This makes both the photometrically-determined star formation rates and the mutual separation of pairs available for all galaxies in the random sample. From this data set the average dependence of the star formation rates on

Fig. II.8.1: Objects of Class 2 – significant close encounters between larger galaxies of similar mass (estimated mass ratio $M_1/M_2 = 1:1$ to $1:4$). In this stage of the gravitational interaction the galaxies can still be recognized as being separate on the high-resolution HUBBLE images shown. The black bar corresponds to a distance of 20 kiloparsecs at the location of the galaxy.



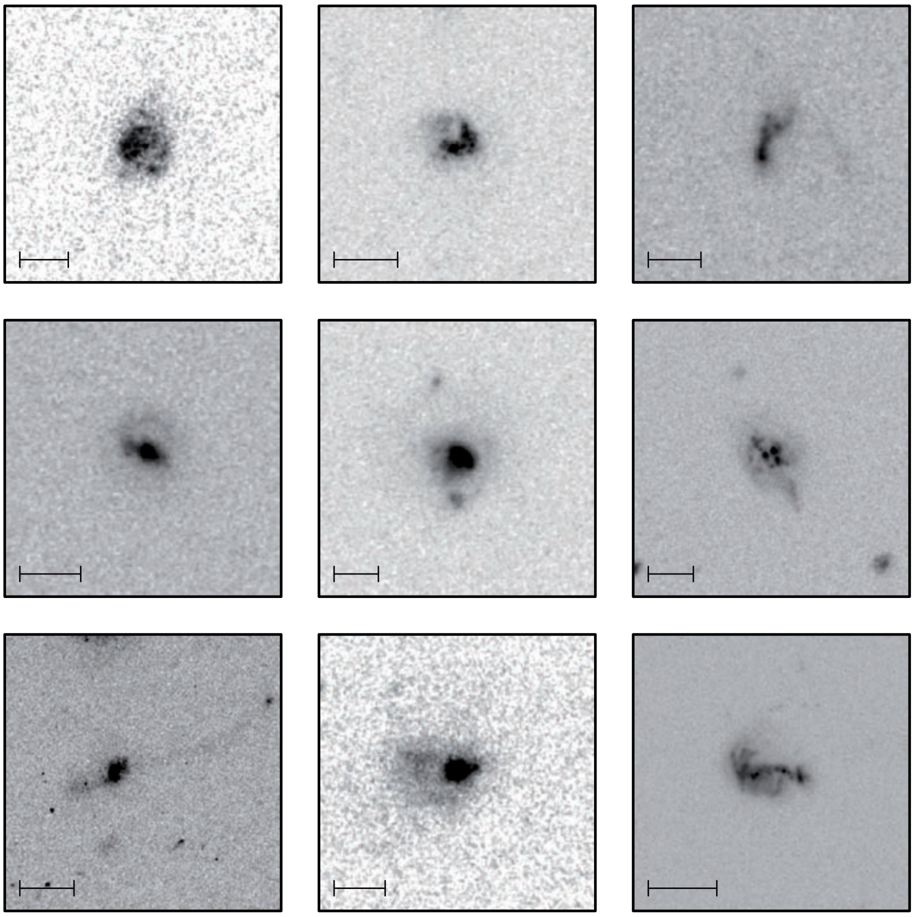
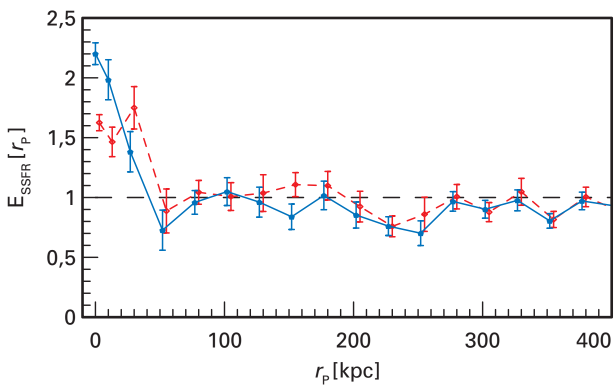


Fig. II.8.2: Objects of Class 3 – larger merger products. The black bar corresponds to a distance of 20 kiloparsecs at the distance of the galaxy.

Fig. II.8.3: The average enhancement of the star-forming activity in pairs of galaxies as a function of mutual separation. *Blue symbols:* all pairs wherein at least one galaxy exhibits star-forming activity; *red symbols:* Pairs with star-forming activity in both components. The measurements at $r_p = 0$ and $r_p = 10$ kiloparsecs were derived for the objects of Classes 2 and 3 which had been selected according to their morphology.



the mutual separation was derived for all possible pairs where at least one galaxy shows signs of starforming activity, as well as for those pairs where both components show starforming activity. The result is shown in Fig. II.8.3: In both cases a significant enhancement of the star-forming activity is discernible for mutual separations of less than 40 kiloparsecs, by an average factor of between 1.5 and 1.8, in fact.

The enhancement factor for the starforming activity of the galaxies thus derived as a function of the distance to their neighbours now makes it possible to estimate this effect in relation to the star formation in all galaxies of the random sample. The result is that only around 8 percent of the starforming activity in the redshift interval between $z = 0.4$ and $z = 0.8$ is *directly* triggered by "significant merger processes" of the type considered here. In terms of the observed decrease in the frequency of these mergers during the last 8 billion years (from $z = 1$ to the present, $z = 0$), this would mean that at $z = 1$ around 14 to 18 percent of all star formation in galaxies was triggered by gravitational interactions of the type considered here, while today it is only around 1 to 2 percent.

On the other hand, the study presented here shows that the strongest starforming episodes, which are deeply embedded in dense dust clouds, occur in merging galaxies in most cases. This finding is therefore compatible with the low average enhancement by gravitational interaction if the strongest bursts of starforming activity each only last around 100 million years.

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III. Selected Research Areas

III.1 Gas in Protoplanetary Disks

In this chapter we discuss recent progress in our understanding of the gas in protoplanetary disks, resulting from various projects performed at MPIA. Such disks are a transient by-product of star formation: for a short time, inside the disks we find conditions to form planetary systems.

The disks around newly-formed stars consist of a mixture of gas and solid particles, the latter collectively referred to as "dust". The gas comprises the vast majority of the disk mass. Yet, the dust is much easier to observe due to its high opacity. The gas is comparatively transparent, and, in particular, its main component, molecular hydrogen (H_2), is almost invisible due to the symmetry of the molecule. Together with helium (He), which is even more difficult to detect, hydrogen makes up about 98 % of the mass in a protoplanetary disk. The remaining 2 % are divided roughly equally between other gaseous species and dust. Since the different gaseous species are well mixed, we can use "tracer molecules" that exhibit strong spectral lines to study the properties of the bulk gas. A host of gaseous species have been detected in circumstellar disks, the most important being carbon monoxide (CO) and water (H_2O). CO and its isotopes are the most-used tracers of gas, which works well except in the coldest regions of the disk interior: at temperatures below $\sim$ 20 K the CO is removed from the gas phase and instead forms ice coatings on dust grains, and therefore is no longer a good tracer for the bulk gas. Water freezes at temperatures of $\sim$ 150 K and forms ice mantels on the dust grains, promoting the sticking together of dust grains to form larger particles and eventually the seeds of planets.

A multitude of more complex molecules, including e.g. methanol, methylether, and formic acid, have been discovered in interstellar space. Also a precursor of aminoacids, aminoacetonitrile, and the simplest sugar, glycolaldehyde, have been found towards star forming regions. Protoplanetary disks may host a rich pre-biotic chemistry, and it is possible that the simplest molecular ingredients of life were present in the disk around the young sun even before the Earth assembled.

As the main constituent of the disk, the gas dominates the kinematics of the disk material. The disk structure is reigned by an interplay between the gas and the dust, with the gas providing the pressure support and the dust dominating the heating and cooling, and thereby the temperature and pressure, of the gas. During the early phases of the star formation process, most of the stellar mass is accreted through the disk. This process is governed by the turbulent viscosity of the gas, which in turn depends on the degree of ionization. Accretion onto the star continues on a lower level in the later phases of the disk evolution, when planets may be forming.

The gas is of pivotal importance for the planet formation process. It has a strong damping influence on the relative velocities of small dust particles, without which collisions between particles would lead to their destruction instead of the formation of larger aggregates. Such large aggregates of dust grains can be trapped in local gas pressure maxima, where they concentrate and can form kilometer sized planetesimals. These can in turn merge to form terrestrial planets or, if they become massive enough to gravitationally trap gaseous material, the cores of giant planets. The latter are largely made up from gas and are thought to form just beyond the "snowline", i.e. at such distance from the central star where the temperature is just low enough that water freezes and forms ice mantels on the dust particles. The gas forms the main mass reservoir of the disk during the planet formation phase, and through gravitational interaction it can exert strong torques on newly formed planets or their building blocks, causing them to migrate through the disk. The architecture of planetary systems around other stars, which shows an astonishing diversity and is often very different from that of our solar system, can be understood only if we comprehend the interactions between forming planets and the gas in the disks.

The schematic representation of a protoplanetary disk shown in Fig. III.1.1 highlights the important physical processes that take place in the various disk regions, and the observational probes by which we can study these processes. The physical dimensions correspond to a young star of roughly a solar mass but can also be used to qualitatively understand lower and higher mass objects by down- or up-scaling the various regions. Close to the central star, the temperatures are so high that no solid material can survive, and the disk contains only gas that may be accreted onto the central star along magnetic field lines connecting the inner disk with the stellar surface. Somewhat further out the temperature has dropped below about 1500 K, and the disk material contains dust as well as gas. At substantially larger radii, the temperature has dropped to below 150 K and the disk contains water-ice as well in the form of coatings on the dust grains. The inner disk regions and at least the disk surface at larger radii are partially ionized, making them turbulent and allowing transport of material and angular

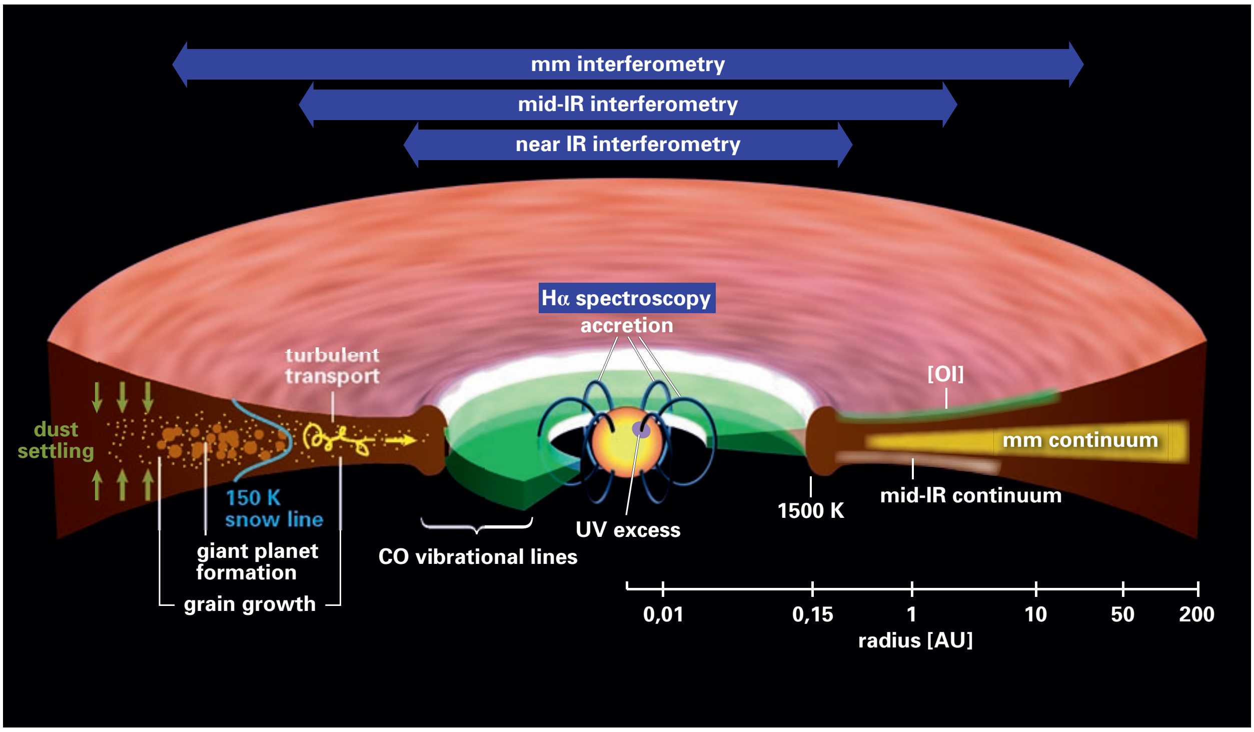


Fig. III.1.1: This sketch of a protoplanetary disk around a young solar-type star illustrates the location of various important physical processes that occur in the disk, as well as a range of observational diagnostics that we use to study these.

momentum through the disk. Dust particles agglomerate into larger particles and may sink to the disks midplane, where the formation of larger bodies and eventually planets proceeds.

The dusty disk material can be observed and spatially resolved with near-infrared interferometry, which is most sensitive to the hot inner disk region, mid-infrared interferometry by which we can study the disk surface in the planet-forming disk region at radii less than about 10 AU, and millimeter interferometry probing the bulk of the dust mass in the disk midplane. The accretion process can be probed by the excess ultraviolet radiation emitted in the accretion shock where the material hits the stellar surface, as well as the emission lines emitted by the accretion funnels, most notably Hα. Near-infrared rotational-vibrational emission lines of carbon monixide (CO) trace the kinematics of the disk material within roughly the central astronomical unit, and pure rotational transitions observed at far-infrared and millimeter wavelengths reveal the kinematics and complex chemistry of the disk material at larger radii.

In the 2007 annual report we presented an extended contribution on “chemistry in disks” based on observations with millimeter interferometers and radiative transfer modeling of these data. The current contribution focusses on results obtained at optical and infrared wavelengths. However, much progress has been made in the field of millimeter observations and disk models including line radiative transfer and chemical networks (Dutrey et al. 2008; Schreyer et al. 2008; Wiebe et al. 2008; Pavlyuchenkov et al. 2008; Vasyunin et al. 2008, 2009; Henning et al. 2010).

The inner disk region

In this section we discuss the properties of the innermost disk region, very close to the central star. In particular we will address the accretion of disk material onto the star, which in early phases of the pre-main sequence evolution, controls the mass built-up of the star, and in later phases may contribute importantly to the disk-dissipation process.

Accretion onto the central star.

Examining the presence of accretion onto the star, or measuring the accretion rates, is one of the most straightforward ways to confirm the gaseous content of the innermost disk, between a few stellar radii and $\sim$ 0.1 AU. The presence or absence of accretion provides information about the processes leading to disk dispersal, especially in disks with low or absent infrared excesses, characteristic of substantial dust evolution. The gas content in the inner disk also affects the disk’s fate: once accretion (or gas mass) drops below a certain value, the formation of giant planets can no longer proceed. Accretion can be confirmed by observing high velocity wings ($>$ 200 km/s) in several optical and IR emission lines, especially the Hydrogen Balmer series, He I emission at 667.8 nm, Ca II H and K lines in the near-UV, and the

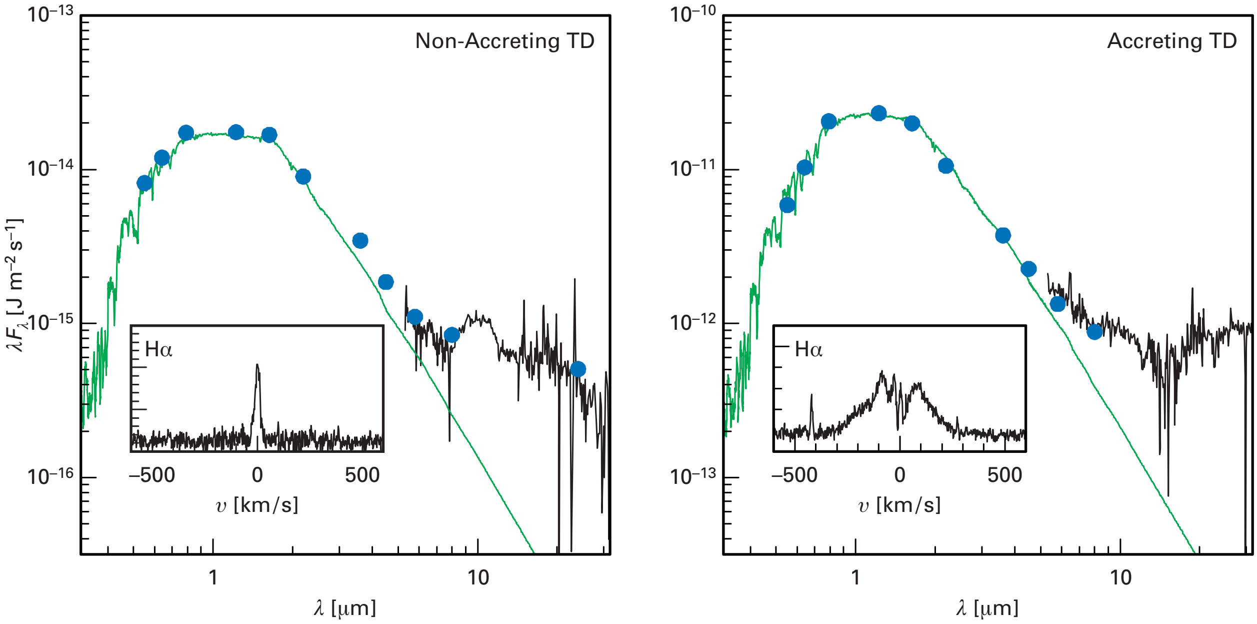


Fig. III.1.2: Examples of non-accreting and accreting transition disks around early M-type stars. While the SEDs may be roughly similar, the spectroscopically revealed presence of accretion points to different evolutionary paths.

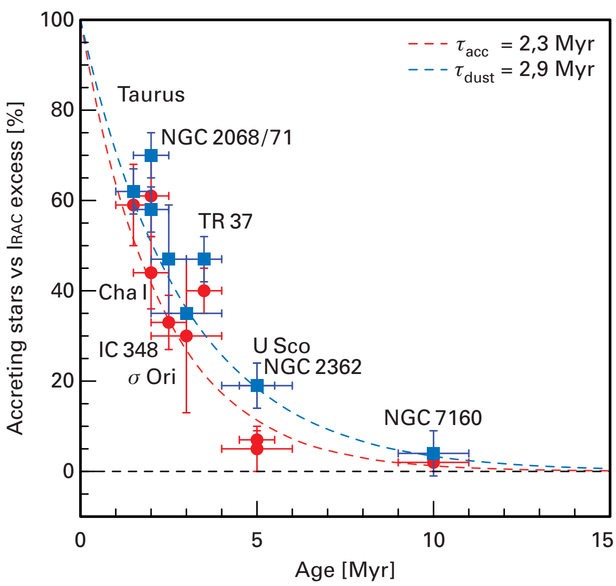
Ca II triplet in the near IR, which indicate gas in free-fall onto the star. In addition, the accreting material causes an accretion shock as it hits the stellar surface, producing observable excess emission over the stellar photospheric level in the near UV, which can be directly related to the potential energy of the accreted mass. The study of statistically significant samples of objects allows to average over the typical accretion variability observed in young objects, as well as to determine the timescales of accretion and the physical mechanisms that dominate disk dispersal with time.

Several MPIA-led projects have been studying the presence of accretion in young and evolved disks, as well as its time evolution, compared to the well-known dust dissipation timescales.

Whereas actively accreting stars show infrared excess emission at wavelengths > 8 – 24 μm, characteristic of a dusty disk, in more than 99 % of cases (Sicilia-Aguilar et al. 2006, 2010), the opposite is not necessarily true: not all objects with infrared excess emission are accreting at detectable levels. In particular, about half of the "transition disk objects", i.e. objects that have zero or negligible near infrared excesses (see Fig. III.1.2), do not show signatures of accretion. (Sicilia-Aguilar et al. 2006, 2010)

We used optical spectroscopy to study the presence of accretion for a large sample of solar-type and low-mass stars in different clusters with ages 1 – 50 Myr. We found that, although about 20 % of the stars aged 5 Myr still show near-IR excess emission, only about 5 % of them are actively accreting at rates > $10^{-11}\,M_\odot$/yr, which suggests that accretion ceases before all the dust in the disk has been removed. The characteristic timescales of dust and accretion dissipation would be 2.9 and 2.3 Myr, respectively, assuming an exponential decay (see Fig. III.1.3). Planet formation and/or migration in the inner disk could explain the lack of accretion in a disk that still contains significant amounts of dusty material (Fedele et al. 2010).

Fig. III.1.3: The timescales of the disappearance of gaseous material as traced by accretion onto the central star (*red*), and of the disappearance of solid material (dust particles) as traced by the infrared excess (*blue*). Although ~ 20 % of stars aged 5 Myr show IR excesses characteristics of disks, only ~ 5 % are still accreting at detectable rates (> $10^{-11}\,M_\odot$/yr).



In a different study we investigated the accretion rates and spectral energy distribution of about 400 young (1 – 2 Myr) stars in the Orion clouds L 1630 N and L 1641 (Fang et al. 2009). The youth of the regions allows peering into the first stages of disk dissipation and the involved mechanisms. The accretion rates were derived from the flux measured in several emission lines (Hα, Hβ, He I), enabling us to measure accretion rates as low as $\sim 10^{-11} M_\odot$/yr for low-mass stars. The results of the survey also pointed to slightly different timescales for dust and accretion, as about 1/3 of the objects with evolved disks did not appear to be accreting within the detection limits. The lack of very young disks with inner holes also suggested that binarity is not a leading mechanism in the production of transition disks (this is also the conclusion from direct detection of companions in transition disks; Pott et al. 2010). A process that requires a substantial amount of time must be driving the disk dissipation. Giant planet formation typicaly takes 3 – 4 Myr in the core accretion scenario (e.g. Mordasini et al. 2009).

Although part of the objects with evolved inner disks (according to their IR excesses) are not accreting, there is no significant difference between the accretion rates of transition and normal disks. This suggests that although both dust emission and gas accretion decrease with time, their evolution does not occur fully "in parallel", as many disks with reduced or negligible IR excesses (and thus presumably with optically thin inner disks due to grain growth / dust removal / planetesimal formation) still have enough gas mass to sustain normal levels of accretion. The different timescales of dust and gas removal could have important consequences for planet formation. For example, gravoturbulent planetesimal formation is much stronger at higher dust to gas ratios (Johansen et al. 2009). Also, the final growth from 0.1 $M_\odot$ protoplanets to terrestrial planets sets in when the damping influence of the gas is gone. This could possibly lead to a higher dust production rate through collisions. Our Orion survey also allowed us to check the dependence of accretion on stellar mass, finding a steeper relation ($\dot{M} \propto M^{2.8}$) than previously thought in the subsolar mass regime. This relation, which cannot be related only to viscous evolution, may indicate deeper differences in the disk structure (accretion mechanisms, viscous timescales, presence of dead zones) depending on the mass of the star, as has been suggested by Hartmann et al. (2006). This is also important in understanding how the disk gas mass scales with the stellar mass. This in turn strongly influences how planets from around different stars (Ida & Lin 2005).

Gas as a tracer for disk evolution

There are several processes that could lead to disk dissipation, with grain growth or settling, planetesimal or planet formation, and stellar UV photoevaporation being probably the most efficient ones in single stars. Observational evidence suggests that they all happen to some extent, but the relative importance and the interplay between the different mechanisms is unknown. In addition, the timescales of all these mechanisms are different, and their efficiency in disk removal is expected to vary over time (Alexander & Armitage 2009), with planet formation being the leading mechanism during the first few million years, and photoevaporation playing a mayor role after about 4 million years. Measuring accretion in evolved young clusters is an important test to reveal the ongoing disk-dispersal processes: while grain growth and settling must not necessarily affect neither the gas content of the disk nor the accretion, the accretion onto a planet will decrease the total accretion onto the star by up to a factor of 10 (compared to objects without a planet; Najita et al. 2007). How much gas is accreted onto a giant planet, and how much by-passes it (i.e. flows through the gap onto the star), is an important open question (see Lubow & D'Angelo 2006). Only a planet that undergoes rapid, runaway gas accretion is able to significantly influence the stellar accretion rate. A planet of at least about 30 $M_\odot$ must be present to have a substantial effect.

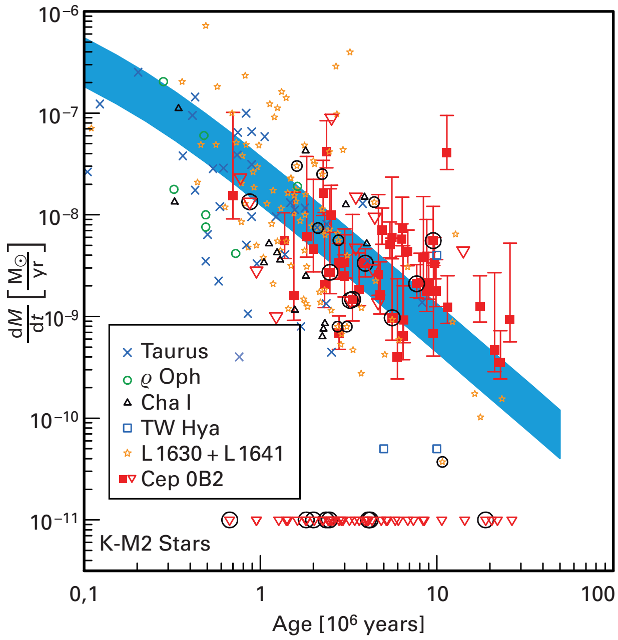


Fig. III.1.4: Evolution of the accretion rates with age in different clusters, compared to plain viscous evolutionary models with different initial disk masses (*blue band*). Since at all ages a substantial fraction of stars are not accreting, it seems unlikely that viscous evolution is the sole responsible for disk dispersal. Other mechanisms, like photoevaporation, are required to remove large amounts of gas by the age of 5 – 10 Myr. Transition objects in Cep OB-2 and Orion are marked with large black circles. Although many of them do not show accretion, those accreting present similar rates as normal disks.

Sicilia-Aguilar et al. (2010) used the excess U band emission to measure the accretion rates in the evolved clusters Tr 37 (median age ~ 4 Myr) and NGC 7160 (~ 10 Myr), in the Cep OB-2 region. Both clusters show significant dust evolution in both their disk fractions (~ 50 % for Tr 37, ~ 4 % for NGC 7160) and in the typical slopes of the spectral energy distribution (SED). The measured accretion rates are also consistent with simple viscous-disk evolutionary models (see Fig. III.1.4). Nevertheless, the presence of non-accreting objects at all ages reveals that viscous evolution alone cannot be responsible for the observed accretion rates. Photoevaporation could be efficient removing half of the disk mass and stopping accretion once the disk mass is low enough (Gorti et al. 2009) and could explain the faster decrease of the accretion rates in some objects (maybe those having lower initial disk masses). The presence of binaries may also be invoked as an important factor accelerating disk dispersal, the end of accretion, and planet formation (Bouwman et al. 2006).

On the other hand, the new accretion rates revealed that some of the disks with normal-looking SEDs (and thus, dust rich inner disks) present very low accretion rates (few times $10^{-10}\,M_{\odot}$/yr), suggesting that photoevaporation is not always efficient to remove the disk quickly once its mass accretion rate has substantially decreased. In addition, about half of the transition disks in Cep OB2 are still accreting, a fraction slightly lower than in Orion. This may be expected if several physical processes with different timescales are acting to clear the inner disk of material. Although none of the transition disks have large accretion rates ($> 10^{-8}\,M_{\odot}$/yr), the presence of many normal disks with low accretion makes the accretion rates of normal and transition disks not significantly different. This provides a further indication of different timescales for dust and accretion, and suggests that at ~ 4 Myr age, accreting transition disks are probably related to strong dust coagulation and settling, which reduces the near-IR emission without substantially affecting the gas content in the disk. The similarly large number of non-accreting transition disks could be explained by photoevaporation and/or giant planet formation, in agreement with theoretical models (Alexander & Armitage 2009).

Gas in the planet-forming disk region

Whereas in the previous section we discussed the properties of the central AU of the disk and the process of accretion onto the central star, we now focus on the surface layer of the disk at somewhat larger radii, between ~ 1 AU and $\sim 10-20$ AU. At these radii, planets are thought to be formed in the disk midplane, and the observable properties of the gas in the surface layers provide important boundary conditions for our understanding of the planet formation process. The gas and dust surface density, the temperature structure and scale height, and how these evolve with time, directly enter the equations describing planet growth and migration (e.g. Alibert et al. 2005).

On the origin of [Ne II] emission in pre-main sequence stars

The irradiation of the surface of circumstellar disks with high-energy photons from the central object or from stars in the immediate vicinity plays an important role in the disk chemistry as well as in the dissipation of the protoplanetary disk by means of photoevaporation. Our understanding of these processes relies heavily on the ability to measure the intensity of the extreme ultraviolet (EUV) and X-ray radiation fields at the disk surface. However, energetic radiation is often difficult to observe since it is strongly absorbed by circumstellar or foreground material. In particular EUV radiation is strongly attenuated by even small columns of intervening hydrogen gas.

The 12.81 μm fine structure line of ionized neon has recently been proposed as a potential tracer for energetic radiation in young stellar objects. With a first ionization potential of 21.6 eV, neon indeed requires EUV or X-ray irradiation to be photoionized. Once ionized, the Ne^{+} must be heated to $\gtrsim 1000$ K for the 12.81 μm [Ne II] transition to be excited. It is a forbidden transition tracing low density gas.

The 12.81 μm [Ne II] line has been detected in infrared spectra of young stellar objects, both from space with ISO (van den Ancker et al. 1999) and in ground-based observations (e.g. Herczeg et al. 2007; van Boekel et al. 2009; Najita et al. 2009; Pascucci & Sterzik 2009). Observations with the sensitive IRS spectrograph onboard the SPITZER Space Telescope have increased the number of YSOs in which the [Ne II] has been detected from a handful to several dozens (e.g. Lahuis et al. 2007; Pascucci et al. 2007).

A number of theoretical studies have attributed the observed [Ne II] emission to the tenuous surface layers of the disks or to slow, photoevaporative disk winds, with the gas being ionized and heated by Xrays or EUV radiation from the central star (Glassgold et al. 2007; Meijerink et al. 2008; Gorti & Hollenbach 2008; Hollenbach & Gorti 2009; Alexander 2008; Schisano et al. 2010). However, [Ne II] emission can also be produced in strong shocks of $70-100$ km s^{-1} (Hollenbach & McKee 1989), and the [Ne II] emission observed towards YSOs has also been attributed to high-velocity shocks in their jets (van den Ancker et al. 1999). The available space-based observations provide line fluxes but have insufficient spatial resolution to distinguish between a disk and jet origin of the [Ne II] emission, and insufficient spectral resolution to attribute the emission to a disk surface, disk wind, or jet, through kinematics. The relation between the observed [Ne II] emission and the local energetic radiation fields in young star systems remains unclear.

In order to advance our understanding of the [Ne II] emission process there are currently two viable approaches, both pursued by MPIA scientists: (1) detailed studies of individual objects using high spatial and spectral resolution observations, and (2) robust statistical studies in which the [Ne II] line fluxes are systematically compared to X-ray properties, outflow indicators, etc.

Following the first approach we performed a detailed study of the proto-typical lowmass YSO: the T Tau triplet. At a distance of $\sim$ 148 pc (Loinard et al. 2007), this multiple system forms a particularly well-suited laboratory, for several reasons. It contains at least three young stars within the central arcsecond, each with infrared excess emission due to circumstellar material, of which at least one (T Tau N) is a strong X-ray source (Güdel et al. 2007). The two stars in the southern "infrared companion", Sa and Sb, are probably also prominent X-ray emitters, but they suffer strong extinction of $\sim$ 15 mag (Duchêne et al. 2005), preventing X-rays from reaching our telescopes. The system drives at least two known jets, causing extended emission from shocked gas on scales of several arcseconds (Herbst et al. 1997). The system exhibits very strong [Ne II] emission in space based observations (van den Ancker et al. 1999; Ratzka et al. 2009), which was neither resolved spectrally nor spatially and therefore could not be attributed to any physical component.

We have performed high resolution spectroscopy of the T Tauri system with Visir at the VLT. We took three longslit spectra, with the slits placed such as to cover the disks of all components as well as the main features of the extended shocked gas emission. Our observations have a spatial resolution of $\sim 0\farcs4$ and a spectral resolution of $R \approx 30\,000$. The [Ne II] line was detected throughout the system. The brightest [Ne II] emission is seen in a spatially resolved (FWHM $\approx 1\farcs1$ or $\sim$ 160 AU) component centered on the southern IRC, which is much larger than either disks within the southern close binary, which are limited in radius to $\sim$ 5 AU due to the gravitational interaction between Sa and Sb. We also find extended [Ne II] emission on scales of several arcseconds, red-shifted towards the north and blue-shifted towards the south. We attribute the bulk of the [Ne II] emission in the system to a jet launched from the southern object. From our data we cannot directly determine whether this jet emanates from Sa or Sb, but circumstantial evidence favors Sa (van Boekel et al. 2010). At the position of the X-ray bright T Tau N we detect strongly blue-shifted [Ne II] emission, which we attribute to the approaching side of the jet emanating from the northern star. A small contribution arising from the disk surface of T Tau N cannot be excluded, but in the T Tau system the [Ne II] emission is fully dominated by the outflows and not by X-ray or EUV irradiated disk surfaces.

Following the second approach, we have reanalyzed all available Spitzer spectroscopy, and all available X-ray data taken with Chandra and XMM, in order to make the first comprehensive comparison between [Ne II] emission from T Tauri stars and their X-ray properties. Our sample contains 92 pre-main sequence stars, among which are 13 transition disk objects and 14 sources known to drive strong outflows. We find that the sources without strong jets show a positive correlation between their X-ray and [Ne II] luminosities that is in agreement with simple calculations of [Ne II] emission from disk surface layers irradiated with high-energy photons from the central source. There is a large scatter about the average relation which may be due to source to source variations in the disk properties and the irradiation spectrum, as previously suggested. In individual cases, high spectral resolution observations have indeed confirmed the disk or slow disk wind origin of the [Ne II] emission (Herczeg et al. 2007; Pascucci & Sterzik 2009). We find that the known jet sources are systematically over-luminous in [Ne II] by one to two orders of magnitude.

In conclusion, we find that the [Ne II] emission observed in YSO systems is indeed strongly related to their local energetic radiation fields, and probes their disk surfaces or photo-evaporative winds. However, in sources with high accretion rates and the associated strong outflow activity the [Ne II] emission is fully dominated by the jet, and has no direct relation to the X-ray or EUV luminosity.

The rich far-IR molecular spectrum of HD 100546 – revealed by Herschel

HD 100546 is one of the nearest and brightest Herbig AeBe stars and hence can be studied in extraordinary detail. It is located at a distance of 103 pc and comparatively old with an estimated age of $\sim$ 10 Myr (van den Ancker et al. 1997). Based on the SED, which shows a deep minimum around 10 μm and a sharp rise towards longer wavelengths, the presence of a large gap in the disk was postulated, possibly related to a giant planet orbiting at around 10 AU from the central star (Bouwman et al. 2003; Acke & van den Ancker 2006).

The Iso spectrum has revealed a rich silicate mineralogy with strong emission bands of crystalline silicates, in particular of the Mg-rich end member of the Olivines called Forsterite, in the 10 to 40 μm region (Malfait et al. 1998). The 69 μm Forsterite band, which probes relatively cool material and is a sensitive probe of temperature and iron content of the crystalline material, was also detected but not well-characterized due to the limited sensitivity of Iso. The source shows strong emission from polycyclic aromatic hydrocarbons (PAHs), as well as a strong [OI] 63 μm and a weaker [CII] 145 μm line. Evidence for cold water ice is seen at 43 and 60 μm in the Iso spectrum of HD 100546. In the near-infrared, a rich spectrum of CO rovibrational emission lines is seen (van der Plas et al. 2009). Pure rotational transmissions of CO are detected at millimeter wavelengths, indicating a warm molecular layer in the outer disk (> 50 AU) with temperatures of at least 50 K (Panic et al. 2010).

Within the Herschel Key Program "Dust, Ice, and Gas in Time" (Digit) the well-studied Haebe star HD 100546 has been observed with the Photodetector Array Camera and Spectrometer (Pacs) onboard the Herschel Space Telescope. At the long wavelengths at which Herschel operates we probe the cool disk regions where the ice/snowline occurs. Giant planets are thought to come typically from just outside the snowline (see e.g. Ida & Lin 2004).

A complete scan of the spectrum from 55 to 210 μm was made using the SED mode of Pacs. A wealth of narrow molecular gas lines were detected, coming from CO, H_2O, and OH. Emission in forbidden transitions of atomic species [CII] and [OI] are also seen. A detailed, high-SNR profile of the 69 μm Forsterite feature was recorded, which may be reconciled in two ways: (1) 50 – 70 K material with a small admixture of 2 – 3 % iron residing in the outer disk region (~ 30 AU), or (2) pure Forsterite (100 % Mg, no Fe) with a temperature of ~ 200 K residing in or near the midplane of the disk close to the outer edge of the disk gap at ~ 13 AU.

In total, 32 gas lines were detected in the Pacs 55 – 210 μm spectrum of HD 100546, including seventeen pure rotational transitions of CO from $J = 14 – 13$ up to $J = 31 – 30$, seven lines of OH, and five water lines. The large number of CO lines detected at high-SNR allows construction of a rotational diagram. A single temperature of $T = 580 \pm 14$ K provides a relatively poor fit to the data. A two temperature-model provides a much better match to the data, where the lower rotational transitions up to $J = 22 – 21$ are fitted by $T = 300 \pm 12$ K. The higher transitions require a higher temperature of $T = 800 \pm 100$ K, providing the connection to the high-temperature gas in the innermost part of the disk detected in near-infrared spectroscopy.

The evolution of circumstellar disks in gas and dust

All young stars are surrounded by circumstellar disks during the early phases of their pre-main sequence evolution. The disks dominate the SED of the systems from infrared to millimeter wavelengths. They are dissipated on timescales of several million years, but the physical mechanisms driving the disk dissipation are still poorly constrained. The main candidate mechanisms are viscous evolution (accretion onto the central star), photoevaporation by UV radiation from the central star or nearby hot stars, and planet formation.

While the gas constitutes an estimated 99 % of the disk mass, the opacity of the disk material is dominated by the dust. Hence, the distribution of the dusty material has the largest effect on the observed SED. Observations suggest that the outer disk regions evolve from an initially flared geometry to a more flattened dust distribution due to dust settling (Meeus et al. 2001). In a later stage, the dusty disks dissipate from the inside, as witnessed by the near-infrared excess which disappears before the far-infrared excess does. The gas distribution reflects less strongly on the SED, but there are a number of means to directly constrain the gas: millimeter rotational lines probing the disk interior, near-infrared rovibrational lines probing hot gas in the inner disk regions, optical lines such as the [OI] 630.0 nm line that probes tenuous gas in the disk surface layers, and emission from PAHs which are so light that they couple well to the gas and, unlike the dust, do not settle.

In a study performed with the Spitzer Space Telescope, MPIA scientists have investigated the gas and dust properties of disks around young sunlike stars (spectral type K1 – M5), in comparison to those of disks around less massive stars and brown dwarfs (M5 – M9). The analysis of high quality spectra of over 60 sources revealed major differences in the evolution of both the dust and gas components between the two sub-samples (Pascucci et al. 2009). Giant planets are more rare around M-type stars compared to FGK stars. By studying disk properties as a function of primary mass, we may understand how planet formation occurs around different stars.

Organic molecules in disks around brown dwarfs were detected for the first time. The detection rate statistics and the line flux ratios of HCN and C_2H_2 show a striking difference between the two samples, demonstrating a significant underabundance of HCN relative to C_2H_2 in the disk surface of low-mass objects. We attribute this to the much lower UV flux impinging on the disk surfaces of low-mass objects. Also the dust emission spectra of both classes of objects are different: low-mass objects show weaker silicate features and more strongly processed material. Whether this points at a truly different dust composition in the disk surface layer, or merely reflects the difference in disk illumination – in the low mass, low-luminosity objects, we observe only a fraction of the central AU of the disk in the Spitzer spectra, whereas in the sun-like objects we see a region that is several AU in size – remains to be investigated.

Our results highlight important differences in the chemical and physical evolution of protoplanetary disks as a function of stellar mass, temperature, and radiation field which should be taken into account in planet formation models. We note that the different chemistry of preplanetary materials in the disk may also influence the bulk composition and volatile content of the forming planets. In particular, if exogeneous HCN has played a key role in the synthesis of prebiotic molecules on Earth as proposed, then pre-biotic chemistry may unfold differently on planets around cool stars.

In a different study, MPIA scientists aim to directly probe the distribution of gas and dust in the planet forming region of the disks around three Herbig Ae stars: HD 179218, HD 135344, and HD 101412.

The gas distribution is traced by the [OI] 630.0 nm line, which is thought to arise in the tenuous upper layers of a disk in Keplerian rotation, as judged by the typical "double-horned" line profiles (van der Plas et al. 2008). Turning the argument around, we can use the assumption of a Keplerian rotating disk to infer the radial intensity distribution of the [OI] emission from high resolution spectroscopy. The emission close to the line center traces regions relatively far from the star that rotate slowly, the broad line wings arise in the high-velocity material close to the central star. In short: high spectral resolution is used as a proxy for high spatial resolution. We have recorded high-SNR spectra of all three targets with a spectral resolution of $R \approx 77\,000$ using UVES at the VLT.

The distribution of the dust in the inner ~ 20 AU of the Herbig Ae star disks is traced by its thermal emission in the 10 µm spectral region. We have used the MIDI instrument at the VLT Interferometer to directly spatially resolve this emission. The measured visibilities are fitted with a combination of a central, unresolved point source and one or two uniform rings. The fit parameters are the inner and outer radii of the rings and the relative flux contributions of the various components. Even though these models are a much simplified representation of the actual intensity distribution of circumstellar disks, they represent the main components seen in more elaborate radiative transfer disk models and adequately reproduce most of the spatial information entrained in the visibility amplitudes measured by MIDI.

HD 101412 and HD 135344 show compact (< 2 AU) 10 µm emission while the [OI] brightness profile shows two maxima. The inner peak is strongest and is consistent with the location of the dust, the outer peak is fainter and is located at 5 – 10 AU. In both systems, spatially extended PAH emission is found. HD 179218 shows a double ring-like 10 µm emission with the first ring peaking at ~ 1 AU and the second at ~ 20 AU. The [OI] emitting region is more compact, peaking between 3 and 6 AU.

In Fig. III.1.5 we sketch the geometry of all three objects as deduced from the UVES and MIDI observations. The disks around HD 101412 and HD 135344 appear strongly flared in the gas, but self-shadowed in the dust beyond ~ 2 AU. The difference in the gas and dust vertical structure beyond 2 AU might be the first observational evidence of gas-dust decoupling in protoplanetary disks. The disk around HD 179218 is flared in the dust. The 10 µm emission emerges from the inner rim and from the flared surface of the disk at larger radii. No dust emission is detected between 3 and 15 AU. The oxygen emission seems also to come from a flared structure, however, the bulk of this emission is produced between about 1 and 10 AU. This could indicate a lack of gas in the outer disk or could be due to chemical effects which reduce the abundance of OH – the parent molecule of the observed [OI] emission – further away from the star.

It may also be a contrast effect if the [OI] emission is much stronger in the inner disk. We suggest that the three systems, HD 179218, HD 135344 and HD 101412, may form an evolutionary sequence: the initially flared disk becomes flat under the combined action of gas-dust decoupling, grain growth and dust settling.

A similar study was performed on the Herbig Ae star HD 95881, where we mapped the distribution of gas and dust in the disk using data from a host of facilities: infrared spectroscopy from SPITZER/IRS, infrared spectroscopy and imaging from VLT/VISIR, near-infrared interferometry from VLTI/AMBER, mid-infrared interferometry from VLTI/MIDI, and high-resolution optical spectroscopy of the [OI] line from VLT/UVES.

Following the same approach as in the previous study, the [OI] emission was used to as a proxy for the gas distribution. Emission from PAHs, macromolecules that are well coupled to the gas, is detected in the SPITZER and VISIR spectra. In the VISIR data, the PAHs are spatially resolved and were used as an additional probe for the gas distribution. The continuum emission detected in the SPITZER and VISIR data, as well as in the AMBER and MIDI interferometric data, traces mainly the dust emission. These data were fitted with a 2D radiative transfer mod-

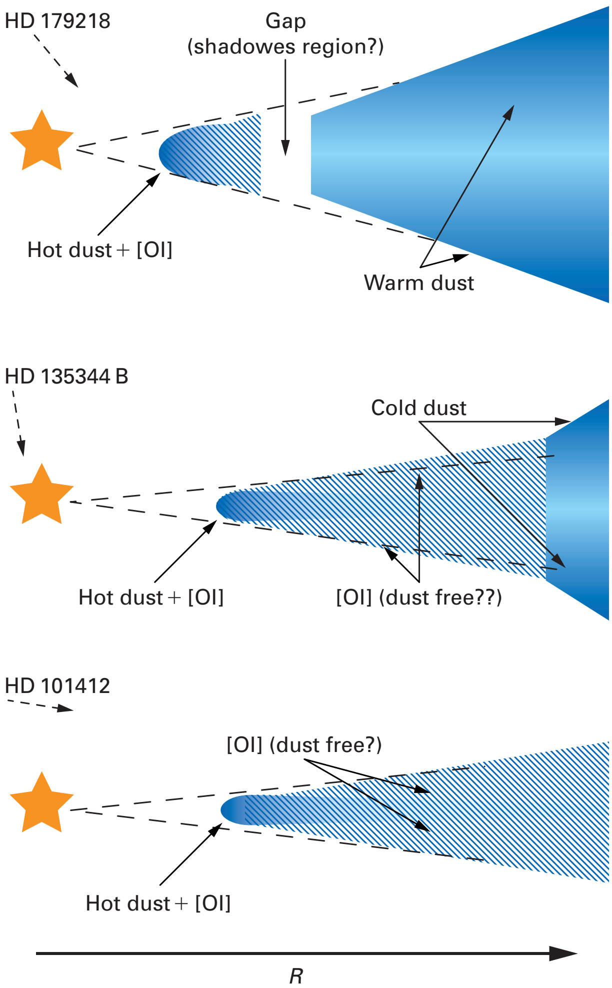


Fig. III.1.5: Sketches of the distribution of gas and dust in three Herbig Ae stars. The dotted arrows indicate the line of sight.

el using the MCMAX code, simultaneously reproducing the SED as well as all spatially resolved data.

We find that the disk of HD 95881 as traced by the dust continuum has a strongly flattened appearance, most likely due to dust-setting. The gas distribution, in contrast, still shows a flared geometry. This strongly resembles the situation in the HD 101412 disk as revealed by the previously discussed, less-detailed study. We conclude that HD 95881 is in a transition phase from a gas rich flaring disk to a gas poor self-shadowed disk (Verhoeff et al. 2010).

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III.2 Early Stages of Low-Mass Star Formation

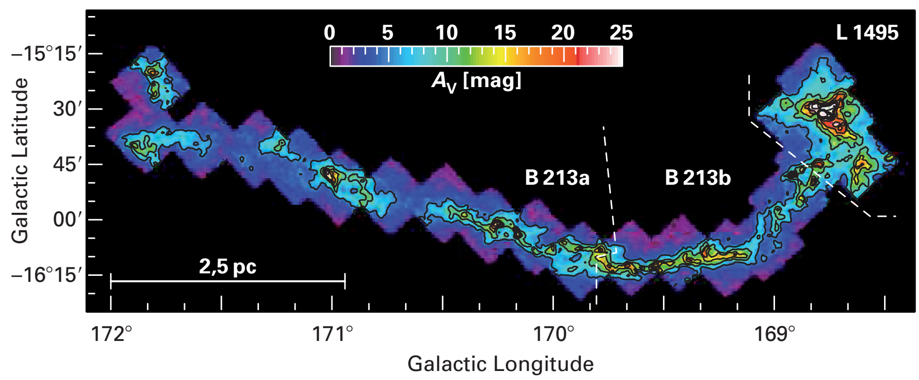
The birth of sun-like stars can be observed at best in inconspicuous, isolated dark clouds. The four studies described here span 3 orders of magnitude in wavelength and utilize many different observational techniques. They give an insight into different aspects of the early phases of the formation of low mass stars and show that no single technique alone is as powerful as the more complete view we are forming by utilizing this multi-faceted approach.

Low mass stars are the most numerous stars in the universe. However, despite their high relative numbers, key aspects of their early formation stages remain hidden, enshrouded by large amounts of dust, short timescales, and the complex and messy processes which can dominate in clustered regions. While larger star-forming complexes are well-suited to investigate, e.g., the relative roles of turbulence and magnetic fields in shaping the clumpmass function and the origin of the stellar mass spectrum, many of the difficulties in studying the detailed properties of individual cores can be partially overcome by observing relatively simple nearby and isolated star-forming regions, such as Bok Globules. These small cloudlets often reside in the filamentary outskirts of larger molecular cloud complexes and mostly contain only one single star-forming core. In order to investigate their star-forming potential and the initial conditions that lead to the protostellar collapse, we have studied a large number of globules for signs of star formation, evolutionary stage, chemical evolution, kinematic structure, and fragmentation, whereas we used as indicators, e.g., the extinction in the near- and mid-infrared, the thermal dust emission at infrared and millimeter wavelengths, as well as several molecular lines.

What can extinction of starlight by dust tell us about molecular clouds?

NIR extinction maps provide an unbiased method to investigate the structure of molecular clouds, as grain properties in this wavelength range are well-understood. Broad-band NIR imaging of background stars in multiple filters are capable of measuring the amount of extinction along pencil-beam lines of sight through molecular clouds; using spatial averaging, these discrete measurements can then be converted to continuous extinction maps. With the OMEGA 2000 camera at the 3.5 m telescope on Calar Alto, we performed deep J, H, and K_s observations of 21 fields along the L 1495-B 213 filament in Taurus during two observing runs in 2004 and 2009. The final mosaic covers 1.1 deg^2 on the sky and contains more than 20 000 background stars and 10 000 galaxies. With the aid of GNICER (Galaxies Near Infrared Color Excess method Revisited; Foster et al. 2008, ApJ 674, 831), we compiled an extinction map with a resolution of 0.′9 (Fig. III.2.1; Schmalzl et al. 2010, in preparation). This is better by a factor of 2.2 than what is possible with

Fig. III.2.1: The extinction map of the L 1495-B 213 filament with a resolution of 0.′9 (3300 AU at the distance of Taurus) reveals a complexity which was hidden in previous studies. L 1495 young cluster is the region of highest column densities and the highest concentration of YSOs. Radiating from it is the strongly meandering filament B 213 with its extreme aspect ratio. Although high column densities would suggest it, only B 213a is associated with YSOs, whereas B 213b is surprisingly devoid of young protostars. Apparently the high column densities are caused by the superposition of two or more filamentary components, therefore mimicking dense material.



2Mass, and by a factor of 7 compared to extinction maps based on star counts.

This extinction map shows the L 1495-B 213 filament in unprecedented detail. Meandering bands of dusty material and many small condensations aligned along the filament have been observed for the first time. Embedded young stellar objects (YSOs) appear in clear correlation with the region of highest column densities. More evolved T Tauri stars, however, show a larger spatial dispersion than the younger Class I sources. This is in agreement with their older age and thus more time available to move away from the filament with velocities of the order of the local sound speed. However, the central part (B 213b) is surprisingly devoid of YSOs despite its high column densities. A possible explanation is that two filaments are actually seen in projection along the line of sight at this position, thus mimicking overdense material.

An analysis of the dense core population in the undisturbed part of the filament (B 213a) showed a total of 42 condensations. We were able to derive general parameters like position, mass, size, density and ellipticity. The derived densities of $1.4 \pm 0.3\,\mathrm{cm}^{-3}$ are about a factor of 2.5 higher than in the Pipe Nebula, a nearby region with almost no sign of star formation. The core masses range from 0.5 to 8 solar masses. For masses exceeding $1.9\,M_\odot$, the Clump Mass Function (Cmf) follows a power law with exponent $\Gamma = 1.5 \pm 0.2$, which is in good agreement with Cmfs from other low-mass star forming regions like Ophiuchus, Serpens and Perseus. At masses below $1.9\,M_\odot$, we see indications for a break point and a considerable flattening. If the Cmf is a scaled-up version of the initial mass function (Imf), then such a break point would be expected, as the Imf shows a well-established peak at about $0.1 - 0.6\,M_\odot$. Whether this break point for our sample is true cannot be said with absolute certainty, as incompleteness could also lead to the same type of Cmf. The average separation of clumps on the other hand leaves not much room for discussion. The preferential separation between two cores is ~ 0.15 pc, which is in excellent agreement with the Jeans length for the derived densities and a local sound speed of 0.2 km/s. This is a clear indicator that the cores formed through thermal fragmentation, for which the Jeans length is the characteristic separation between neighbouring cores. Therefore, the Taurus Molecular Cloud most likely formed through large-scale flows, and core formation is dominated by self–gravity.

Looking into the darkness: where new stars will eventually be born

On smaller size scales and at the very earliest stages of formation, the identification and characterization of truly pre-stellar cores – cores that are forming or will soon form stars – is the first step towards revealing the details of the low-mass star formation process. In Stutz et al. (2009, ApJ 707, 137), we studied a sample of 14 low-mass starless cores with the Spitzer Space Observatory. Analogous to the higher-mass Infrared Dark Clouds (IRDCs), this sample of starless cores was selected to be seen in absorption at 8 µm, 24 µm, and sometimes 70 µm. The observed absorption features, or shadows, are cast by the most embedded and dense core material at the heart of the clouds (Fig. III.2.2). Taking advan-

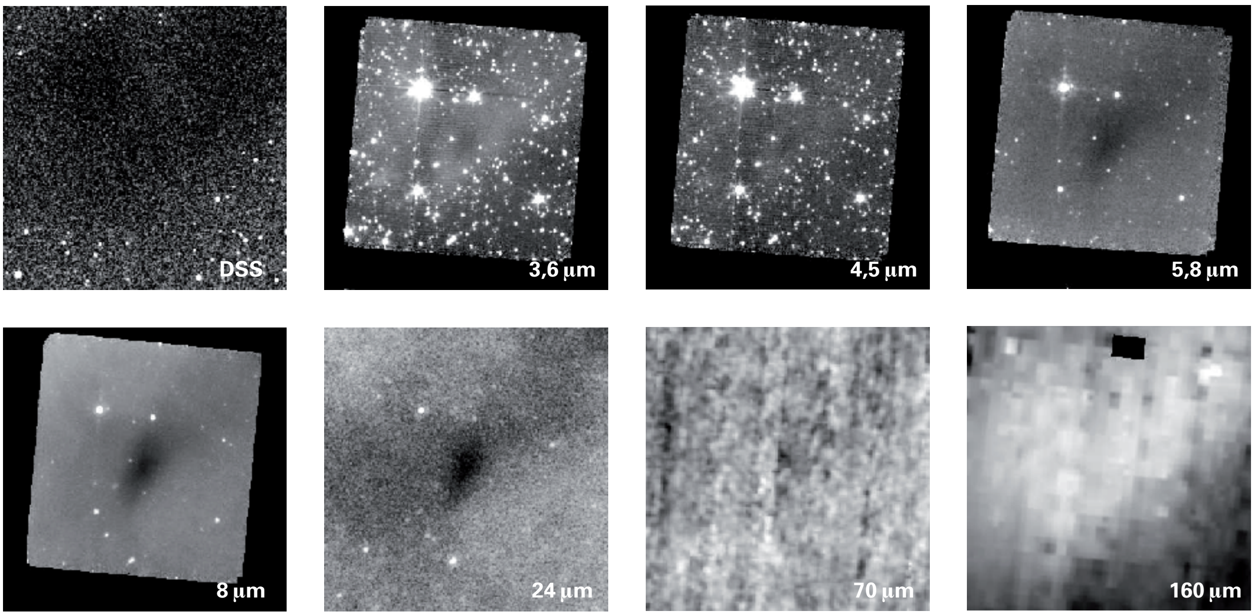
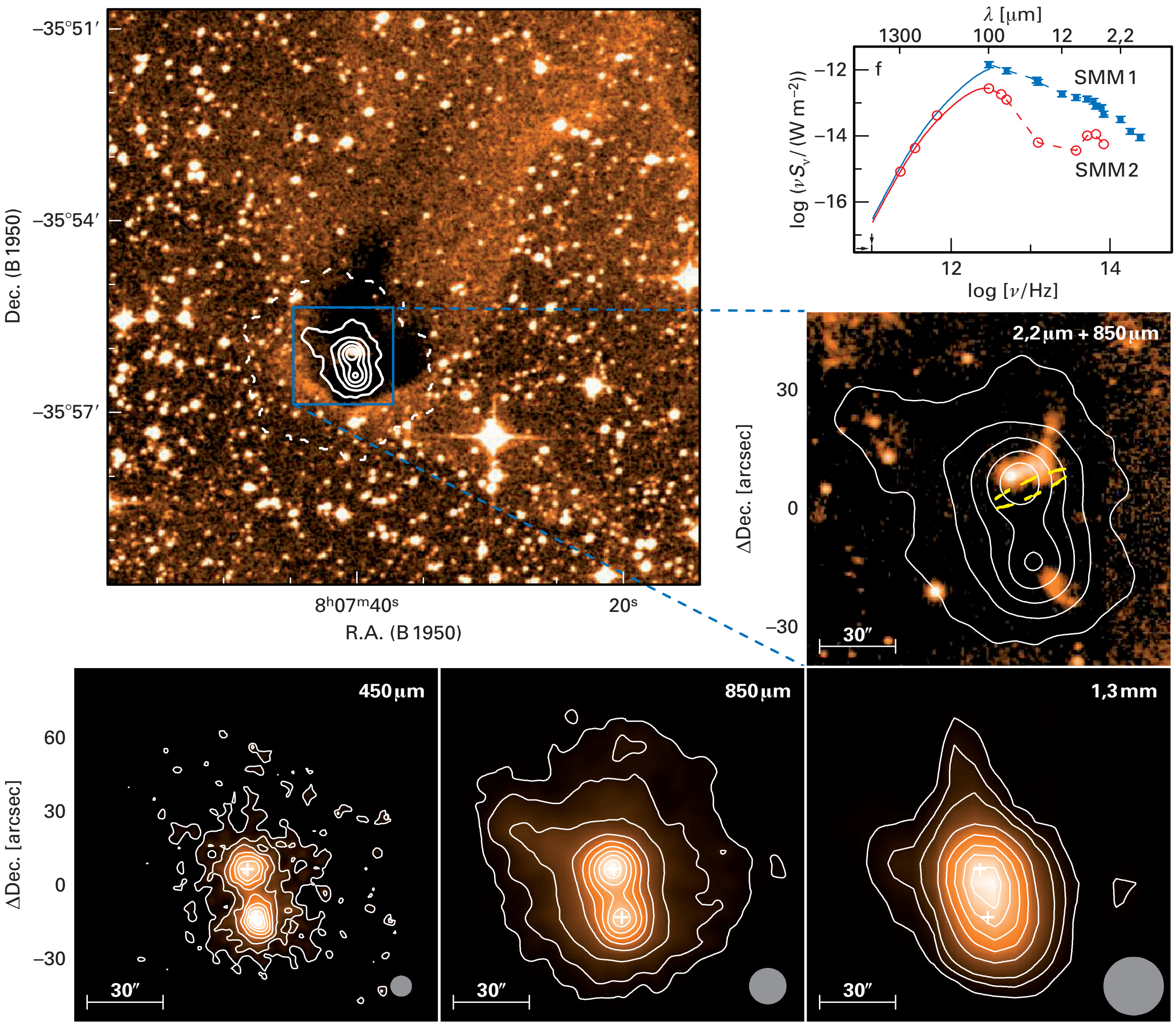


Fig. III.2.2: 5′ × 5′-images of the starless core L 1544. The densest core material is seen in absorption at 8.0 µm and 24 µm, and marginally at 70 µm; at 3.6 µm, faint extended emission is observed.

tage of the high spatial resolution of about 5″ provided by Spitzer's multi-band infrared photometer (Mips) at 24 µm, this sample reveals the varied and often complex geometries of starless cores. The observation of the detailed projected geometries of such low-mass cores are generally inaccessible at longer wavelengths due to large beam sizes, line-of-sight ambiguities, and spatial filtering associated with bolometric and interferometric studies.

Using a simple Jeans mass criterion, we find that about 2/3 of cores selected to have prominent 24 µm shadows are collapsing or near collapse, a result that is supported by millimeter line observations. Of this subset of collapse candidates, at least half of the cores have indications of 70 µm shadows. All cores observed to produce absorption features at 70 µm are close to collapse. Furthermore, the majority of cores producing 70 µm shadows show observed blue asymmetries in their line profiles, an independent indicator of infall motions. We conclude that 24 µm shadows, and even more so the 70 µm ones, are useful markers of cloud cores that are approaching collapse, and place detailed observational constraints on starless core masses, sizes, and geometries. While the Spitzer Mips 70 µm data are of great importance to this study, high spatial resolution observations with Herschel Pacs at 70 µm and 100 µm of this sample of near-collapse cores will provide further constraints on the configuration of dense core material at the earliest stages of star formation.

Fig. III.2.3: CG 30 (BHR 12), an isolated cometary Bok globule in the Gum nebula region at 400 pc distance. *Upper left:* Optical image (DSS2 red) with contours of the 850 µm dust continuum emission. *Middle right:* Nir K-band image with 850 µm dust continuum contours. The Iras PSC position is marked by a dashed ellipse. *Lower panel:* 450 µm, 850 µm, and 1.3 mm dust continuum emission; beam sizes are indicated as grey ellipses. *Upper right:* Spectral energy distributions of SMM1 (Class I YSO, filled squares) and SMM2 (Class 0 protostar, empty circles) showing the Atca 3 mm, Sest 1.3 mm, Scuba 850 and 450 µm, Iras PSC, Spitzer Mips and Irac, and ground-based Nir data.



The star-forming hearts of Bok globules: unexpected complexity

While extinction maps are a robust way of studying molecular cloud properties, they have three fundamental limitations that constrain their usefulness to certain classes of objects. First, they require a high surface density of background stars which restricts their applicability to the galactic plane. Second, it requires a certain number of background objects in each pixel such that angular resolutions $< 1'$ are usually out of reach. Third, at the high column densities through the centers of pre-stellar and proto-stellar cloud cores, extinction is so high that no measurable light passes through and the method breaks down. Observing instead the thermal emission from dust grains with large telescopes and sensitive bolometers is a good way of circumventing these limitations, although this latter method requires a good knowledge of the dust opacity and temperature. In order to reveal the star-forming properties of nearby Bok globules and to establish a catalog of nearby and well-characterized star-forming cores at different evolutionary stages, we have studied 32 Bok globules at NIR and submm wavelengths using different large groundbased telescopes and compiled and fitted spectral energy distributions (SEDs) of the embedded sources (Fig. III.2.3; Launhardt et al. 2010, ApJSS 188, 139).

In 26 out of the 32 globules observed, (sub)mm dust continuum cores were detected. In 18 globules with detected (sub)mm cores, we derived evolutionary stages and physical parameters of the embedded sources. The other eight globules are either at too large distances and multiple embedded sources could not be resolved, or the (sub)mm maps were of too low quality, or we simply did not have enough data to draw any reliable conclusions. In total, we identified nine starless cores, presumably prestellar, nine Class 0 protostars, and eleven Class I YSOs in these 18 globules. We find that the bolometric temperature is the most reliable tracer to discriminate between Class 0 protostars and Class I YSOs and confirm the empirical boundary of 70 K (Fig. III.2.4). The spread of L_{smm} / L_{bol} ratios within the Class 0 and Class I groups is relatively large (2 – 10 % within Class 0 and 0.8 – 3.5 % within Class I), with no significant correlation between T_{bol} and L_{smm} / L_{bol} within the groups. However, the three most evolved Class I sources, with visible stars and compact (sub)mm emission arising presumably from circumstellar disks, also have the lowest L_{smm} / L_{bol} ratios ($<$ 1.3 %). We take this as tentative indication that the L_{smm} / L_{bol} ratio, as indicator of envelope dispersal, may better trace the evolution within the Class 0 and Class I phases.

At least two thirds (16 out of 24) of the star-forming globules studied here show evidence of forming multiple stars on scales between 1000 and 50 000 AU, either as multiple star-forming cores, wide embedded binaries, or small star clusters. The fraction of closer binaries formed from unresolved mm cores might be higher, but remains unknown from this study. The most interesting aspect of this multiplicity is that the large majority of these small prototstar and star groups are comprised of sources with very different evolutionary stages. This includes neighbouring mm sources with obviously different evolutionary stages, prestellar or protostellar cores with nearby IR sources, presumably more evolved protostars or Class I YSOs, as well as NIR star clusters next to large (sub)mm cores with the potential to form more stars (Fig. III.2.5). In only three globules we find coeval pairs, ranging from multiple prestellar cores in CB 246, embedded Class 0 protostars in BHR 71, to an embedded Class I YSOs pair in CB 230. This widespread non-coevality possibly suggests a picture of slow and sequential star formation in isolated globules. These findings also call for special attention when compiling SEDs and attempting to derive source properties from flux measurements with insufficient angular resolution. One may easily end up classifying the combined SED of a prestellar core and a nearby, more evolved YSO as a Class 0 protostar.

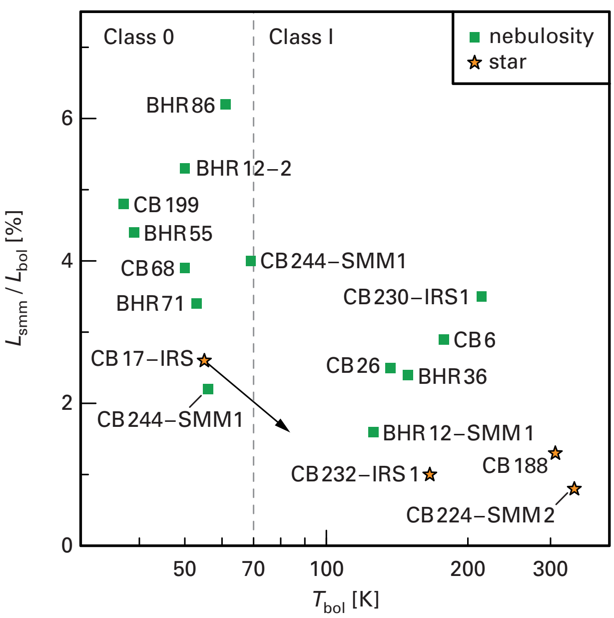


Fig. III.2.4: Ratio of submm to bolometric luminosity vs. bolometric temperature for the sources embedded in Bok globule cores. The vertical dashed line marks the T_{bol} = 70 K boundary between Class 0 and Class I sources. Sources with NIR/MIR nebulosity only (i.e. no star-like point source) are marked as filled squares. Sources with NIR point source (star) are marked as open asterisks. For CB 17-IRS, no resolved FIR and submm fluxes could be retrieved and the partial SED provides only lower and upper limits on T_{bol} and luminosity ratio, respectively.

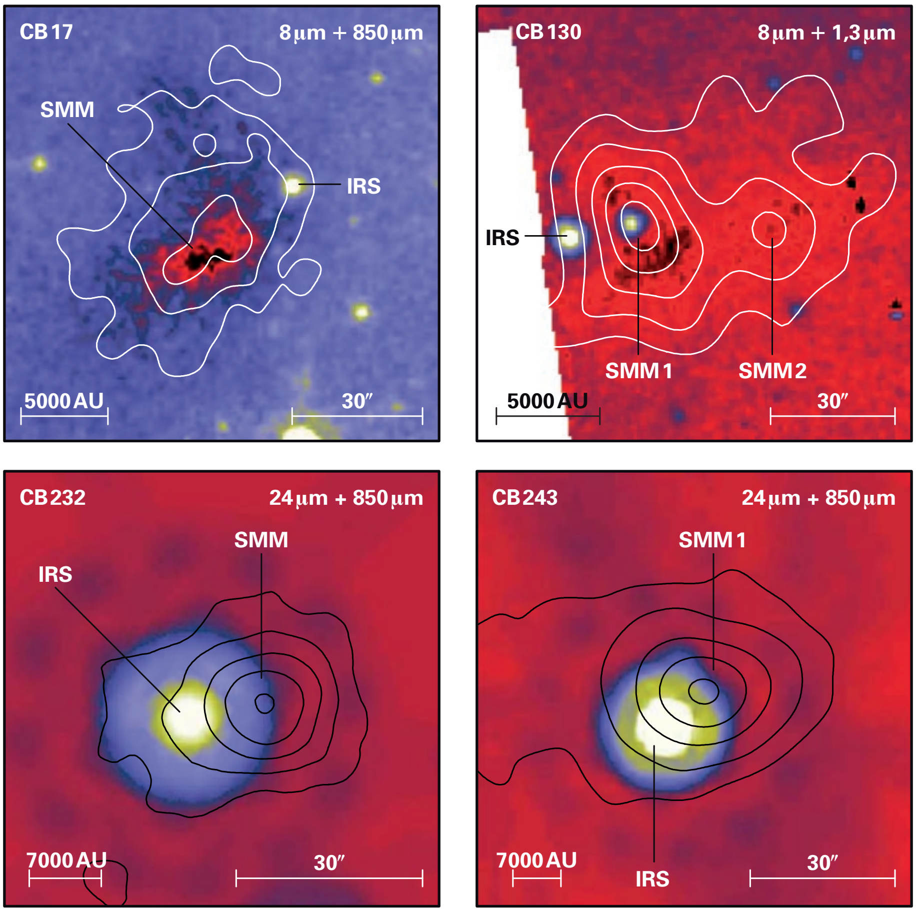


Fig. III.2.5: Four examples of globule cores in which MIR and submm sources are not identical and which obviously contain two or more sources of different evolutionary stage within a few thousand AU. *Top left:* CB 17, IRAC 8 µm image and 1.3 mm dust continuum contours. *Top right:* CB 130, IRAC 8 µm image and 1.3 mm dust continuum contours. *Bottom left:* CB 232, MIPS 24 µm image and 850 µm dust continuum contours. *Bottom right:* CB 243, MIPS 24 µm image and 850 µm dust continuum contours.

Using HERSCHEL as a thermometer for dust in molecular clouds

One of the major shortcomings of studies like the one described above is the fact that mass and density profile estimates mostly have to rely on assumptions or model calculations of the dust temperature, rather than on actual temperature measurements. In particular at the low temperatures inside pre-stellar cores (10 K and below), a small error in the assumption of the dust temperature leads to a large error in the estimate of the mass of the emitting dust. Since the temperature gradients inside pre-stellar cores are mostly known from model calculations only, "measurements" of the density profiles of such cores are mostly not very reliable. The HERSCHEL satellite, with its 3.5 m telescope and sensitive FIR bolometers that cover the peak of the SED of such cores, provides for the first time a way to measure the dust temperature inside such cores.

We used the PACS 100 and 160 µm, SPIRE 250, 350, and 500 µm data in conjunction with the NIR extinction map, MIPS 70 µm, SCUBA 850 µm, and IRAM 1.3 mm dust emission maps to model the line-of-sight-averaged dust temperature and column density of the Bok globule CB 244 (Fig. III.2.6). The calibrated maps were convolved to the SPIRE 500 µm 37″ beam and projected onto a common 8″ / pix grid. For each image pixel, a Spectral Energy Distribution (SED) was then extracted and fitted with a single-temperature modified black-body of the form $S_\nu = \Omega\, B_\nu(\nu,T_d)\,(1 - e^{-\tau(\nu)})$, where Ω is the solid angle of the emitting element, B_ν is the Planck function, T_d is the dust temperature, and $\tau(\nu)$ is the optical depth at frequency ν. Using a dust model with broad grain size distribution, thin ice mantles, and no coagulation, which has a $\varkappa_{1.3\,\mathrm{mm}} = 0.5\ \mathrm{cm^2\,g^{-1}}$, we then searched for the optimum T_d and hydrogen column density N_H values (the two free parameters) by calculating flux densities and A_V values and then comparing to the emission and extinction observations.

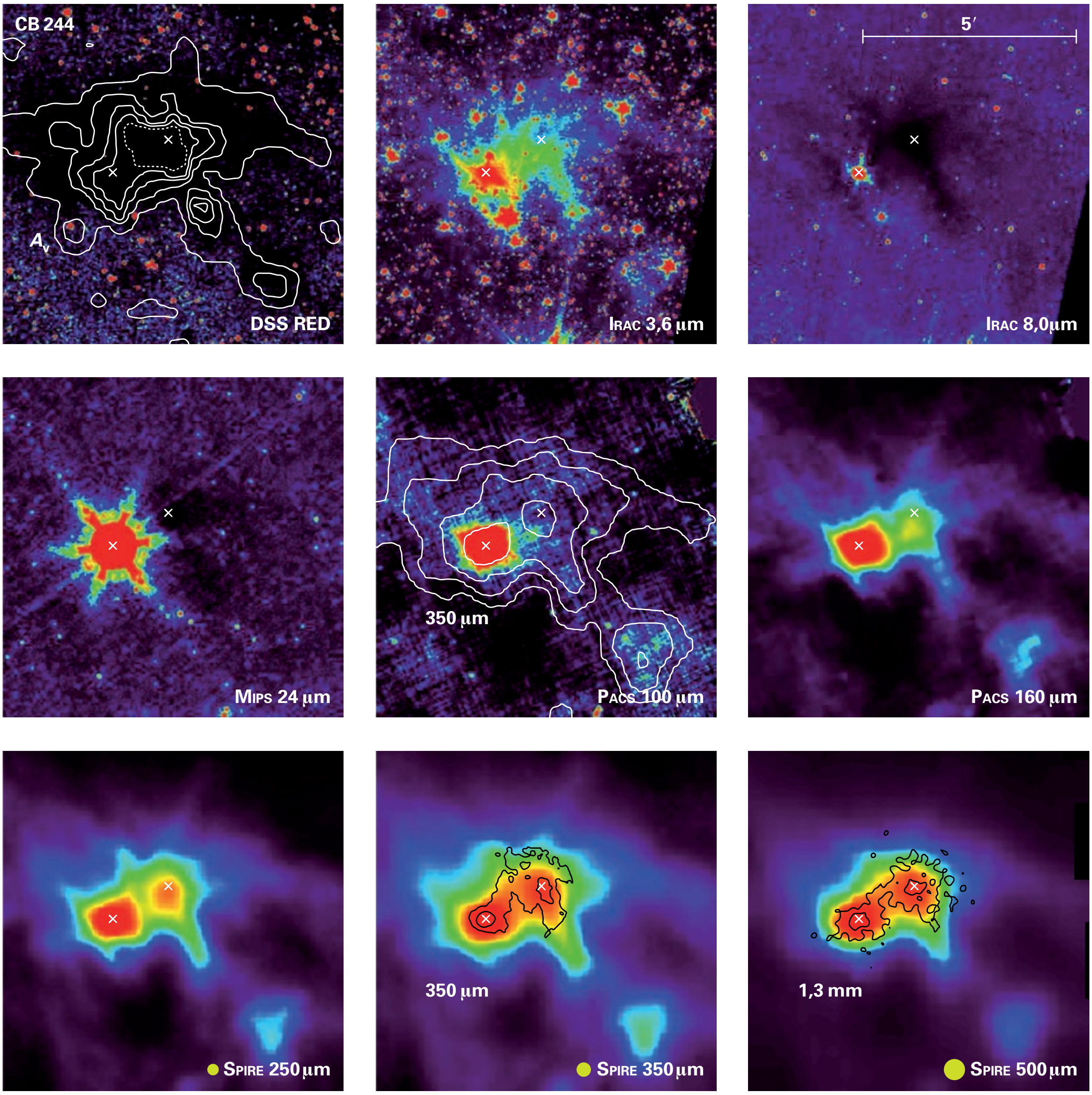


Fig. III.2.6.: Nine views of one globule: $8' \times 8'$ images of CB 244, shown at the wavelengths indicated in the bottom-right of each panel. The panel contours are labeled with their corresponding wavelengths. Beam sizes are indicated as yellow circles. The locations of the protostar and starless core are indicated with x-symbols. (Stutz et al., 2010)

The resulting line-of-sight-averaged dust–temperature and column density maps are shown in Fig. III.2.7, together with the SED fits at the central positions of the two submillimeter peaks. We found the best-fit column-averaged dust temperatures for the protostar and prestellar core of ~ 17.7 K and ~ 10.6 K, respectively. Despite the fact that each individual image pixel was fitted independently and the maps at different wavelengths have different outer boundaries, both the temperature and the column density maps have very little noise and are very smooth, demonstrating the robustness of our fitting approach. Integration of the column density map yields $M_H = 1.6 \pm 0.3\, M_\odot$ for the protostellar core and $M_H = 5 \pm 2\, M_\odot$ for the prestellar core, where the uncertainties are derived from an assumed ± 1 K uncertainty in the dust temperature. The total mass of the globule (within the $N_H = 1 \times 10^{21}\,\mathrm{cm}^{-2}$ contour) is $M_H = 15 \pm 5\, M_\odot$. These masses imply that up to about 45 % of the mass of the globule is participating in the star-formation process.

The four studies described here span 3 orders of magnitude in wavelength and utilize many different observational techniques. These four studies of different aspects of the early stages of the low-mass star formation

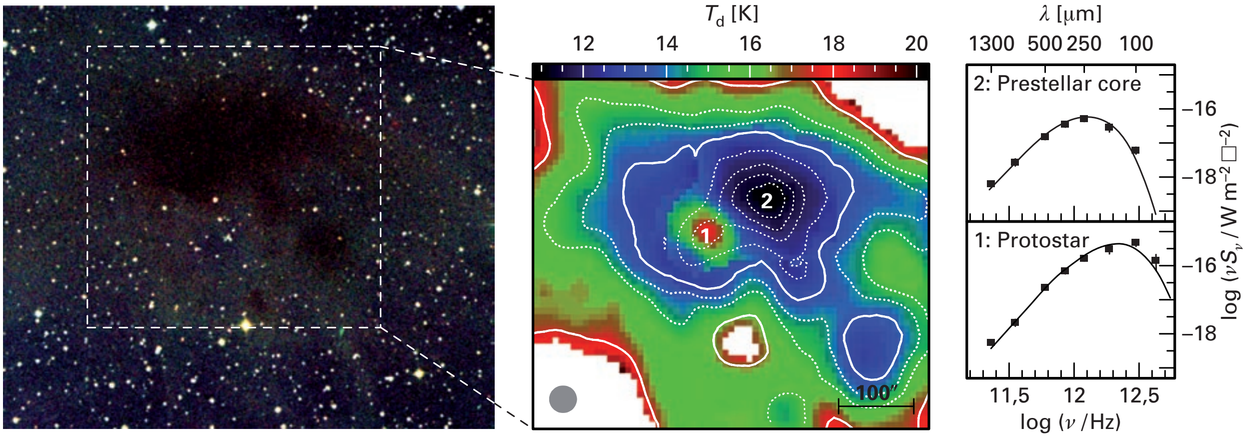


Fig. III.2.7: *Left* – Optical true-color image of the Bok globule CB 244, constructed from DSS 2 blue, red, and infrared images. *Middle* – Dust-temperature (*color*) and hydrogen column density (*white contours*) in CB 244, derived pixel by pixel from modified black-body SED fits to the homogeneously beam-smoothed emission maps from Herschel Pacs and Spire, Spitzer Mips 70, and ground-based sub-millimeter dust continuum maps at 0.8 and 1.2 mm, as well as a Nir extinction map. Column density contours are at (0.1 (*thick*) 0.3, 0.5, 1 (*thick*), 2, 3.5, 5, and 7) $\times$ 10^{22} H cm^{-2}. The 37″ beam size is indicated by a grey circle. Note that the dust temperature map reproduces even such tiny features as the small extinction "blob" at the very bottom of the region shown. *Right* –Two SEDs and the respective modified black-body fits are shown for the positions of the Class 0 protostar ("1") and the prestellar core ("2").

process, which cover only part of the related activities in our department (e.g., molecular line studies or theoretical work are not even mentioned here), already show that no single technique alone is as powerful as the more complete view we are forming by utilizing this multifaceted approach.

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III.3 Quasars as Cosmological Probes

When and how was the hydrogen in the Universe reionized? What physical process shuts off starformation in massive elliptical galaxies? These are among the most fundamental questions studied by cosmologists today. Remarkably, all of them can be addressed by observing close pairs of quasars with small angular separations on the sky. Here we present our research on this topic.

Quasars are the most luminous objects in the Universe, which are thought to be powered by the infall of matter onto a supermassive black hole at the center of a massive galaxy. Quasars are intrinsically rare on the sky, such that the probability of finding a close companion is vanishingly small — one in 100 000. By sifting through hundreds of millions of celestial objects provided by the Sloan Digital Sky Survey imaging database, we have located hundreds of these unique astrophysical laboratories. Extensive follow-up observations with the world's largest telescopes have allowed us to collect unprecedented data enabling novel observational experiments for understanding the distant Universe.

Why Quasar Research?

In 1963, shortly after Maarten Schmidt discovered the first quasar, Time magazine wrote that his discovery had "rocked the worlds of astronomy, physics, and philosophy." The existence of these objects at distances larger than one billion light years from Earth flew in the face of many of the cosmological theories of the time and seemed to vindicate the Big Bang model. Even more perplexing were the unfathomable luminosities implied by the extreme distances to quasars. What physical process could power such a prodigious outpouring of energy?

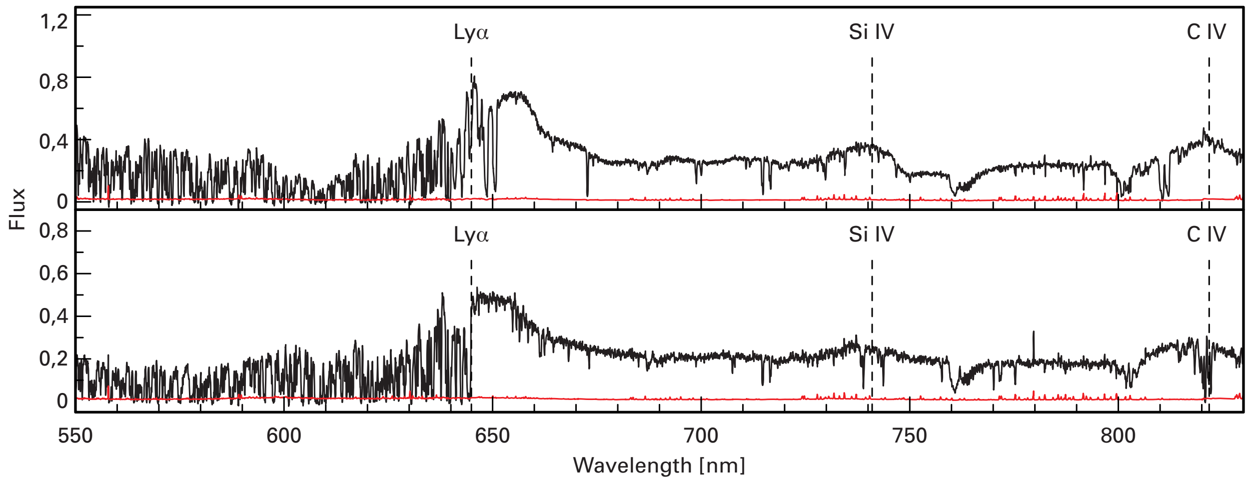
Today we know that quasars constitute a brief phase of galaxy evolution powered by the infall of matter onto a supermassive black hole at the center of a massive galaxy. During this phase they are the most luminous objects in the Universe, outshining their host galaxies by factors of more than a hundred. The peak of quasar activity occurred when the Universe was about one fifth of its current age. Today all massive galaxies are observed to have dormant supermassive black holes at their centers, which are believed to be relics which were formed during a quasar episode in the distant past.

Quasars play a fundamental role in shaping our understanding of the distant Universe. Because they are hosted by massive galaxies, quasars can be used as signposts for identifying protogalaxies in the early Universe. Bright and easily observed at cosmological distances, quasars act as cosmic lighthouses, allowing us to study extremely rarefied matter between Earth and the quasar *in absorption*. This contribution concerns the cosmological applications of *close pairs of quasars* with small $\sim 10''\text{–}\,1'$ angular separation on the sky. We will show that pairs of quasars constitute unique astrophysical laboratories which can address a multifarious set of cosmological questions. But because the quasar phase is about a thousand times shorter than the present age of galaxies, quasars are intrinsically sparse on the sky with only a few per square degree. Close quasar pairs are thus extremely rare, occurring once per hundred square degrees. Consequently, finding them has had to wait until the era of large area digital sky surveys and massive astronomical datasets.

Needles in a Haystack: Finding Quasar Pairs

Because quasars emit from an extremely small region < 0.01 pc, they appear as unresolved sources in astronomical images and are thus indistinguishable from galactic stars. But since stars outnumber quasars by a factor of one hundred on the sky, they constitute a huge source of confusion. Locating pairs of quasars is thus like finding a needle in a haystack and a brute force approach would result in a meager efficiency of $\sim 10^{-4}$ for finding them. However, quasars can be distinguished from stars by exploiting subtle differences in their broadband colors. Finding significant numbers of quasar pairs thus requires precisely calibrated digital images of a very large area of the night sky, as well as spectroscopic follow-up observations to ultimately determine the identity of the candidates.

MPIA scientists have played a major role in the Sloan Digital Sky Survey (SDSS), which is a major multi-filter imaging and spectroscopic redshift survey using a dedicated 2.5-m wide-angle optical telescope which successfully imaged and obtained spectra of astronomical objects over a quarter of the night sky. Although the SDSS spectroscopic quasar survey has provided the largest sample ($\sim 10^5$) of quasars in existence, it selects against close pairs of quasars due to the finite size of optical fibers in the multi-object spectrograph. This fiber collision limit implies that only one member of a pair with $\Delta\theta < 1'$ will make it into the quasar catalog. In order to recover the missed quasars pairs, we had to revisit the entire SDSS imaging database. We developed machine learning techniques to sift through hundreds of millions of celestial objects and statistically separate quasars



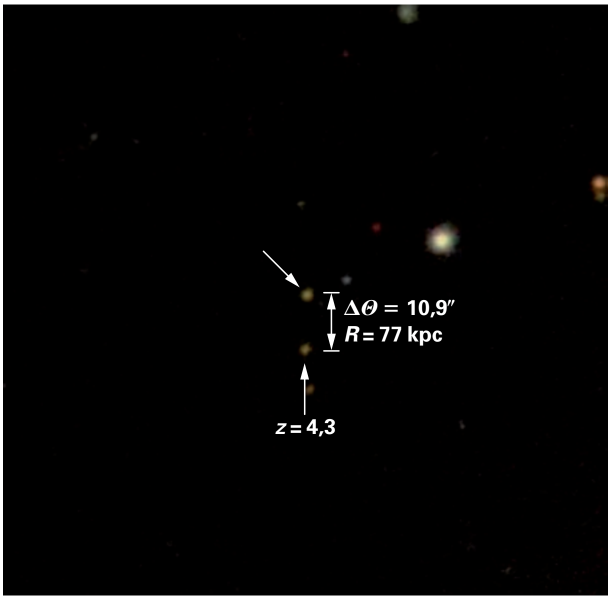


Fig. III.3.1: The most distant close binary quasar known ($z = 4.3$, $\Delta\theta = 10\farcs9$). *Left:* SDSS color image. *Top:* High signal-to-noise ratio optical spectra of both members of the binary quasar shown at left from the Keck telescope. The red curves indicate the 1σ error array. The strong common feature in the spectra at 760.0 nm are atmospheric telluric absorption. The Lyman-α emission line is labeled along with several other strong emission lines. The Lyman-α forest regions of both spectra extend blueward of the Lyman-α line at 650.0 nm.

from stellar contaminants. Small telescopes including the MPIA/Caha 3.5 m are used to spectroscopically confirm candidate quasar pairs, resulting in a success rate of about 25 %, a dramatic improvement over the brute force efficiency $\sim 10^{-4}$. To date we have confirmed a sample of ~ 200 pairs of quasars with angular separations $< 1'$, increasing the number of such systems known by a factor of ~ 20.

Fig. III.3.1 shows an image and spectrum of a binary quasar at $z = 4.3$ with an angular separation of $10\farcs9$ discovered in our search for close quasar pairs. The high-redshift and small transverse separation of 77 kpc make this the most distant close binary quasar known. Our survey uncovered five other close binaries at $z \sim 4$, a time when the Universe was just a tenth of its current age. These sightlines are extremely rare: given the small separations, high redshifts, and large luminosities, we estimate that only 50 exist in the entire observable Universe.

Small-Scale Environments of High Redshift Quasars

A powerful tool in understanding the nature of galaxies in the distant Universe is to measure their clustering pattern on the sky. We live in a hierarchical Universe in which structure formation is driven by the merging of dark matter halos — small objects form first and then continuously merge to form ever larger structures. In this paradigm the large-scale ~ 10 Mpc clustering of a population of objects can be directly related to the masses of the dark matter halos hosting them. Hence quasar clustering probes the relationship between supermassive black hole growth and the underlying dark matter, providing important constraints on models of quasar and galaxy co-evolution. At high redshifts $z \sim 4$ large scale ~ 10 Mpc clustering measurements indicate that quasars inhabit rare massive ($M \geq 10^{13}\,M_\odot$) dark matter halos.

On small scales ($R < 200$ kpc) quasar clustering yields independent and complementary constraints. For example it is widely believed that quasar activity is triggered by the frequent galaxy mergers which are a generic consequence of our bottom up structure formation paradigm. During these mergers, angular momentum can be violently redistributed, efficiently funneling fuel onto the central black hole and providing a natural mechanism to power a short-lived quasar phase. Is quasar activity more common in dense environments where mergers are more likely to occur? If so this may manifest itself as a strong small-scale clustering pattern.

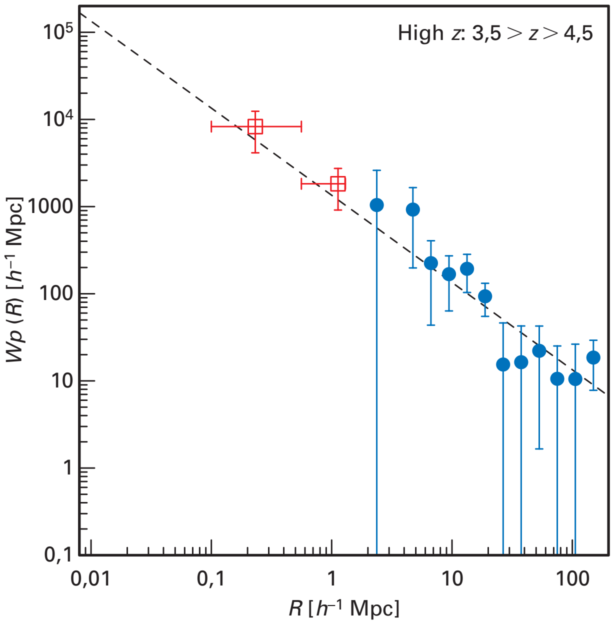


Fig. III.3.2: Measurement of the small-scale clustering of high redshift $z > 3.5$ quasars. Filled circles are the large-scale (> 1 Mpc) projected correlation function measurements from the SDSS spectroscopic quasar catalog. The dashed line is a power-law fit to the large scale clustering data with a fixed correlation function slope of $\gamma = 2$. Open squares show our measurement of the small-scale (< 1 Mpc clustering from a sample of just eight high-redshift binary quasars (see Fig. III.3.1) discovered in our quasar pair search. This first ever measurement of small-scale clustering can constrain the physical mechanism triggering quasars activity as well as shed light on the nature of extremely rare binary quasars.

Fig.III.3.2 shows the first measurement of the small-scale ($R < 1$ Mpc) clustering of distant quasars ($z > 3.5$) measured from a sample of binaries like that shown in Fig. III.3.1. Although this measurement is based on just a handful of objects, they amount to a significant clustering signal because the probability of such associations occurring at random is extremely small. What are these high-redshift binary quasars? Do they correspond to exponentially rare high sigma peaks, the analogs of superclusters, in the early Universe's initial conditions? Can our current ΛCDM structure formation paradigm accommodate them? These questions push the limits of our theoretical models of structure formation. State-of-the-art cosmological supercomputer simulations have not yet determined the non-linear structure of such exponentially rare dark matter halos, because that would require simulation volumes significantly larger than our search volume of $\sim 10\,\mathrm{Gpc}^3$. Although computationally demanding, simulating such large volumes is however just within reach. On the observational side, the obvious next step is to conduct detailed follow-up investigations of the individual binaries to search for large overdensities of galaxies around them. This would test whether they are really proto-superclusters in the early Universe, and shed light on the nature of these enigmatic objects.

The Intergalactic Medium

There is no such thing as empty space. Indeed the closest one gets to emptiness is in the barren expanses between galaxies known as the intergalactic medium (IGM). But even these remote regions of the Universe are suffused with extremely low-density primordial hydrogen gas, which becomes increasingly rarefied as one ventures farther away from galaxies. Understanding the physics of the IGM is a fundamental goal of cosmologists, since it is the essential material from which molecules, stars, and galaxies ultimately formed.

But how do we observe this tenuous gas in the IGM which emits no light of its own? Consider the spectrum of a distant quasar shown in Fig. III.3.3. The strongest feature is the Lyman-α emission line, produced near the quasar's black hole. As excited electrons decay to the ground state of hydrogen they emit Lyman-α resonance photons with a precise wavelength of 121.567 nanometers. But because the quasar – carried by the Universe's expansion — is racing away from Earth, we observe the emission line at a redshifted wavelength of 560 nanometers. Now consider what happens as light from the quasar is transmitted through the IGM towards Earth. Photons at 121.567 nanometers intercept hydrogen atoms along the way, are absorbed by the atom, and we will observe an absorption line in the spectrum (see Fig. III.3.4). The IGM contains hydrogen gas clouds at different distances from us, and because clouds at different distances have different redshifts, a quasar spectrum shows a series of absorption lines at different wavelengths. The wavelengths blueward of the hydrogen emission line thus appear to be 'eaten' away according to the location of each cloud between the quasar and us. This collective absorption pattern is known as the Lyman-α forest, and provides a one-dimensional sampling of primordial density fluctuations in the early Universe.

A great success of the theory of structure formation is that our theoretical models are able to precisely reproduce the statistical properties of the Lyman α forest fluctuations in the spectra of quasars. Using supercomputers we can simulate the formation of structure in the cosmic web (see Fig. III.3.5). The initial conditions for these simulations are set by the level of anisotropy in the cosmic microwave background radiation, which has been precisely measured. By shooting "skewers" through these simulated Universes, mock spectra are constructed and compared to real spectra of quasars obtained with large telescopes. The results of these comparisons indicate that the theory and the data are in incredible agreement. However one important unknown has been swept under the rug in these comparisons. Specifically, we have only crude knowledge of the temperature of the hydro-

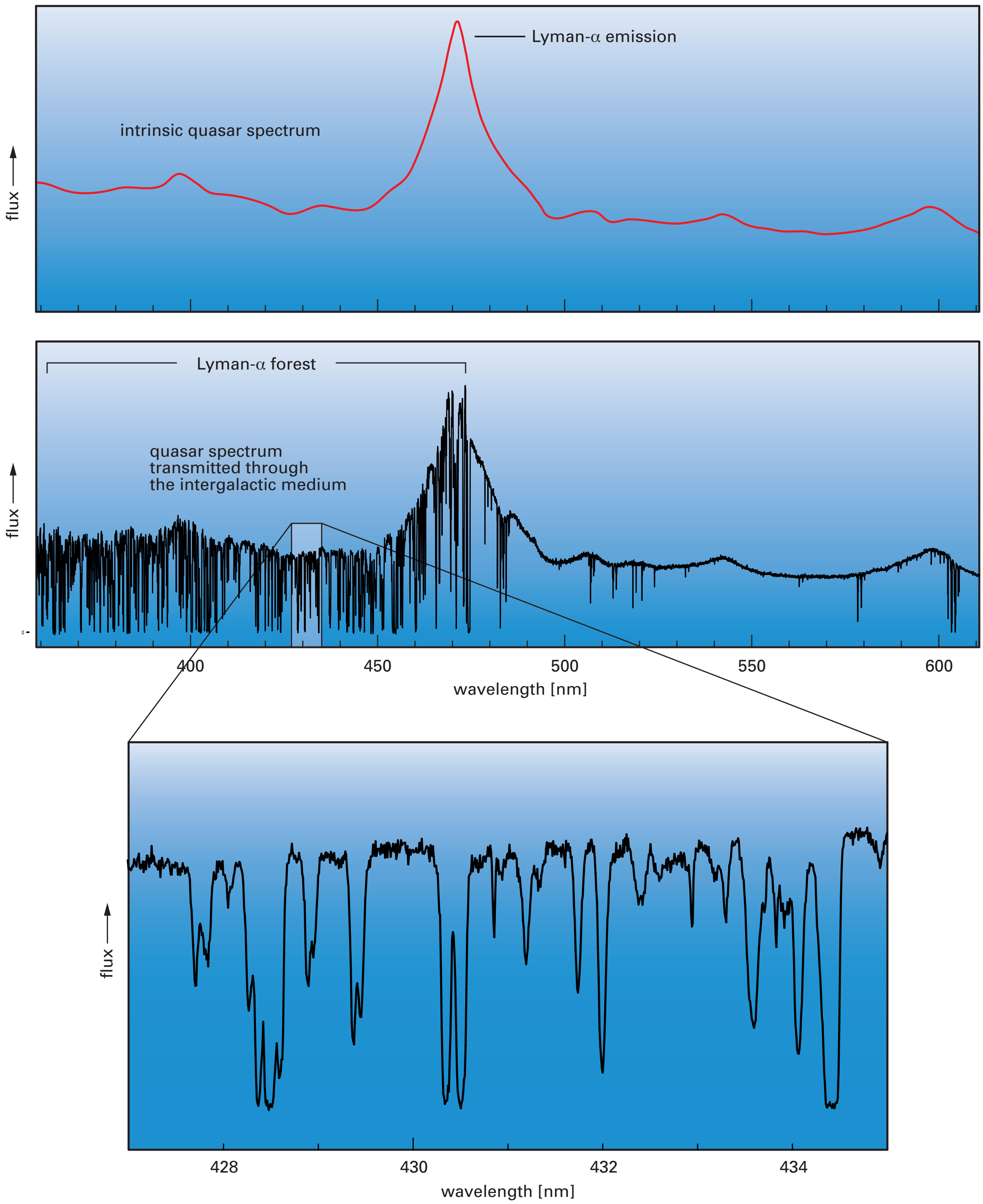


Fig. III.3.3: *Top:* Lyman-α forest absorption from the intergalactic medium. The intrinsic spectrum of a quasar reveals the amount of light it emits at different wavelengths. The central peak is produced by hydrogen atoms, which give off photons at a wavelength of 121.567 nm known as the Lyman-α emission line. Here this line appears at about 560 nm because the expansion of the universe redshifts the light to longer wavelengths. *Middle:* As the quasars light travels through the intergalactic medium its spectrum is eaten away (middle, hash to left of peak), because intervening clouds of hydrogen gas absorb light that locally has a wavelength of 121.567 nm, but these absorptions take place at different redshift-distances from the Earth, producing a "Lyman-α forest". Some heavy elements absorb photons with longer wavelengths, producing the few absorption lines to the right of the peak. In recent years, high-resolution spectra have allowed astronomers to study the individual clouds in the intergalactic medium. (Credit: AmSci/R. Simcoe)

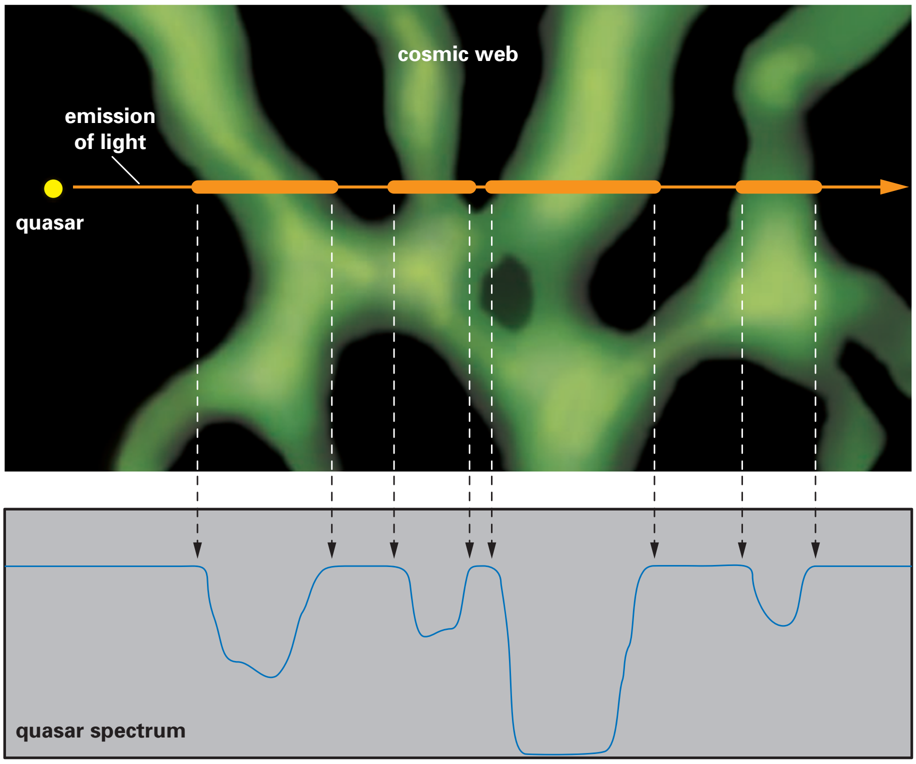


Fig. III.3.4: Absorption by the cosmic web. The cosmic web of gas filaments (*top, green*) in the intergalactic medium interrupts the light of a distant quasar before it reaches the Earth, producing the absorption lines in a quasar's spectrum (*bottom*). (Credit: AmSci/R. Simcoe)

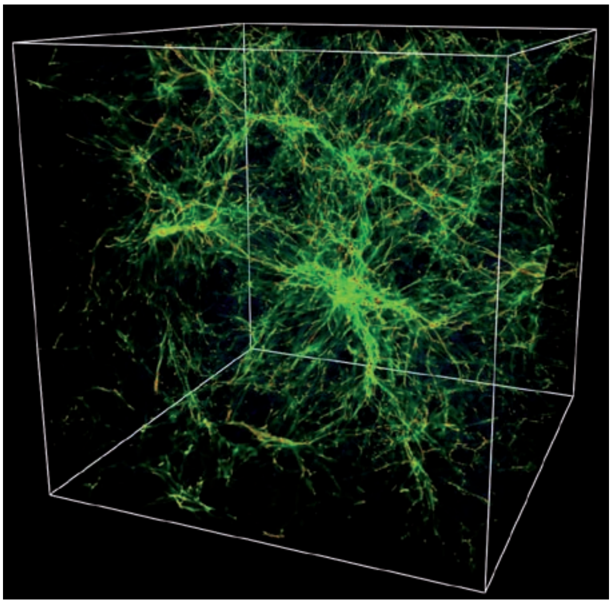
gen gas in the IGM. As it turns out, the one-dimensional spectra of the Lyman-α forest (see Fig. III.3.3) have very little sensitivity to the detailed thermal state of the gas. But the thermal state of the IGM is intimately related to one of the most fundamental questions in cosmology. How and when was the Universe reionized?

Fig. III.3.5: The Cosmic web. Numerical simulations of structure formation in the Universe show segregation of intergalactic gas into filaments (*green*) and voids (*black*) the cosmic web. Such computer modeling, paired with telescopic observations of the Lyman-α forest in quasar spectra, reveals that the cosmic web had a filamentary structure when the Universe was about two billion years old, or one seventh of its current age. The initial conditions for this numerical simulation were set by the precisely measured level of anisotropy in the cosmic microwave background radiation. Those initial density fluctuations, when the Universe was just 380 000 years old, grow over cosmic time into the cosmic web via the 'gravitational-runaway' effect, in which slight density enhancements grow progressively larger as they accumulate more and more mass. The simulation box is about 30 million light-years on a side. At the scales depicted here, the Milky Way galaxy would be a tiny fraction of a millimeter across effectively invisible. (Credit: Renyue Cen, Princeton University)

Cosmic Reionization

To understand cosmic reionization, one must consider the early history of the Universe (see Fig. III.3.6). During the first 380 000 years, relic heat from the Big Bang kept the Universe so hot that electrons and protons in the primordial soup could not combine to form neutral hydrogen atoms.

But as the Universe expanded, this ionized plasma of dissociated electrons and protons continuously cooled. Then when the Universe was 380 000 years old a cosmic

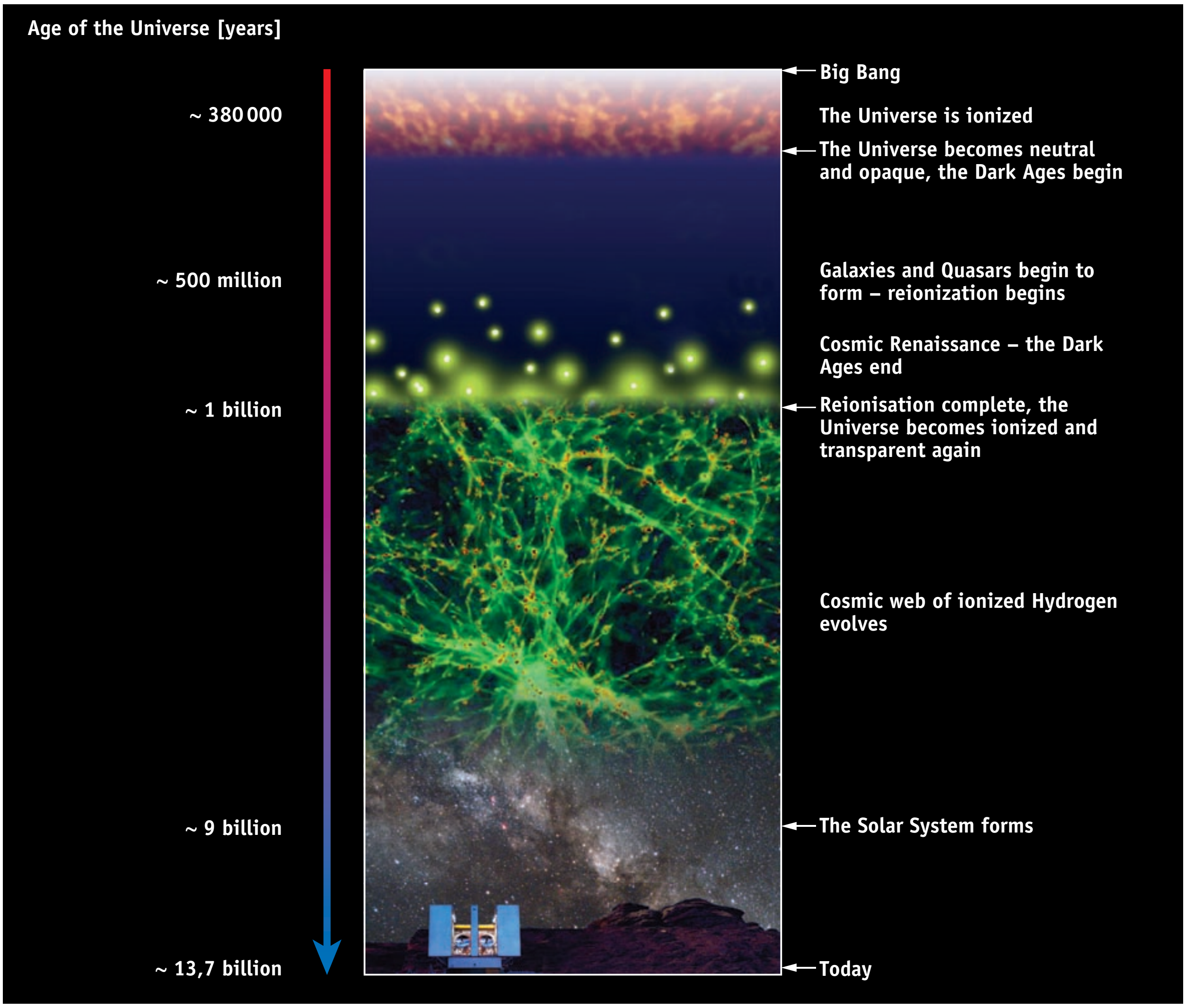


phase transition known as recombination occurred — it became cold enough (below 5000 K) for electrons and protons to combine to form the first hydrogen atoms. The Universe, now full of neutral hydrogen, continues to expand cooling to ever colder temperatures during a period known as the cosmic 'dark ages.'

But the light would eventually triumph over the dark. As structure formation progresses, the first stars and galaxies begin to form producing increasing numbers of stellar ultraviolet photons. These photons begin to *reionize* bubbles of nearby hydrogen atoms, which had remained neutral ever since the recombination era. As more galaxies continue to form, more photons are produced, and these ionized bubbles eventually percolate and coalesce. This final cosmic phase transition is known as reionization, when the Universe went from a totally neutral to a predominately ionized gas phase.

Understanding the details of the cosmic reionization phase transition is one of the most active research areas in cosmology. But the small number of empirical constraints compared to the large number of unknowns leaves ample room for speculative theoretical models. A promising ob-

Fig. III.3.6: A brief history of the Universe. During the first three minutes after the Big Bang only the smallest atoms, hydrogen and helium, were formed. Initially they were ionized (stripped of their electrons) as the Universe was still hot and dense. As the Universe expanded, the gas cooled, and after 380 000 years, when the temperature dropped to about 5000 degrees, the atomic nuclei and electrons were able to combine to form entire neutral atoms. Since no sources of light were present yet and because all the neutral hydrogen made the Universe opaque to ultraviolet ionizing radiation, cosmologists refer to this period as the cosmic "Dark Ages". As structure formation progresses, the first stars and galaxies begin to form producing increasing numbers of stellar ultraviolet photons. About one billion years after the Big Bang, these ionizing photons reionize the Universe, at which point it becomes completely transparent to ultraviolet radiation. This phase transition from a completely neutral to a highly ionized hydrogen gas is known as cosmic reionization. (Credit: S.G. Djorgovski/Digital Media Center, Caltech)



servational approach is to observe the aftermath of reionization via its imprint on the thermal state of the intergalactic medium. Reionization constitutes a watershed moment in the thermal history in the Universe. Before reionization, the neutral atoms which formed at recombination had cooled down to temperatures of tens of Kelvin. The ionizing radiation which reionizes this gas impulsively heats it to 10 000 K. Because the gas in the IGM is so rarefied, the time that it takes the gas to cool is comparable to the age of the Universe. Thus the intergalactic medium should retain *thermal memory* of the reionization phase transition.

Taking the Universe's Temperature

So how can we take the Universe's temperature and constrain how reionization occurred? The key point is that the thermal state of IGM is encoded in its small scale ($\sim$ 100 kpc) structure. This is intuitive if one considers that the density fluctuations of the IGM gas respond to two competing forces, gravity and pressure. On the largest scales $\geq$ 1 Mpc gravity wins and the hydrogen traces out a cosmic web of density fluctuations determined by the gravitational pull of the dominant underlying dark matter (see Fig. III.3.5). But on small scales, hydrogen clouds in the IGM behave in an analogous way to stars. In stars, heat produced by nuclear fusion results in gas temperatures high enough that pressure can balance the pull of gravity. Similarly, in the IGM, relic heat left over from reionization provides pressure support against gravitational collapse. The upshot is that the density distribution of hydrogen making up the Lyman-α forest should become completely smooth on small scales because gravitational instability cannot win against pressure.

Unfortunately, it has been notoriously difficult to measure the small-scale structure of the Lyman-α forest using the traditional method of studying single quasar lines-of-sight. Recall that the Doppler effect from the Universe's expansion determines the mapping between distance and wavelength along one dimensional skewers through the IGM. If the expansion of the Universe were perfectly uniform measuring the small-scale structure of the Lyman-α forest would be trivial. But instead density inhomogeneities drive motions that deviate slightly from uniform expansion. As the IGM gas falls into overdensities and streams away from voids, distance and velocity are irrevocably mixed, making it extremely challenging to eke out the structure of the IGM at small distances with just one dimensional measurements.

At MPIA we are developing a new technique for measuring the small-scale structure and hence characterizing thermal state of the IGM. Because quasars are so sparse on the sky, our view of the IGM has always been one-dimensional. But using close pairs of quasars we can measure the small scale structure of the IGM in two dimensions for the first time. The quasar pairs which we have discovered have transverse separations small enough to resolve the characteristic physical scale $\sim$ 100 kpc on which the IGM gas clouds becomes pressure supported against gravity. The upshot is that for pairs with progressively smaller separations, the Lyman-α forest fluctuations in the two sightlines will become increasingly more coherent across the beam. Fig. III.3.7 shows spectra of the overlapping Lyα forests of the binary quasar from Figure 1 taken with the Keck telescope. A comparison is made to spectra of a pair of quasars at similar redshift but with much larger separation ($\sim$ 1 Mpc). The striking similarity of the absorption pattern in the two members of the close pair illustrates that we have resolved the scale on which pressure forces smooth out the IGM. Converting these high-quality spectra into constraints on the thermal state of the IGM, and ultimately into insights about cosmic reionization, will be an active area of research in our group for the coming years.

Quasars Probing Quasars

In addition to finding binary quasars which are at the same redshift and hence physically associated, our survey for quasars pairs also resulted in a tenfold increase in the number of close projected pairs. These pairs have small angular and hence transverse separations but large line-of-sight separations, such that the quasars are completely physically unassociated. In these unique sightlines, absorption lines from hydrogen and other heavier elements, measured in the spectrum of the background quasar, encodes valuable information about the physical state of gas in the the environment of a foreground quasar. These unprecedented measurements provide a new window for studying the physical and hydrodynamical processes that shape the formation of distant galaxies from collapsing IGM gas.

Until recently, the accepted model for galaxy formation was very simple. As gas from the IGM collapses onto dark matter halos gravitational potential energy is converted to thermal energy when gas gets shock heated to temperatures of $T \sim 10^6$ K. This hot plasma then subsequently cools to low temperatures sufficient to form a cold interstellar medium from which molecules and ultimately stars are formed. However it is now clear from hydrodynamical simulations of galaxy formation, that gas cooling from a shock heated 'virialized' plasma accounts for only a small fraction of the cold fuel for star-formation. Instead, a 'cold mode of accretion' occurs whereby $T \sim 10^4$ K gas from the IGM funnels from large filaments directly onto galaxies. The most attractive feature of this now ubiquitous picture, is the efficient transport of cold gas to the centers of galaxies, providing a natural mechanism to sustain the high star-formation rates observed in many distant galaxies. Yet, direct observational evidence for the existence of this cold flow gas is thus far non-existent.

Another important question in galaxy formation is understanding the dichotomy between low mass blue spiral galaxies and more massive red elliptical galaxies. Spirals are blue because they possess young stellar populations. Since the age of young blue stars is short compared to the age of the Universe, this indicates re-

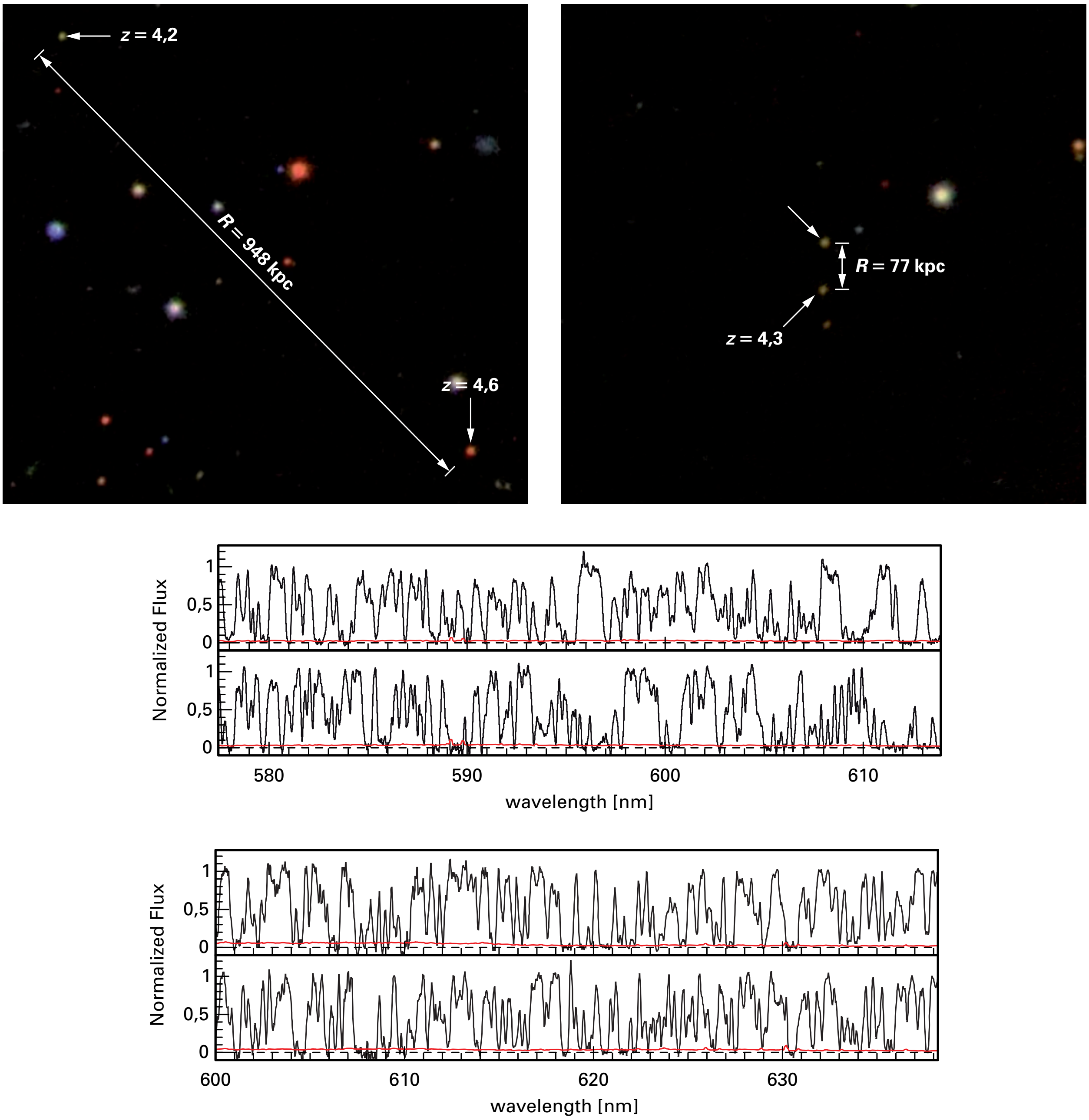


Fig. III.3.7: Comparison of overlapping Lyman-α forest spectra of wide and close quasar pairs. *Top Left:* A wide separation projected pair of $z > 4$ quasars with transverse impact parameter of $R_\perp = 948$ kpc. *Center:* Spectra of the overlapping Lyman-α forests for each member of the quasar pair. The differences in the absorption pattern in the two sightlines illustrate that we are probing different parts of the cosmic web. Nonetheless, the absorption is significantly correlated for these two sightlines, but it just not obvious by eye. *Top right:* The close binary quasar shown in Fig. III.3.1 at $z = 4.3$ with separation $R_\perp = 77$ kpc. *Bottom:* Overlapping Lyman-α forest spectra for each member of the pair. For the small separation pair, the similar absorption features in the two sightlines is now striking and even obvious by eye. The high coherence between the two sightlines indicates that the transverse beam between the quasars resolves the scale on which pressure begins to dominate over gravity and smooths out the structure of the IGM. By comparing the correlations between this and other quasar pair sightlines to cosmological simulations (see Fig. III.3.5), we can characterize the thermal state of the IGM and constrain cosmic reionization.

cent and continuous star-formation. On the other hand, ellipticals are red because they are no longer actively forming stars and their older redder stellar populations have begun to fade. In the aforementioned cold accretion picture, large quantities of gas should continue to accrete from the IGM onto the progenitors of elliptical galaxies over the age of the Universe. Without some mechanism to shut off the conversion of this fuel into new stars, the result would be an unseen population of massive blue galaxies. But the physical processes which 'quench' star-formation leaving massive galaxies 'red-and-dead' remains a mystery.

A popular scenario for explaining quenching, or the halting of star-formation, is that a "feed-back" mechanism couples the quasar phase of rapid supermassive black hole growth with the evolution of the host galaxy. This can be easily understood if one considers the energetics. Over the course of a quasar's lifetime, the accretion of material onto its $\sim 10^9\,M_\odot$ supermassive black hole will liberate an enormous energy $E = \varepsilon\, M_{BH}\, c^2 \simeq 10^{55}$ J. For comparison, the binding energy of a massive galaxy is $\sim 10^{53}$ J. Thus if just a few percent of the energy emitted by a quasar could couple to large scales, that would be sufficient to eject all the gas in the galaxy or shock heat it to high temperatures $T \geq 10^6$ K, and completely extinguishing star-formation.

These 'cold-flow' and quasar feedback scenarios have become a panacea for explaining the observed properties of galaxies, although to date no convincing obser-

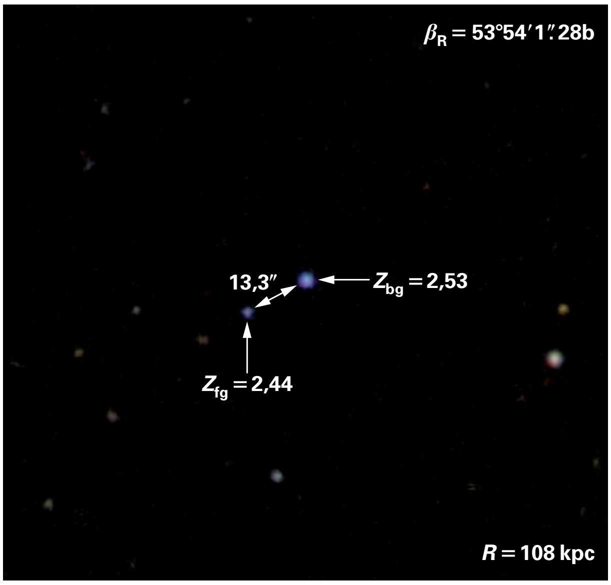
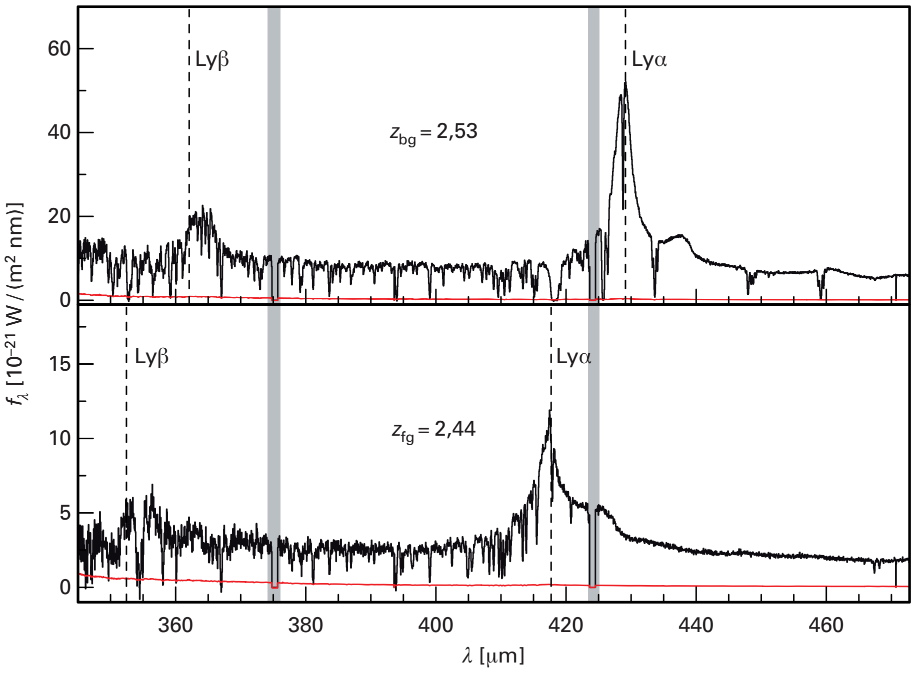


Fig. III.3.8: Projected quasar pair studies. *Left:* SDSS color image of a projected quasar pair with separation $\theta = 13.3''$ corresponding to $R_\perp = 108$ kpc at the redshift of the foreground quasar. The line-of-sight separation implied by the redshift difference is ~ 50 Mpc, indicating the two quasars are physically unassociated. Below top: Gemini/GMOS spectrum of the background quasar SDSSJ 1204+0221 BG at $z = 2.53$. Its Lyα and Lyβ emission lines are marked and the gray bands show gaps in the wavelength coverage due to the gaps in the detector array. Blueward of Lyα emission, one notes a thicket of absorption features associated with the intergalactic medium (a.k.a the Lyα forest). The strongest Lyα absorption line occurs at $\lambda \approx 4180$°A which is offset by only a few hundred km s^{-1} from the foreground quasar. *Below bottom:* Gemini/GMOS spectrum of the foreground quasar. Again, its Lyα and Lyβ emission are indicated and it is evident that the Lyα emission coincides with the strong Lyα absorption present in the background quasar spectrum. Detailed analysis of the absorption line spectrum in the background quasar allows us to determine a wealth of information about the physical state of cold gas in the halo surrounding the foreground quasar.



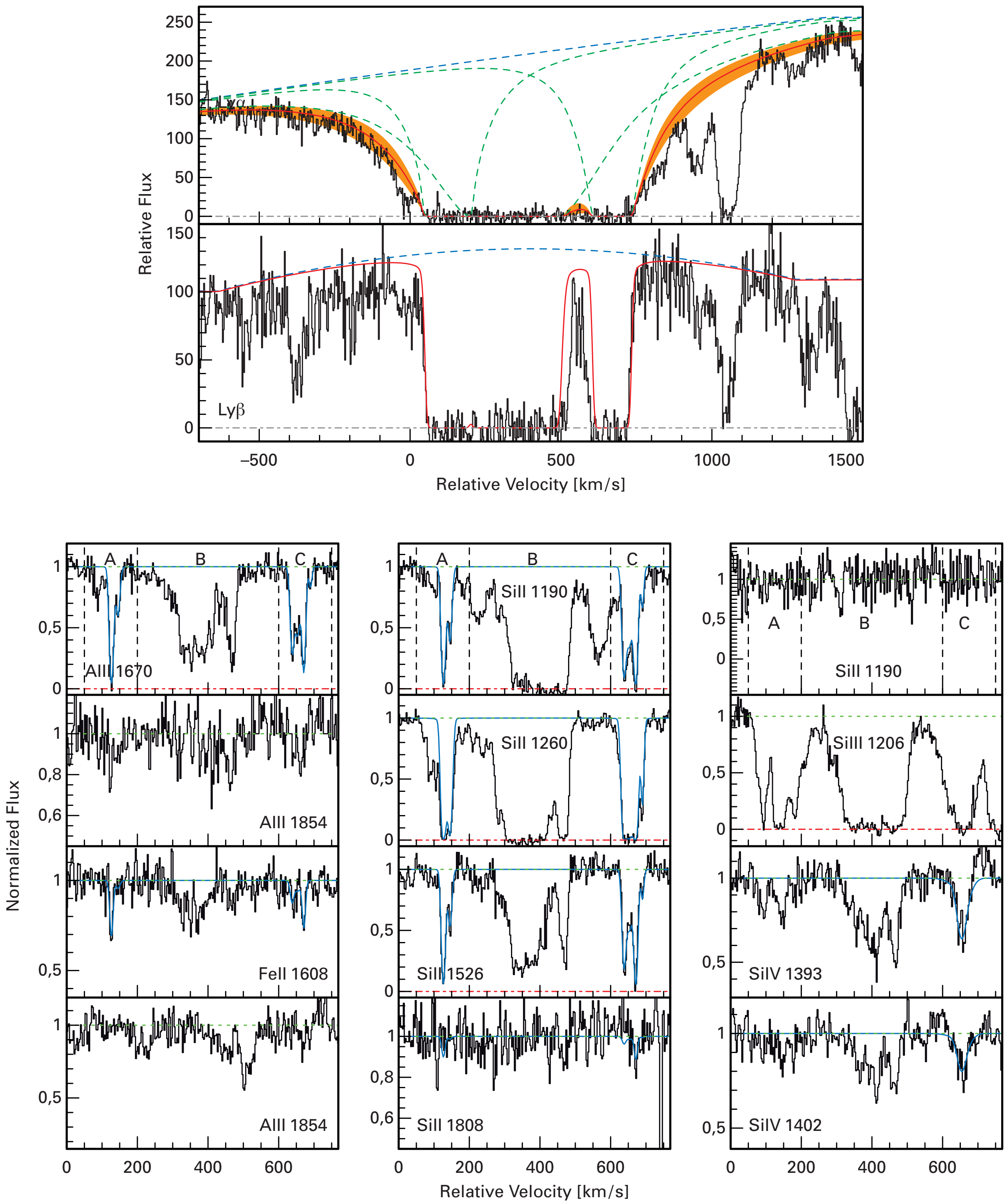


Fig. III.3.9: Studying quasar halo gas in absorption with a projected quasar pair. *Top:* Lyα and Lyβ profiles for the cold gas identified in the spectrum of the background quasar from Fig. III.3.8, at the redshift consistent with the foreground quasar. The relative velocity $v = 0$ km s^{-1} corresponds to the redshift of the foreground quasar. We derive $N_{\rm HI} = 1019.65 \pm 0.15$ cm^{-2} from a simultaneous fitting to Lyα and Lyβ indicating a large reservoir of cold $T \sim 10\,000$ K predominantly ionized gas. *Bottom:* A subset of over twenty transitions of various ionization states of heavy elements identified in the background quasar spectrum associated with the neutral hydrogen gas shown on the left. The gas is highly enriched with heavy elements with a relative abundance of metals to hydrogen of nearly the solar value. A detailed photoionization model allows us to estimate a total cold gas reservoir of $M \sim 10^{11}\,M_\odot$. The metal line complexes also indicate extreme kinematics with absorption extending to $+780$ km s^{-1} from the foreground quasar.

vational evidence has been presented favoring either. To observationally test these ideas, we must study the physical state of gas on scales 10 kpc – 1 Mpc at the formation epoch of today's massive red elliptical galaxies. Several lines of evidence indicate that quasars are indeed the progenitors of massive ellipticals. Motivated by this, we have introduced a novel experiment using projected quasar pairs, whereby a foreground quasar's interstellar medium (ISM) and halo gas can be studied in absorption against a bright background quasar, resolving scales as small as 30 kpc. This approach has the advantage of tracing diffuse gas over a wide range of density and temperature, ranging from cold neutral material $T \sim 100$ K to collisionally ionized plasma $T \approx 10^6$ K, and with column densities in the range $N \sim 10^{12} – 10^{22}\,\mathrm{cm}^{-2}$. Fig. III.3.8 shows a projected quasar pair with an impact parameter of $R_\perp = 108$ kpc ($\theta = 13.''3$), where one notes strong Lyα absorption from neutral hydrogen in the background quasar spectrum coincident with the foreground quasar position. Our Keck HIRES echelle spectrum (Fig. III.3.9) allows us to directly measure the amount of neutral hydrogen in the quasar environment and resolve the velocity field of the absorbing gas. Most interestingly, the gas we observe in absorption is enriched with heavy elements or 'metals', which we detect in absorption through over twenty ultraviolet transitions of various ionization states of elements like Si, C, N, O, and Fe.

The stratification of these ionic metal states depends on the detailed physical properties of the absorbing material. Through painstaking comparison of our absorption line spectrum to photoionization, collisional ionization, and collisional excitation models we came to the following conclusions about the absorbing halo gas: (1) the kinematics are extreme with absorption extending to $+780\,\mathrm{km\ s}^{-1}$ relative to the foreground quasar; (2) the gas is highly enriched with a relative abundance of heavy elements comparable to the sun (3) the gas is predominantly ionized with a temperature of $T \approx 10\,000$ K (4) the electron density is $n_e \sim 1\,\mathrm{cm}^{-3}$, suggesting that the cold neutral phase which we detect could be in pressure equilibrium with an (undetected) hot plasma (7) there is a negligible amount of warm gas $10^5\,\mathrm{K} \leq T \leq 10^6\,\mathrm{K}$ in the quasar environment; (8) the gas is not illuminated by the foreground quasars intense ionizing radiation, thus we are likely probing 'shadowed' material from a partially obscured quasar; (9) the mass of cold $T \sim 10^4$ K gas is significant ($M \sim 3 \times 10^{11}\,\mathrm{M}_\odot$).

Our detection of such a large amount of highly enriched cold gas at such a large distance from the quasar $R \sim 100$ kpc is challenging to explain. It is possible that we have made *the first detection of the cold mode of cosmological accretion*. However, if we have really detected primordial gas infalling from the IGM, the fact that this material is so heavily enriched with metals is extremely puzzling. Recall that all heavy elements in the Universe are synthesized in the nuclear furnaces of stars. But the primordial hydrogen in the IGM has never been contaminated by this nuclear waste. It is observed to be pristine with a heavy element abundance per hydrogen atom, or metallicity, one thousand times smaller than that of our Sun. In the cold accretion picture the gas raining onto galaxies from the IGM should also be pristine, so our detection of a high enrichment level seems at odds with this interpretation. Indeed, the high metallicity is more consistent with the ejection of this gas from the quasar's host galaxy. But if we associate the detected cold gas with material swept up by a large scale galactic outflow, then we run into another contradiction. Our observations imply that the energetics this presumed outflow are extreme, amounting to ≥ 5 % percent of the total luminosity being emitted by the foreground quasar as matter accretes onto its supermassive black hole. Although quasar feedback models require that a comparable fraction of accretion luminosity couple to the host galaxy as heat, we believe that our estimated energetics push the limits of plausibility, because even more energy should also have been radiated away by such an outflow.

With just a single sightline, we cannot distinguish between cold cosmological accretion or a quasar powered outflow. In the future we will analyze statistical samples of ~ 100 similar projected quasar pair spectra with the same techniques, to map out the properties of gas near distant galaxies in detail. The power of our absorption line approach for studying galaxy formation is that it provides the first observational constraints on the physical state of the gas on scales $\geq$ kpc scales in high-redshift proto-galaxies. From a theoretical perspective, the advantage of directly probing the gas in galaxies is that many of the relevant hydrodynamical and physical processes are already (or nearly) resolved by current simulation grids. This provides a far more direct test of galaxy formation models than observations of the stellar populations of galaxies, because in order to predict the stars, the uncertain 'sub-grid' physics of star-formation must be inserted by hand.

The Future of Quasar Pair Research

Quasar pairs are unique astrophysical laboratories and this article highlighted a few of their cosmological applications. All of the experiments we described were being conducted for the first time, and so it is not surprising that many open questions still remain. Currently much of the interpretation is limited by the small sample sizes and/or the small number of objects studied in detail. Three MPIA projects will allow us to put the study of quasar pairs on a firmer statistical and observational footing.

Our first sample of quasar pairs was discovered by mining the SDSS imaging database. MPIA is a partner in the Panoramic Survey Telescope & Rapid Response System (Pan-STARRS1), the most ambitious sky survey project ever undertaken. Pan-STARRS1 uses a dedicated 1.8-meter telescope with a 7 deg^2 field of view and a record-breaking 1.4-Gigapixel Camera, to repeatedly map the sky in five filters over the three fourths of the celestial sphere which is visible from its location in Haleakala (Hawaii). A key advance is that the Pan-Starrs1 survey is synoptic, which means it repeatedly images the sky multiple times. This means that we will be able to select quasars based on their variability and color, dramatically improving the efficiency for finding quasar pairs. Because Pan-Starrs1 covers an area three times larger than the SDSS, extends to fainter magnitudes, and has a higher efficiency, we estimate that we can increase the number of close quasar pairs by an order of magnitude, so that sample sizes of ~ 1000 are well within reach. Follow-up spectroscopy of these pair candidates to confirm their identity will be carried out using the 3.5m telescope at the Calar Alto Observatory.

All of the experiments we described required high quality follow-up observations from 8 m class telescopes and the first generation of instruments on the Large Binocular Telescope are highly complementary to our requirements for quasar pair research. In particular, deep images taken with the Large Binocular Camera (LBC) will be used to search for overdensities of galaxies around $z \sim 4$ binary quasars to determine if they are indeed rare proto-clusters in the early Universe. We are using the recently commissioned LBT Near Infrared Spectroscopic Utility with Camera and Integral Field Unit for Extragalactic Research (Lucifer) to obtain near-infrared spectra of foreground quasars in our projected pairs. Spectra in the near-IR are desired to pinpoint the precise redshift of the foreground quasars, which can then be used to study the relative kinematics between the foreground quasar and the absorbing gas measured in the background quasar sightline. Finally, we are eager to use the Multi-Object Double Spectrograph for the Large Binocular Telescope (Mods), which will allow us to obtain more high quality spectra similar to those shown here.

Finally, we have begun observing projected quasar pairs with the Iram Plateau de Bure Interferometer. Using sensitive millimetre observations, we hope to measure the molecular gas masses, molecular kinematics, and star-formation rates of the foreground quasars. By comparing these quantities to the amount of large scale ($\sim 10-100$ kpc) cold fuel falling into the galaxy measured from our background quasar spectrum, we will have all of the pieces to the puzzle for understanding how distant star-forming galaxies are fueled. If just 10 % of the cold gas detected in Fig. III.3.9 can be deposited on the foreground quasar in a dynamical timescale, then this would be sufficient to replenish the molecular gas reservoirs and power the vigorous star-formation characteristic of the population of $z \sim 2-3$ quasars which have been studied at millimetre wavelengths.

Exploiting the scientific potential of these quasar pair laboratories requires a varied set of tools at the forefront of modern cosmological research: mining large surveys, observations with the largest telescopes and most powerful instruments, understanding the detailed physics governing quasar absorption lines, massively parallel supercomputer simulations including hydrodynamics and/or radiative transfer, and complex statistical methods for analyzing the large-scale structure of the Universe. Luckily, the Galaxies and Cosmology group at MPIA hosts a diverse group of researchers and is involved in projects that spanning all of these areas.

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Princeton University,
University of Illinois at Urbana-Champaign.

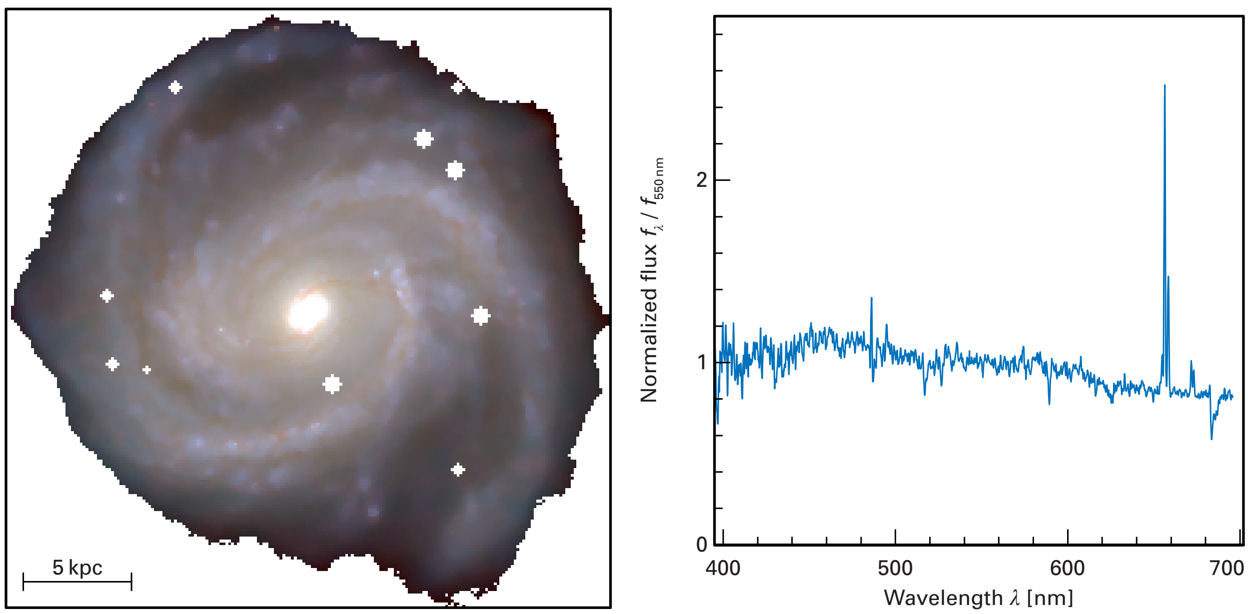
III.4 The Stellar Populations of Galaxies

Stars are an essential component of galaxies and, although they constitute less than 10 percent of the total baryonic content of the Universe, they carry important information about the complex star formation and assembly processes that shaped present-day galaxies. The amount of stars formed in a galaxy (i.e. the galaxy stellar mass) and their ages and chemical compositions are the result of the galaxy's past history of star formation and chemical evolution. The physical properties of galaxy stellar populations are imprinted into the integrated galaxy light. Stellar population synthesis models are the major tool to interpret the integrated colors and spectra of galaxies in terms of the physical parameters of their stellar populations.

The stellar content of distant galaxies is accessible to us thanks to the radiation that reaches us in the UV to optical and near-IR wavelength range (see Fig. III.4.1). This integrated radiation results from the emission of a huge variety of stars, which span several orders of magnitude in mass and luminosity and may have widely different chemical compositions, depending on the physical properties of the gas from which they formed and the time when this happened. In addition, the radiation is further processed by dust, which absorbs and scatters light with an efficiency that depends on wavelength and on the relative spatial distribution of stars and dust. Interpreting the observed radiation to derive the basic physical properties of stellar populations (mass, chemical composition and formation history) is therefore a very challenging task. Astronomers at MPIA are bringing fundamental contributions to this field, in collaboration with international scientists.

Given the complexity of the relations between observables and physical parameters and the vastness of the possible parameter space, the approach to infer physical parameters from integrated galaxy light has to heavily rely on models. Comprehensive libraries of models are created to predict observables given different sets of input physical parameters. The predicted observables are then matched with the actually observed quantities in order to infer the physical properties of galaxies. The technique that modelists use to predict observables is called stellar population synthesis.

Fig. III.4.1: The spiral galaxy M 100 as it appears at optical and near-IR wavelengths and from a medium resolution spectrum. The image on the left is the "true color" composite of three images taken at 1.65 µm (*red channel*), 750 nm (*green*) and 450 nm (*blue*). The medium-resolution spectrum on the right provides a wealth of additional information concerning star formation activity, witnessed by the prominent emission lines (the Balmer Hα at ~656.3 nm in particular), and the age and chemical composition of stars and gas. (Credits: Sloan Digital Sky Survey and Goldmine)



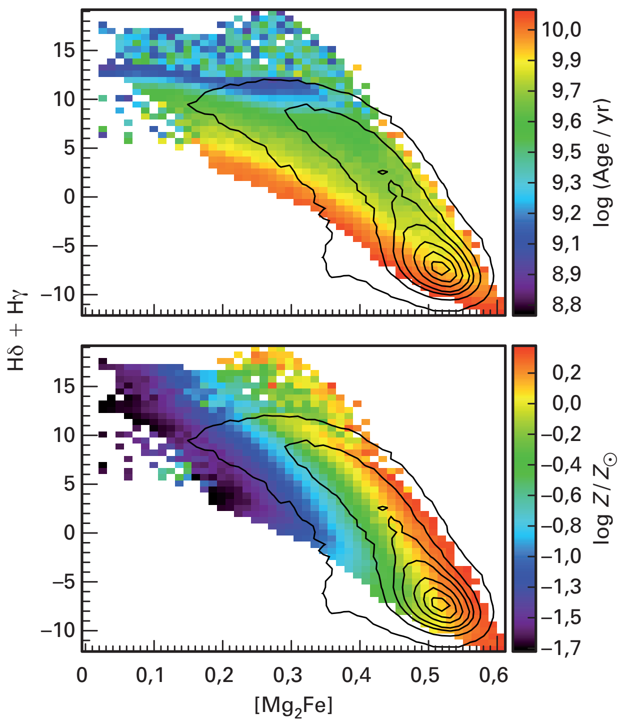
Stellar Population Synthesis models

Distant galaxies cannot be resolved into individual stars – we can only measure their integrated light, which results from the contribution by various generations of stars with different ages and metallicities. The stellar populations of a galaxy with any star formation history can be decomposed into a series of Simple Stellar Populations (SSPs), i.e. a coeval population of stars formed instantaneously (in a burst) with a given metallicity. This idea is at the basis of Stellar Population Synthesis (SPS) models. The goal of SPS models is to describe the time-dependent distribution of stars in the effective temperature-luminosity diagram and derive the integrated spectral evolution of a stellar population.

The main ingredients of SPS models are 1) the Initial Mass Function (IMF) of stars, which describes the distribution in mass of a freshly formed stellar population, 2) the theoretical time evolutionary tracks of stars of different mass, and 3) the libraries of stellar spectra, either observational or theoretical, which are attached to each star in each evolutionary phase. SPS models are used to predict in the first place the time evolution of the spectrum of an SSP of a given metallicity by combining these three ingredients. The spectral properties of a complex stellar population are then predicted by co-adding the spectra of the SSPs (of different ages and metallicities) of which it is composed. Since galaxies typically form their stellar mass over several billion years, going beyond the SSP modeling and taking into account complex star formation histories (SFHs) is fundamental to obtain realistic models. Comparison of the predicted spectral energy distributions with those observed for real galaxies allows to infer physical parameters of galaxies, such as the total mass in stars, the average age of their stellar populations (weighted by their luminosity) and their average metallicity.

Broad-band colors are the first diagnostic of a galaxy's stellar populations. They show clear correlations with the stellar mass-to-light ratio (M/L) and hence they provide us with a cheap and relatively robust estimate of the galaxy's stellar mass. A more detailed interpretation of broad-band colors in terms of stellar populations is however limited by the strong degeneracy between age and metallicity, and further complicated by dust attenuation in gas-rich systems: all these parameters tend to redden galaxy colors in similar ways. A well-established method to lift these degeneracies, at least partly, is to rely on more refined spectral diagnostics that isolate the strength of individual absorption features which have distinct sensitivities to age and metallicity and are hardly affected by dust attenuation (being defined on narrow wavelength ranges). (See Fig. III.4.2)

Fig. III.4.2: Strength of the Balmer absorption lines (Hδ+Hγ) against the metallicity indicator [Mg_2Fe]. The distribution of the models is color coded to reflect the average stellar age (*upper panel*) and the average stellar metallicity (*lower panel*) at each position in the plane. The Balmer lines are primarily sensitive to age, while the Mg-Fe feature is primarily sensitive to total metallicity: the combination of such indices thus helps in breaking the age-metallicity degeneracy. The contours show the distribution of SDSS galaxies at redshift $z \sim 0.1$.



Modern SPS models are able to predict not only broad-band colors or the strength of individual features but the full spectrum of any stellar population at high spectral resolution, based on spectral libraries with an improved coverage of the stellar parameter space. This translates into a large flexibility in the comparison of predicted and observed galaxy spectra, by allowing the adjustment of the models to the observed data quality (rather than the opposite) and hence exploit the full information from observed galaxy spectra. The improved coverage of stellar parameters in spectral libraries allows better handling of the complexity in SFHs of real galaxies and extend the interpretation to young stellar populations.

Stellar masses

From many points of view the stellar mass is among the most fundamental parameters characterizing a galaxy and is known to drive a number of so-called "scaling relations", as we show below. Accurate estimates of galaxies' total stellar mass are crucial to understand how galaxies evolve by converting primordial gas into stars and which factors influence the efficiency of this process. Moreover, having access to the actual spatial distribution of stellar mass in a galaxy throws light onto its dynamics and its secular evolutionary processes.

Stellar population synthesis models allow the derivation of conversion factors between luminosity and stellar mass (so-called mass-to-light ratios, M/L) by the comparison of observables to model predictions. The generic prediction of SPS models that M/L increases with the age, metallicity and dust extinction of a stellar population has been largely exploited in the past following the observation that all three parameters similarly affect the colors by making them redder. Bell & de Jong (2001) correctly concluded that the color of a stellar population must correlate with its M/L and provided a set of fitting formulae to obtain M/L from a given optical or NIR color based on simple assumptions. On the other hand, having access to higher resolution spectral information allows the resolution of the almost degenerate effects of age and metallicity and improves the precision of the inferred M/L. In the last years scientists at MPIA have been working on refining these methods and on quantifying the systematic uncertainties due to the assumptions on which models are based.

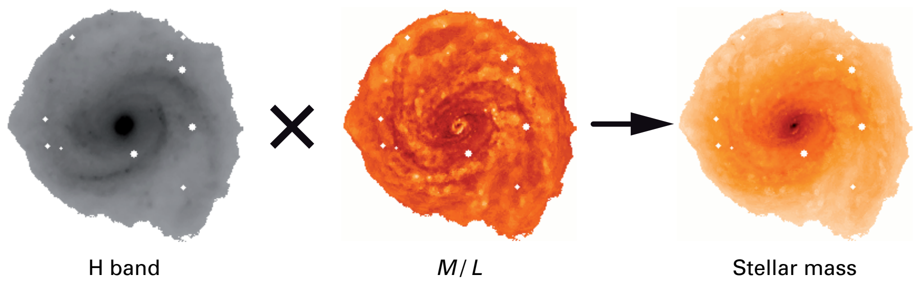
In a work published in 2009 Stefano Zibetti, Stéphane Charlot (Institut d'Astrophysique de Paris) and Hans-Walter Rix have used a comprehensive library of models, including a broad variety of SFHs, different metallicity and amount and distribution of dust, to estimate median likelihood M/L as a function of two colors in the optical and NIR. These models incorporate state-of-the-art prescriptions for the most critical stellar evolutionary phases and substantially improve on precursory works thanks to the adoption of much more realistic SFHs and to the inclusion of the effects of dust.

These new M/L estimators deliver a typical precision of 30 % in the NIR, hence a dramatic improvement with respect to previous methods based on one color only. This method is not significantly worse than those based on spectral indices. In contrast to spectroscopic information though, broad-band images with typical ground-based resolution allow the mapping of M/L in galaxies, and therefore their stellar mass distribution, in a much cheaper way for large samples of galaxies. The photometric information in three optical and NIR bands is reliably extracted at each "pixel" over the whole extent of a galaxy, based on an advanced image processing technique called "median adaptive smoothing" (Zibetti 2009) and then combined to obtain the M/L. In turn this is multiplied by the luminosity of the pixel to obtain its stellar mass content, as illustrated in Fig. III.4.3. The analysis of a preliminary sample of nine galaxies has shown that systematic M/L variations (e.g. as a function of radius) may significantly alter the structure of a galaxy as inferred from the light distribution, with a strong impact on the inferred dynamics. A first application of the new method of dynamical studies has been presented in the work on gravitational torques in spiral galaxies by Kelly Foyle, Hans-Walter Rix and Stefano Zibetti. Moreover it has been shown that the total stellar mass derived by integrating spatially resolved maps can substantially differ (up to 40 %) from the one obtained from global colors and luminosity. This occurs in the presence of strongly dust-obscured regions in a galaxy: while these regions affect only negligibly the global luminosity and colors of the galaxy, their mass content may be significant and can only properly be accounted for if local M/L values are computed.

This result highlights one of the main uncertainties that hamper the accurate determination of the stellar mass in a galaxy, i.e. the presence of dust. Other assumptions, especially concerning the star formation history, can produce even larger biases. Anna Gallazzi and Eric Bell have investigated where the limits of our knowledge of stellar mass in galaxies lie, by simulating stellar mass measurements on model "galaxies" including different kinds of information (photometric and spectroscopic) with different levels of accuracy.

In general high-quality spectroscopic information allows us to reach accuracies better than 20 %. Color-based estimates can reach a comparable level of accuracy when dust is negligible and for galaxies dominated by old stellar populations and with a smooth SFH. The presence of a recent burst of star formation limits our ability of constraining M/L with an accuracy better than 40 % and may introduce large biases when colors alone are used. An important conclusion is that any mismatch between the assumed SFH and metallicity distributions and the true ones can have a significant impact on the de-

Fig. III.4.3: Concept of stellar mass mapping. The broad-band image in the NIR (*left*, dark means brighter) is multiplied by the mass-to-light ratio map (*middle*, dark means high M/L) derived by combining the fluxes in different bands pixel by pixel, to obtain the stellar mass distribution (*right*, dark means massive).



rived M/L estimates. Any study that aims at accurately quantifying and characterizing the stellar populations in galaxies should thus pay particular attention to making the most plausible and comprehensive assumptions on SFH and metallicity.

The involvement of MPIA in the CALIFA integral field spectroscopic survey (see below for more details) will allow us to extensively test stellar mass reconstruction methods for different galaxies and in different physical conditions by combining resolved broad-band and spectroscopic information for several hundred galaxies: a huge playground to challenge our understanding and ability to trace stars!

Inclusion of spatially resolved information from other wavelengths, in particular the IR provided by the space borne observatory HERSCHEL, will allow us to better describe the influence of dust on stellar mass estimators. Astronomers at MPIA are actively contributing to the KINGFISH (Key Insights on Nearby Galaxies: A Far-Infrared Survey with HERSCHEL) survey which will observe roughly 60 nearby galaxies in the IR with exquisite resolution. Stefano Zibetti is leading an effort to follow up these observations with optical and NIR imaging (KINGSTAR: Key Insights into Nearby Galaxies: the STellar mass Ancillary suRvey for KINGFISH) at the Spanish-German observatory in Calar Alto and at the ESO-MPG 2.2 m telescope in La Silla, in order to create stellar mass maps taking advantage of this huge wavelength coverage and of the simultaneous information about stellar and dust-reprocessed radiation.

Basic assumptions included in the construction of SPS models also lead to systematic biases. Among these the most important are certainly 1) the initial stellar mass function for SSPs, which can change M/L by roughly a factor 2 when switching between extreme prescriptions; and 2) the prescriptions adopted to model the critical stellar evolutionary phase of thermally pulsing asymptotic giant branch (TP-AGB), which may substantially affect the flux, especially in the NIR, of stellar populations of age between 0.3 and 2 Gyr. Programs of NIR spectroscopy have been started at MPIA in order to provide observational constraints to the theoretical models and spectral templates of this stellar phase.

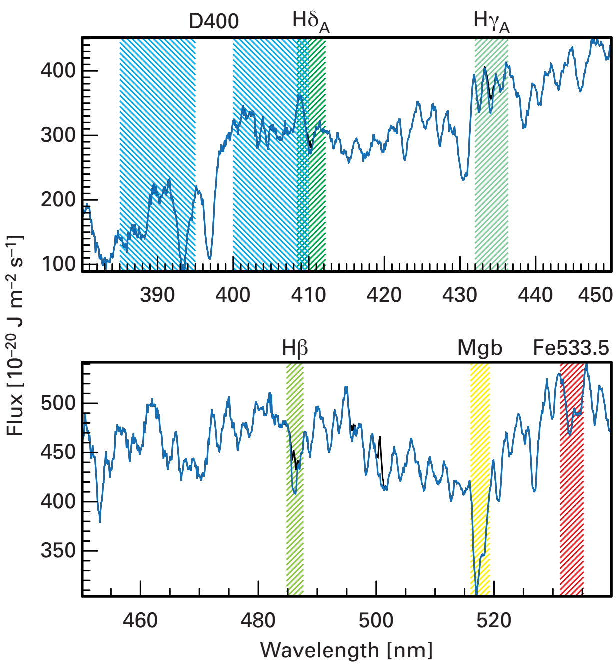


Fig. III.4.4: SDSS spectrum of the elliptical galaxy NGC 5846. The blue hatched regions indicate the two bandpasses that define the 4000 Å break (D4000), while the other regions highlight the central bandpass of some age or metal-sensitive absorption indices. The D4000 index in combination with the strength of Balmer absorptions is a diagnostic of the recent SFH (in the last 2 Gyr) and of the mean stellar age. Mg and Fe features are instead indicators of the abundance of such elements. The high resolution of the models allows us to accurately correct for even weak emission lines contaminating the pure stellar absorption (*blue spectrum*).

The ages and metallicities of present-day galaxies

The last decade has been marked by enormous advances in our understanding of present-day stellar populations. These have been driven by the advent of large and homogenous spectroscopic surveys, such as the Sloan Digital Sky Survey in which MPIA is involved, together with the continuous development of SPS models.

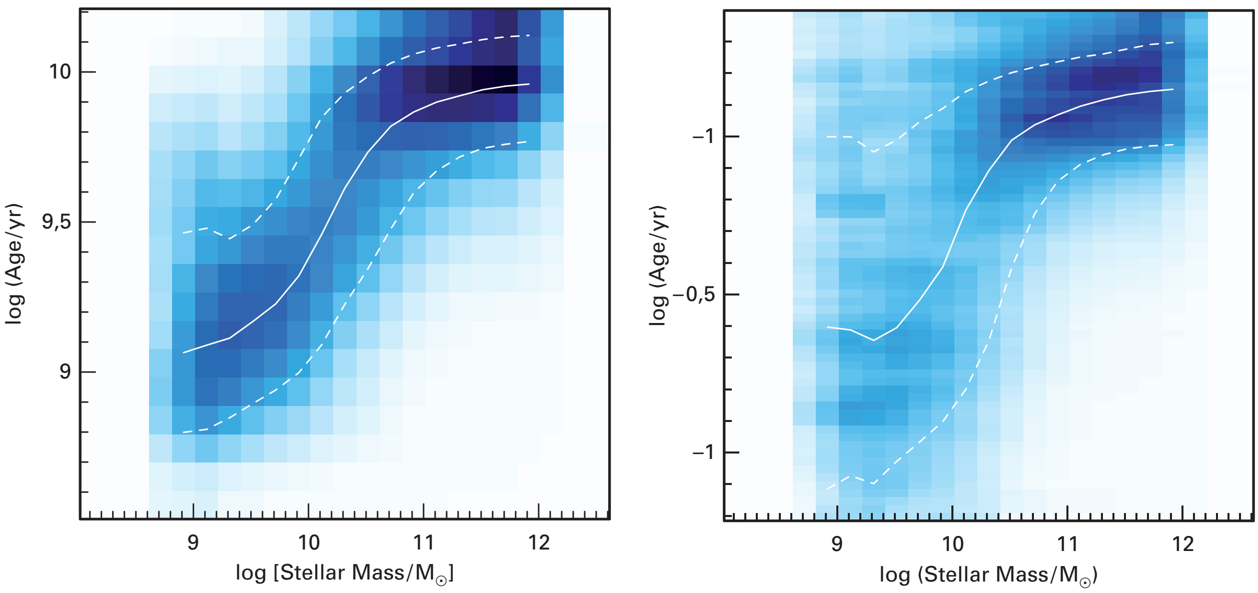
Scientists at MPIA make use of state-of-the-art SPS models and optimized fitting procedures to interpret in great detail the stellar populations of present-day galaxies. The SDSS provides photometry and medium resolution spectroscopy for hundreds of thousands of galaxies in the nearby Universe ($z \sim 0.1$). Anna Gallazzi has developed a code to compare the observed spectrum of each galaxy to a comprehensive library of model spectra encompassing a large range of SFHs and metallicities leading to robust constraints on the mass, age and chemical composition of the galaxy stellar populations. The comparison is focused on an optimized set of stellar absorption features sensitive to either age or stellar metallicity (see Fig. III.4.4). The improved spectral resolution of the models allows to accurately correct the pure stellar spectrum for contamination by emission lines of the ionized gas, which is particularly important in galaxies with ongoing star formation. Moreover the model spectra can be broadened to match the galaxy velocity dispersion which affects the strength of the absorption features.

The analysis conducted by Anna Gallazzi on a representative sample of nearby galaxies from the SDSS has provided a complete census of the baryons and metals presently locked-up in stars. These measures, as a whole and as a function of integrated galaxy properties, set crucial constraints to the cosmic SFH and the efficiency of feedback mechanisms regulating the amount of gas and metals expelled from galaxies, and provide fundamental benchmarks for models of galaxy formation and evolution.

Galaxies separate into two broad classes according to their observables; 'red-sequence' galaxies, whose red colors mostly reflect the aging of their stellar populations after star formation cessation, characterized mostly by spheroidal morphologies, and 'blue-cloud' galaxies, still actively star forming and characterized by disk-like morphologies. This reflects distinct physical properties deriving from different evolutionary paths, which are to first order predictable by the galaxy stellar mass. Indeed there is a clear correlation between the mean stellar age and metallicity of galaxies and their mass which holds over three orders of magnitude in galaxy mass, as probed by SDSS (see Fig. III.4.5). A rapid transition from young, metal-poor to old, metal rich galaxies occurs around a characteristic stellar mass of 3×10^{10} solar masses, which corresponds to the transition range in several observed properties, such as color and morphology. There is a large scatter in these relations, in particular around the transition mass where disk-dominated star-forming galaxies and spheroidal quiescent galaxies overlap. The large scatter indicates that galaxies with similar mass have followed different evolutionary paths and that there must be at least a second parameter determining current galaxy properties.

The environment in which galaxies live can have an important effect on their evolution. A galaxy living in isolation will continue forming stars undisturbed until its gas reservoir is exhausted. If a galaxy lives in a group or cluster of galaxies it can experience different types of interactions with other galaxies or with the intergalactic medium, altering its gas reservoir, star formation rate and hence its current stellar populations. A group of scientists led by Anna Gallazzi and Anna Pasquali at MPIA has explored the environmental dependence of the age/metallicity vs. mass relations. They find significant differences between galaxies that are either isolated or the central galaxies of groups or clusters ("centrals") and galaxies that have been accreted into groups or clusters, but are not centrals ("satellites"). Satellite galaxies are older and more metal-rich than centrals of similar stellar mass. The differences between satellites and centrals are more pronounced below the characteristic mass of 3×10^{10} solar masses and, at fixed stellar mass, increase with increasing mass of the group or cluster in which satellites live. These trends are understood if satellite galaxies are depleted of their hot gas reservoir (leading to a faster quenching of star formation) through the interaction with their environment, which is stronger in more massive groups and clusters.

Fig. III.4.5: Relation between the galaxy stellar mass and the luminosity-weighted average age (*left panel*), and between the galaxy stellar mass and the average stellar metallicity (*right panel*) of galaxy stellar populations. On average (*solid lines*) more massive galaxies host older stellar populations and have reached a higher degree of chemical enrichment, but both relations show significant scatter around the mean relation (*dotted lines*). The shaded regions indicate the number density of galaxies at each position in the plane and show that galaxies populate preferentially two distinct regimes: *i)* low-mass, young and metal-poor and *ii)* high-mass, old and metal-rich. The transition between these two regimes occurs around a stellar mass of 3×10^{10} solar masses.



Above the transition stellar mass of 3×10^{10} solar masses the scaling relations discussed above flatten and galaxies span a narrower range in physical properties. This regime is dominated by quiescent, red-sequence galaxies. However, even red-sequence galaxies are far from being a homogeneous class of objects: both their age and metallicity increase with galaxy mass, spanning a range of almost 4 Gyr in age and a factor of 2 in total metallicity. This gives us important indications about the efficiency of the astrophysical processes that form elliptical galaxies. Low-mass ellipticals also have a non-negligible scatter in stellar age, at fixed stellar mass, indicating either that small bursts of star formation episodically "rejuvenate" some of these galaxies or that the red-sequence is continuously built-up at the low mass end through quenching of star formation in blue cloud galaxies.

Room for improvements ...

Despite the indisputable progress in our understanding of present-day galaxies, improvement of the models and spectral fitting techniques remains of primary importance in order to get more accurate constraints on the masses and stellar population parameters of galaxies both nearby and at higher redshifts. In particular, most SPS models available so far are based on spectra of stars that reflect the abundance ratios of chemical elements in the solar vicinity. The ratio [α/Fe] between α elements and Fe-peak elements is an indicator of the relative enrichment by type II supernovae (SN II) and type I supernovae (SN I). SN II contribute mainly to the enrichment in α elements and occur over a short timescale of 10 million years. SN I instead are major contributors of Fe-peak elements and occur over a longer timescale of few billion years. Given the different timescales of these events, [α/Fe] is a clock of star formation activity.

The limitation of SPS model stellar libraries can potentially bias the analysis of 1) massive ellipticals which both have high total metallicity and are suspected to be overabundant in alpha elements with respect to Fe, and 2) high-z galaxies where SN I did not have time yet to enrich their interstellar medium in Fe. In collaboration with international scientists, Anna Gallazzi is working on developing a new approach to predict the response of the full spectrum to variations both in total metallicity and in [α/Fe]. With these advanced tools it will be possible to reliably constrain [α/Fe] of the stellar populations in galaxies with any SFH, in addition to the mean age and total metallicity. This will provide direct insight into the timescale of star formation as a function of galaxy mass and environment.

Another limitation affecting most stellar populations studies at low redshift, including those based on SDSS, is that spectra sample only a fraction of the galaxy light due to instrumental limitations. This fraction varies with the distance of the galaxy and its light distribution (i.e. its morphology). This may introduce biases in physical parameter estimates because the typical age and metallicity of stars can vary as a function of galactic radius. Accounting for such effects is extremely difficult without an accurate knowledge of age and metallicity gradients as a function of mass and morphology. Gaining such knowledge is one of the goals of the CALIFA Survey, an integral field spectroscopic survey of nearby galaxies that will be conducted at the Calar Alto 3.5 m telescope, in which several MPIA scientists are involved. The data collected by this survey will allow the construction of spatially resolved maps of absorption line indices and derived stellar population parameters for a representative sample of nearby galaxies spanning a large range in stellar mass and star formation activities. Moreover, gradients in stellar age and metallicity, combined with gradients in gas-phase metallicity, stellar mass distribution and dynamics (all of these outcome of CALIFA) will provide fundamental constraints to different scenarios of galaxy formation and chemical enrichment.

The evolution of massive galaxies

The galaxy population above the transition mass of 3×10^{10} solar masses is dominated by quiescent red-sequence galaxies. Today, they contribute more than half of the total stellar mass density of the Universe and contain twice the amount of metals locked in stars in blue-cloud galaxies. The general increasing trend of age and metallicity with galaxy mass observed at low redshift builds a picture in which the stars in more massive objects must have formed earlier than those in low-mass objects. This is also in agreement with the observed decline since redshift $z = 1$ in cosmic star formation rate as a function of mass: massive red-sequence galaxies have experienced an epoch of major star formation more than 8 billion years ago and have been mostly quiescent since then, while lower-mass galaxies keep on forming stars till the present albeit at an ever decreasing rate. Nevertheless, observations at different redshifts indicate that the population of red-sequence galaxies has been continuously growing over this period of time, doubling their total stellar mass density. What are the mechanisms that operate on galaxies from $z = 1$ to $z = 0$ leading to the suppression of star formation in blue-cloud galaxies and to the build-up of the red-sequence?

Tracing the evolution of the age and chemical composition of the massive galaxy population over this period of time is crucial in order to shed light onto this question. An international team of astronomers, led by Anna Gallazzi, has gathered deep medium-resolution multi-object spectroscopy of a sample of 100 massive galaxies at redshift $z \sim 0.7$. The sample is drawn from the MPIA COMBO-17 survey which benefits from observations at several wavelengths from the UV to the far IR, along with well characterized morphology from Hubble Space Telescope imaging (MPIA Gems survey). The spectroscopically-derived stellar population properties of high redshift galaxies, in combination with star formation diagnostics and morphology, will allow us to assess their evolution and to elucidate whether violent (such as galaxy merging) or gradual (such as gas stripping) processes have a major role in shaping present-day galaxy populations.

Anna Gallazzi, Stefano Zibetti,
Eric Bell, Kelly Foyle,
Anna Pasquali, Hans-Walter Rix,
in collaboration with:
Institut d'Astrophysique de Paris,
Max-Planck-Institut für Astrophysik,
Esa-Estec, University of Utah.

IV. Instruments and Projects

From our present instrumentation activities of the LBT we report here about high-fidelity and interferometric imaging instruments and spectrographs (Lucifer 1 / 2 and Linc-Nirvana) as well as about artificial stars and adaptive Optics (Argos). MPIA participates in the design of Metis, a camera with spectrograph for the European ELT. For the Calar Alto Observatory, the survey-camera Panic is under construction. Finally, we report on special technological developments in our technical departments.

IV.1 Instruments and Projects for the LBT

Lucifer 1 and 2: Imaging and Spectroscopy in the Near Infrared

Lucifer 1 and Lucifer 2 are nearly identical Nir instruments. These complex systems both consist of a high resolution infrared camera, a long-slit spectrograph, and a multi-object spectrograph. They will be the workhorse infrared instruments at the LBT. In 2009, the first has been successfully commissioned. The second will follow in about one year.

Lucifer 1 and 2 provide infrared images and spectra with both seeing and diffraction limited angular resolution. The instruments will work at internal temperatures of less than 70 K. Essentially the following observational modes will be available:

- Seeing-limited imaging
- Diffraction-limited imaging with a field of view of 0.5×0.5 arc minutes
- Seeing- and diffraction-limited long-slit spectroscopy
- Multi-object spectroscopy with cryogenic slit masks.

In addition, a differential imaging mode is in preparation for Lucifer 2, which will be especially useful for studying exoplanets.

The observational mode can be changed from direct imaging to spectroscopy by swiveling the grating rotation mechanism unit (exchanging a flat mirror with a grating) and changing the focal plane mask from a field-limited mask to a long-slit or multiple-slit mask. This

Fig. IV.1.1: Lucifer 1 being attached to the left bent Gregorian focus of the LBT.

Fig. IV.1.2: Three colours image of the star-forming region S 255 taken with LUCIFER 1. The field of view is 5.5 × 5.5 arc minutes (dithered image, single FOV is 4 × 4 arc minutes). Blue corresponds to *H*-band, green to the H_2 (2.12 µm) line and red to the *K*-band. (Arjan Bik et al., in preparation)

swap of focal masks is realized by a complicated cryogenic robot system that picks up a certain mask from a magazine and positions it into the focal plane. The mask magazine can be exchanged during daytime without cryo-cycling the instrument.

In 2009, several commissioning runs took place to test and optimize the interplay between the instrument and the telescope. In addition, the observatory instrumentation team has been trained in maintaining and operating LUCIFER on Mount Graham. One last commissioning run was performed before the science demonstration team started operation in December 2009. Even though the full adaptive-optics supported resolution was not yet available at the telescope, all observing modes have been successfully tested. Possibly remaining non-common path errors (below the seeing limit) can be taken into account and corrected by the AO system, as soon as the deformable mirror becomes operational.

By the end of the year, LUCIFER 2 was being prepared by the MPE, and in spring 2010, it will be sent to the MPIA for its final integration and testing. After acceptance in Europe at the end of 2010, it will be delivered to the telescope.

Rainer Lenzen, Werner Laun,
Michael Lehmitz, Ulrich Mall,
Vianak Naranjo, Karl Wagner, Clemens Storz
in collaboration with:
Landessternwarte Heidelberg, MPE-Garching
and other partners.

LINC-NIRVANA: Imaging near-infrared Interferometer for the LBT

The combination of LINC-NIRVANA (LN) and LBT provides a unique platform for interferometry, since the two, co-mounted 8.4 meter primary mirrors of the telescope present an orientation-independent entrance pupil to the instrument. This allows LN to operate in so-called Fizeau-mode, delivering 23-meter spatial resolution and 12-meter effective collecting area for panoramic imagery. LINC-NIRVANA employs a number of innovative technologies, including multi-conjugated adaptive optics, state-of-the-art materials, low vibration mechanical coolers, active and passive control, and sophisticated software for data analysis.

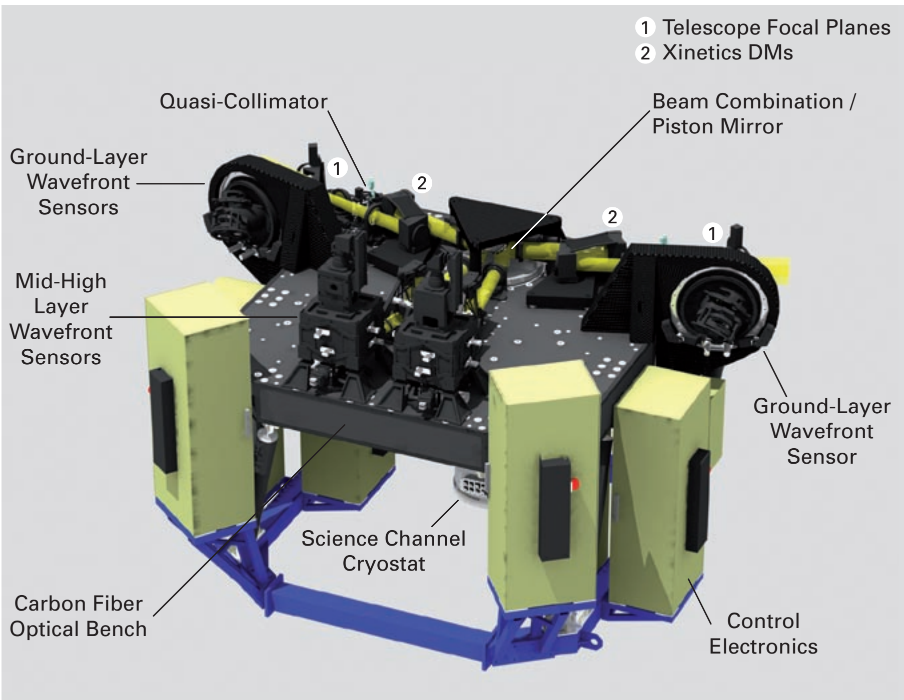
During 2009, the LINC-NIRVANA team continued to make steady progress on the integration and testing of the instrument. The LN consortium has adopted a hierarchical approach to this process, in which individual components are verified and tested at the supplier then delivered to a traditional lab setting for integration into the appropriate subsystem. Finally, the working subsystems come together in the large clean room integration hall at the MPIA in Heidelberg. As of the end of 2009, most of the major components and sub-systems of LINC-NIRVANA were complete, and several have been delivered to Heidelberg for integration.

Important adaptive optics (AO) milestones during 2009 include alignment of the individual star probes in the first Mid-High layer wavefront sensor, closing of the AO loop in the lab, and the design of the two, multi-layer turbulence simulators. Also during this period, the LN partners at Bologna and Padova completed the second Mid-High Wavefront Sensor and the first Ground-Layer Wavefront Sensor; both are ready for delivery to Heidelberg and integration on the optical bench during 2010.

There was considerable progress in 2009 on the large cryostat containing the science channel and fringe tracker. All of the internal cryo-mechanisms, including the secondary mirror, filter wheel, dichroic wheel, and detector de-rotator, were either verified or in the process of verification under operating conditions in a smaller test cryostat. The team achieved an additional important milestone in 2009 by completing the characterization and minimization of the vibrations induced by the unique cooling mechanism, and an initial integration of the cold components into the cryostat proved successful. In addition, the MPIA team verified the procedures for cryostat installation and alignment to the large optical bench.

Regular releases of the updated common software package continued during 2009, and portions of the final control software were put in place for hardware integration and testing in the labs. Interactions with the future user community culminated in summer 2009 with a workshop on observation preparation and planning. The associated software is now mature, allowing greater focus on the incomplete common software modules. The data reduction packages are also well advanced and in the hands of potential users.

Fig. IV.1.3: Computer rendering of the LINC-NIRVANA bench and its subsystems. The yellow shading indicates the optical path.



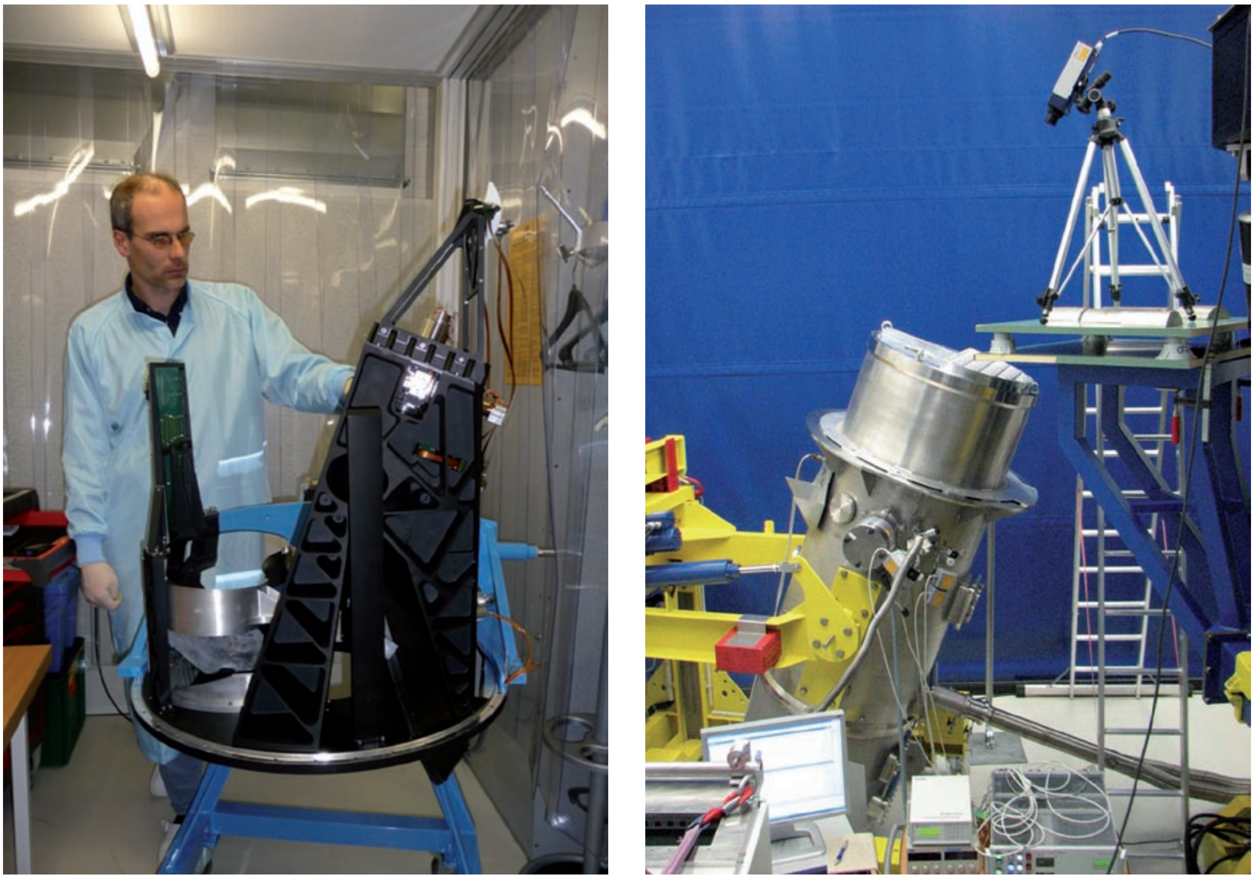


Fig. IV.1.4: *Left* – The LINC-NIRVANA cold opto-mechanics in the clean room. (*Right*) Interferometric vibration testing of the cryostat cooling system Note the Helium gas lines connecting the cryostat to the remote mechanical cooler.

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

Harald Baumeister, Thomas Bertram, Jürgen Berwein, Peter Bizenberger, Armin Böhm, José Borelli, Florian Briegel, Mario Brix, Fulvio DeBonis, Roman Follert, Wolfgang Gässler, Tom Herbst (PI), Ralph Hofferbert, Frank Kittmann, Martin Kürster (PM), Lucas Labadie, Werner Laun, Ulrich Mall, Tobias Maurer, Daniel Meschke, Lars Moohr, Vianak Naranjo, Aleksei Pavlov, Jörg-Uwe Pott, Jose Ricardo Ramos, Hans-Walter Rix, Ralf-Rainer Rohloff, Eva Schinnerer, Clemens Storz, Jan Trowitzsch, Karl Wagner,
In collaboration with:
INAF (Padova, Bologna, Arcetri, Roma, Genova), University of Cologne, MPIfR Bonn.

ARGOS: Artificial Stars and Adaptive Optics

ARGOS, the Advanced Rayleigh Ground layer adaptive Optics System for the LBT, will create artificial laser guide stars and will correct the deformation of the wave-front within a 4 arcmin wide field of view. To correct for the ground layer turbulence three pulsed lasers beams will be used above both LBT primary mirrors, respectively. In contrast to usual single conjugated adaptive optics, ARGOS does not reach to the diffraction limit of the telescope. But it will be capable to improve the imaging quality for LUCIFER by a factor of at least 1.5 in full width half maximum, as well as the energy concentration of LUCIFERs multi-object spectroscopy unit by at least a factor of 2.

After passing the Preliminary Design Review in March 2009, the seeing reducer ARGOS (the Advanced Rayleigh Ground layer adaptive Optics System) was on its way to the Final Design Review which will end in March 2010. The system will illuminate the sky above Mt. Graham with 6 laser guide stars, three for each eye of the LBT, to improve the image quality of LUCIFER by a factor ≥ 1.5 in Full Width Half Maximum and to increase the energy concentration by a factor ≥ 2 for LUCIFER's Multi-object-spectroscopy unit. The ARGOS system is quite complex and distributed over several locations at the telescope. The control system and software of ARGOS have

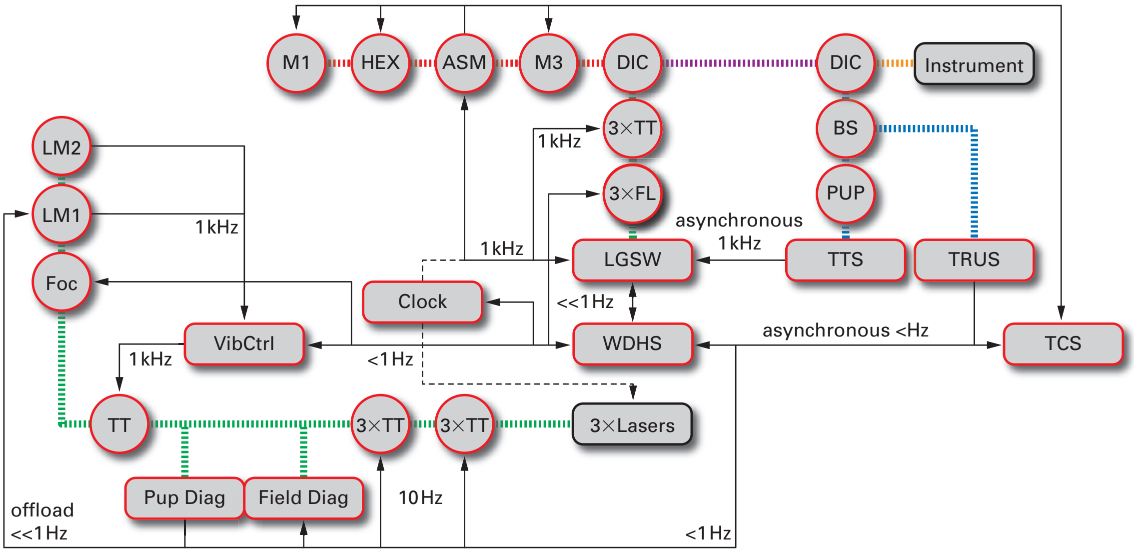


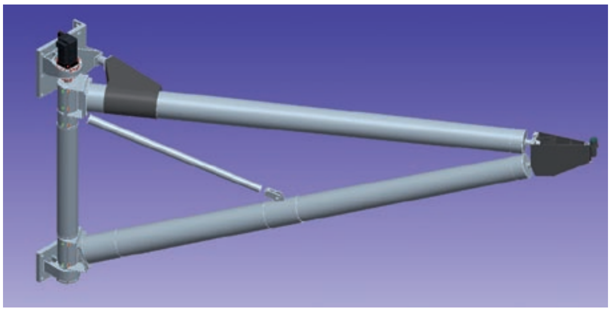
Fig. IV.1.5: Control architecture for ARGOS. Circles are optical elements (M1 – primary, HEX – hexapod, ASM – Adaptive Secondary, M3 – Tertiary, Dic – Dichroic, TT – Tip Tilt mirror, BS – Beam splitter, LM – Launch mirror, PUP – Pickup mirror), while rectangles are control units or other hardware.

been designed and will be implemented by the MPIA.

The schematic diagramm in Fig. IV.1.5 shows the control architecture for ARGOS. The optical path is drawn in ultra fine dashed lines, the control interaction with solid lines and arrows. The clock synchronizes the wave-front sensor (LGSW) and the lasers. This hardwired connection is drawn with a dashed line.

One of the crucial parts to operate an adaptive optic system and to reduce night-time for calibration and testing is an artificial light source. For ARGOS, such a tool is being developed and will be integrated at MPIA. To deploy the source remotely at any time, an additional swing arm is needed and which will be made of carbon fiber. In future, such novel materials will be used much more often in large telescopes to reduce weight and increase stiffness. The company CGB GmbH, collaborating with the MPIA on constructing the swing arm, developed a new technique to be able to build in an industrial and cheap way complex structures in carbon fiber from a 3D model. Astronomical instrumentation will benefit from such development in the future.

Fig. IV.1.6: The ARGOS calibration swing arm, which is built out of carbon fiber parts.



Wolfgang Gässler, Thomas Blümchen, Diethard Peter, José Borelli, Michael Lehmitz.
In collaboration with:
MPI für extraterresrische Physik, Garching, INAF-OAA, Arcetri, University of Arizona, Tucson, Landessternwarte Heidelberg, Astrophysikalisches Institut Potsdam, LBT Observatory.

IV.2 METIS – a Phase-A-Study for the E-ELT

METIS is the Mid-infrared ELT Imager and Spectrograph, the only E-ELT instrument to cover the thermal/mid-infrared wavelength range from 3 – 14 µm. Following an ESO call for proposals in November 2009, an international team of experts presented a phase-A study on observational capabilities and technical feasibility of such an instrument.

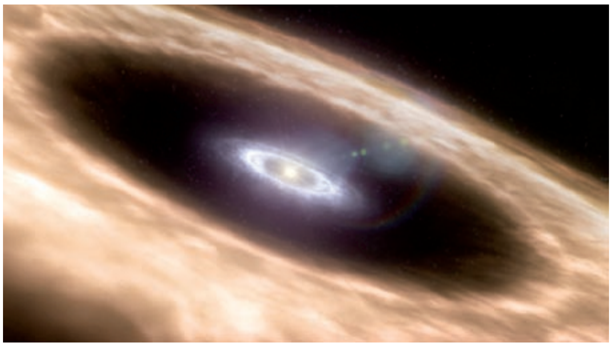
The METIS consortium consists of five partner institutions from Germany, the Netherlands, France, the United Kingdom, and Belgium. The METIS Science Team consists of two members per partner country, and two adjunct members. In addition, about 25 scientists from within Europe, the United States and Australia have contributed to the science case for METIS.

Science case

The E-ELT with its 42 m aperture will open up new perspectives for optical/infrared astronomy. It will not only enable observations of fainter and fainter targets – scaling sensitivity from the VLT to the E-ELT – but also it will allow new kinds of observations that have never been possible before. These new perspectives include the thermal and mid-IR range beyond 2.5 µm wavelength.

The mid-infrared wavelength range is rich in spectral diagnostics, which are complementary to diagnostics found at other wavelengths. It contains emission and absorption lines of virtually all molecules, numerous atoms and ions, and unique solid-state features. One of the main METIS science cases in which the MPIA is especially interested in is the study of protoplanetary disks and exoplanets. The large diversity of exo-planetary systems belongs to the most surprising findings in exoplanet research. The origin of this diversity must lie in the structure and evolution of protoplanetary disks out of which they form.

The exact process that led to the formation of these planets is largely unknown. METIS will allow us to spatially resolve protoplanetary disks in the mid-IR, to search for the footprints of protoplanets, and to perform spectral line imaging and spectro-astrometry. METIS may be able to directly detect the signatures of hot, accreting protoplanets and the dynamical structure of the accretion flow onto the planet. These observations will allow us to



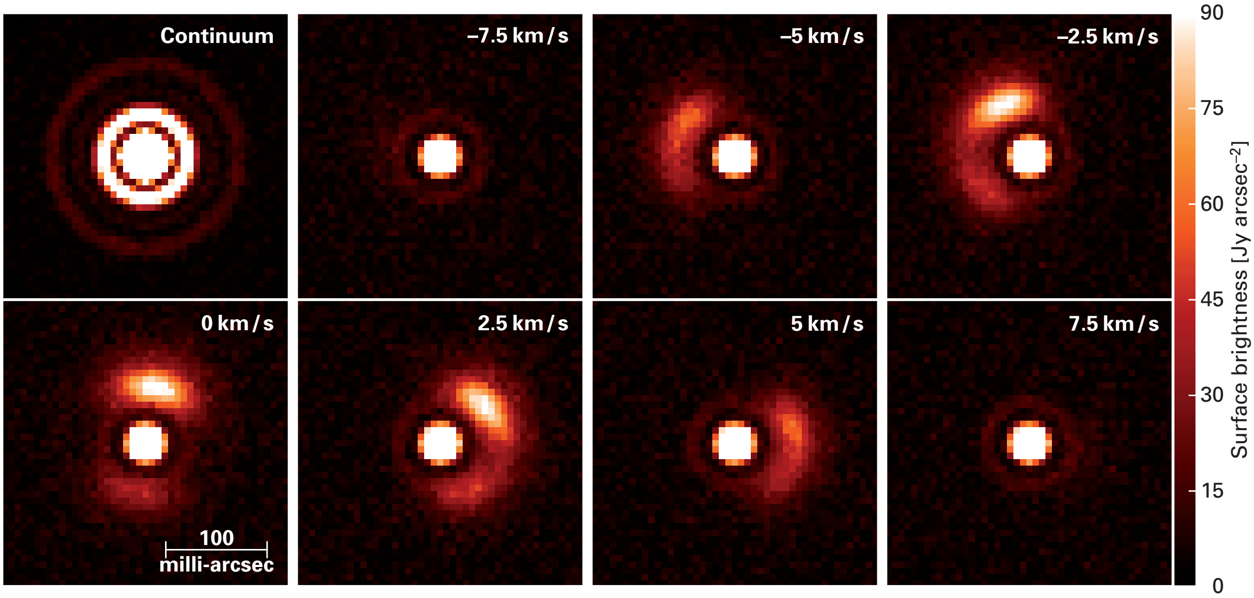


Fig. IV.2.1: *Right* – Artist's impressions of a protoplanetary disk showing planet formation (ESO). *Bottom* – Simulation of a METIS image cube of the CO P(8) line from the protoplanetary disk around the star SR 21 for an assumed distance of 125 pc. (Pontoppidan et al. 2009)

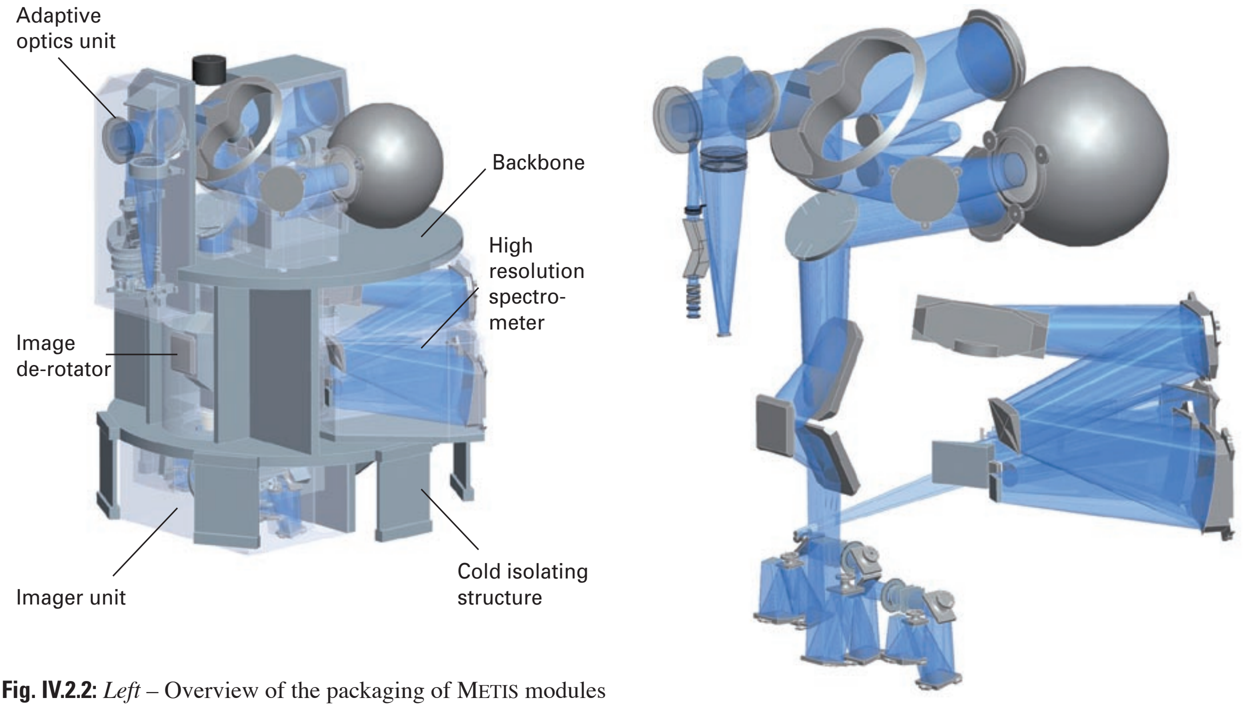


Fig. IV.2.2: *Left* – Overview of the packaging of METIS modules into a common cryostat. *Right* – the optical components and light paths.

target the dominant mechanisms for gas dissipation and the chemical content of the planet-forming regions with a statistically significant sample, and to clarify the role of water and organic molecules, which are of astrobiological interest.

Technical capabilities

METIS will add extremely high spatial and spectral observational capabilities to the existing or planned (JWST) facilities in the mid-infrared wave-length region. The instrument baseline includes the following two main subsystems:

1. A diffraction limited imager in the L/M [2.9 – 5.3 μm], and N band with an approximately $18'' \times 18''$ wide FOV and pixel sizes of 17 mas and 34 mas, respectively. The imager also includes the following observing modes:
   - Coronography in the L and N band
   - Low-resolution ($R \leq 5000$) long slit spectroscopy in the L/M and N band
   - Polarimetry in the N-band.

   Long slit spectroscopy is realized by infrared grisms that can be inserted into the collimated beam. L/M- and N-band imaging is provided in parallel.
2. An integral-field-unit fed high-resolution spectrograph at L/M band. The IFU field of view is about $0\farcs4 \times 1\farcs5$, and the spectral resolution is $R \sim 100\,000$. The small central field of view is picked up near the focal plane; thus, the surrounding field of view can be used in parallel by the imager module.

The deformable mirror of the E-ELT adaptive optics system is part of the telescope itself. However, for mid-infrared applications, a special wave-front sensor is planned that will be part of METIS. This allows on-axis adaptive-optics operation with natural guide stars without adding thermal background due to a warm dichroic mirror.

MPIA is one of the major partners of the METIS project and will be responsible for the mid-infrared imager and the wavefront sensor. As soon as METIS is selected as a first generation instrument for the E-ELT, the METIS team will start developing this exciting observational capability to be prepared to receive first light with a 42 m-telescope in 2018.

Status

The METIS phase-A study ended in December 2009 with a final study review. The subsequent board report acknowledged the very high overall quality of the study, recommending to ESO to consider the goals of the METIS Phase-A study.

Rainer Lenzen, Wolfgang Brandner,
Thomas Henning, Stefan Hippler,
Vianak Naranjo, Ralf-Rainer Rohloff
In collaboration with:
NOVA, Leiden,
Astronomy Technology Centre, Edinburgh,
Katholieke Universiteit Leuven,
CFA Saclay, Paris.

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

The aim of the PANIC project is to build a wide field near infrared camera for Calar Alto. Its field of view is 0.5 × 0.5 degrees at a scale of 0.45 arcsec per pixel at the 2.2 m telescope, ideal for survey-type observations. PANIC can also be used at the 3.5 m telescope with half the field of view and pixel scale, a configuration well suited for observations requiring higher spatial resolution. The spectral range extends from the *z*- to *K*-band. Narrow band filters can also be used. Cold stops reduce the thermal background and increase the efficiency of PANIC in the *K*-band.

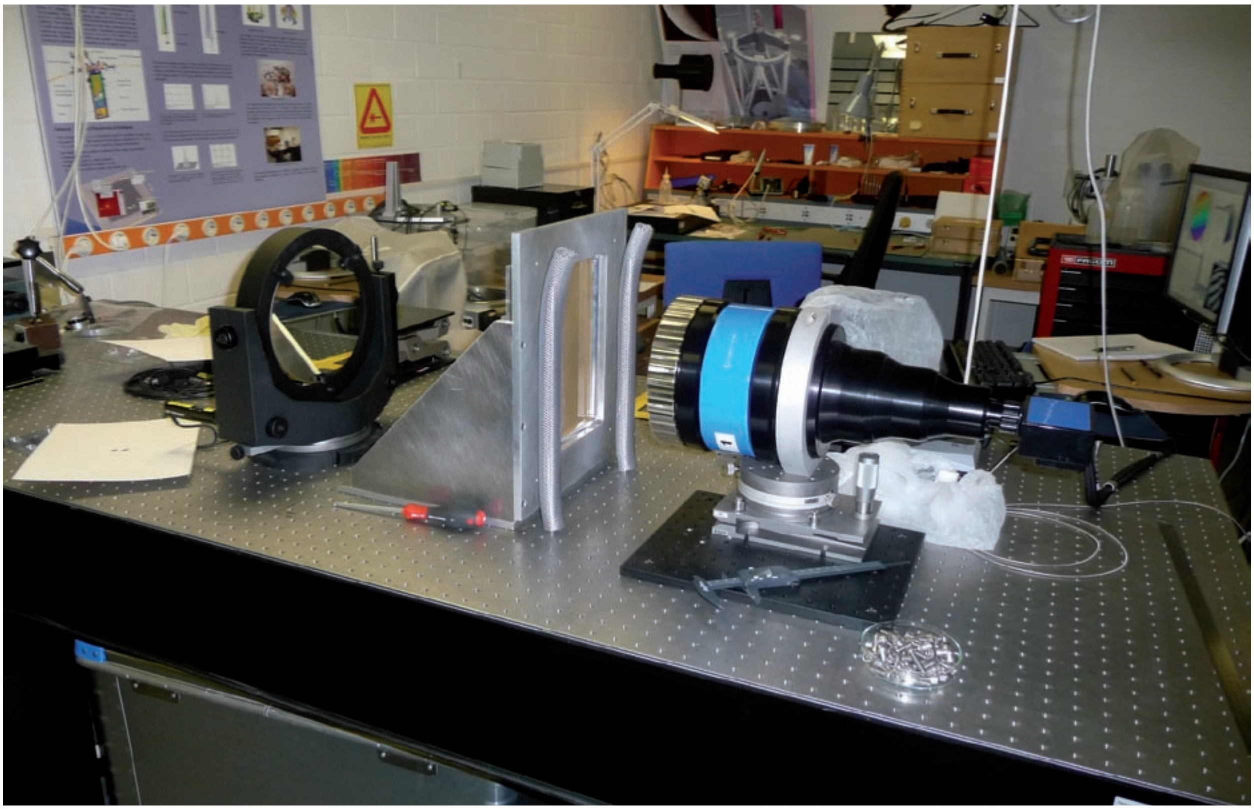
The PANIC team continued to make progress in 2009 in all work packages. The optical design had already been approved at the end of 2008, and after iterations with the manufacturer, the optics were ordered in early 2009. Folding mirrors have been fabricated and were tested interferometrically in our laboratory. These tests also showed that the reflecting surface is not degraded by the mounting of the mirrors. A test set-up appears in Fig. IV.3.1.

After the optical design was fixed, the mechanical design could be finished. Critical design aspects include the total weight limit of 400 kg at the 2.2 m telescope and the tolerances for some optical elements: on the order of 50 microns. Detailed finite element analysis was used to ensure that the mechanics meet these requirements. An example of such simulations is shown in Fig. IV.3.2. The mechanical design was approved in a final design review. The manufacturing of the mechanical parts was started in the mechanical shop. The cryostat and the cold bench were ordered from local industry.

The detector array, which consists of four Hawaii-2RG detectors mounted in a single module, was delivered. All four detectors were individually tested using the recently developed MPIA read-out electronics. These electronics use FPGA technology, which makes them flexible in use, compact and cheap. The test showed that all detectors and the electronics are working. Optimization of the read-out process is a substantial but essential work package, which will extend until the end of the project.

Software for the read-out and for control of the wheels, which hold filters and cold stops, and for the temperature control of the cryostat is a further development of our GEIRS software package. Adaptation of this software to the freely programmable detectors is continuing. This software will also enable guiding by non-

Fig. IV.3.1: Interferometric tests of the mirrors.



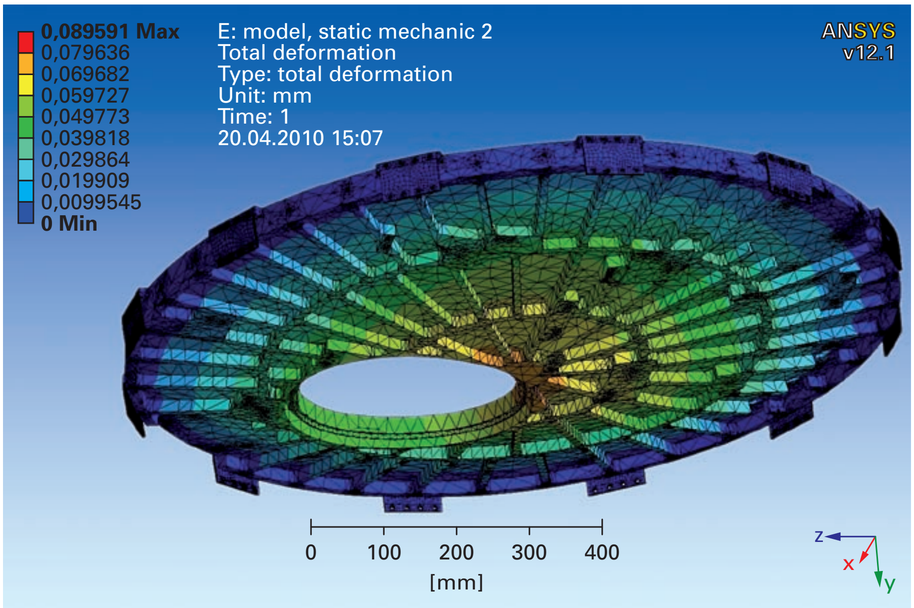


Fig. IV.3.2: Extensive finite element analysis calculations were used to ensure compliance with the tight tolerances on the mechanics.

destructive read-out of a window on one detector. The observer will control PANIC with an observation tool, which ensures easy use. Quick-look-viewers and pipelines for data control and reduction will supply the observer with astrometrically and photometrically calibrated images and object catalogues.

By the end of 2009, all design aspects were fixed and approved in reviews. Manufacturing and assembly of the instrument will start in 2010. First light is expected during 2011.

PANIC is the first joint project between IAA and MPIA, with IAA responsible for optics and software, MPIA for design, mechanics, detectors and electronics.

Josef W. Fried, Ralf-Rainer Rohloff, Harald Baumeister, Armin Huber, Armin Boehm, Karl Wagner, Jose Ricardo Ramos, Matthias Alter, Heiko Ehret, Ulrich Mall, Vianak Naranjo, Werner Laun, Clemens Storz, in collaboration with: IAA, Granada.

IV.4 Special Developments in the Technical Departments

The development of increasingly demanding measuring devices raises continually new technological challenges. In the following, we present some examples of the technological innovations made by engineers and technicians at the MPIA.

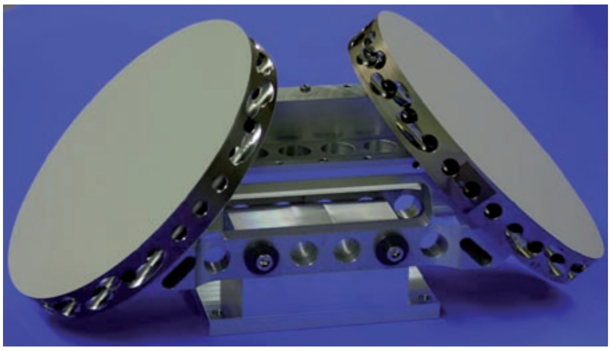


Fig. IV.4.1: Piston mirror for LBT interferometric beam combiner LINC-NIRVANA at the LBT.

Ultra precise metal optics

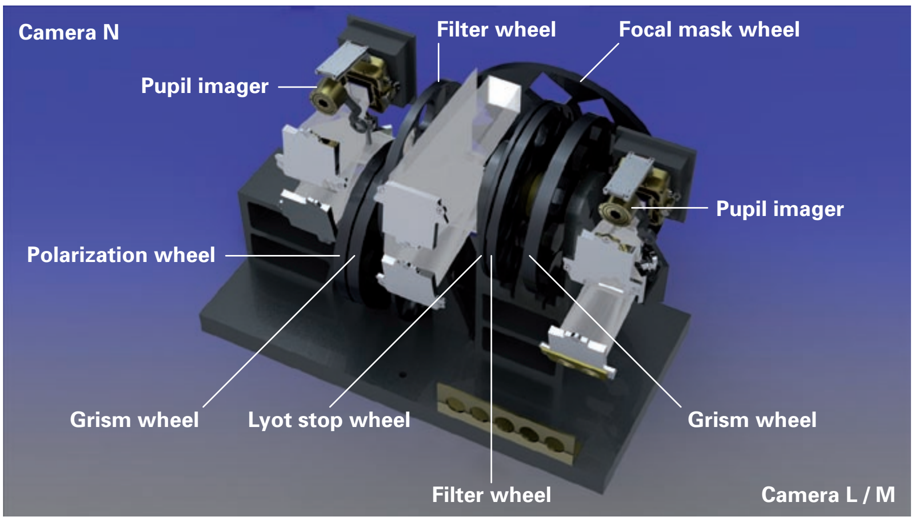
Single-point diamond turning (SPTD) is a common method for the production of metal mirrors, but the form accuracy and surface roughness achieved is insufficient for applications at wavelengths shorter than 5 µm. Polishable coatings are necessary, but due to the combination of two different materials, bi-metallic effects can occur. This report describes a patented method developed by the MPIA Heidelberg in collaboration with the Fraunhofer Institut für Angewandte Optik (IOF) in Jena to overcome this problem.

"Chemical nickel" is an excellent candidate for a polishable coating. However, conventional materials for metal optics such as aluminium either have a considerably higher expansion coefficient than nickel or are very expensive. Therefore, when subjected to temperature fluctuations, the sought-after material should expand and contract in the same manner as the nickel coating. Otherwise, dissimilar expansion behaviour in the materials will warp the mirrors and impair the image quality.

A newly developed silicon-aluminium alloy adapted for expansibility exhibits properties similar to chemical nickel and is also comparatively economical. This alloy also fulfills a second requirement: its relatively high degree of rigidity makes it ideal for manufacturing very stable low-weight structures. The tests conducted thus far confirm the suitability of the material. Combining this alloy with nickel in the so-called piston mirror (see Fig. IV.4.1) for the LBT beam combiner LINC-NIRVANA represents the first such application for an optical component.

SPTD-manufactured metal mirrors are standard optical components in infrared astronomical instruments working at cryogenic temperatures. Instruments like METIS (see Fig. IV.4.2), planned for the European Extremely Large Telescope (E-ELT), require a higher-quality micro-roughness and shape accuracy for the cryogenic mirrors.

Fig. IV.4.2: E-ELT METIS imager module with cryogenic metal mirrors.



Therefore, the MPIA and the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) in Jena decided to expand their studies to cryogenic temperatures. The Max Planck Society and the Fraunhofer Society support this work financially.

Measuring instruments

The first steps in this project were made in sample preparation of both silicon-aluminum and chemical nickel; the latter will be shaped in a cylin-drical way by a novel electro-plated method (IOF Jena). Meanwhile, the following measuring instruments are being commissioned at MPIA to analyze material properties under cryogenic conditions:

Dilatometer

The low-temperature version of the NETZSCH DIL 402 C dilatometer allows measurements of the thermal expansion between –180 °C and room temperature (see Fig. IV.4.3). While this measurement system with a high-resolution displacement transducer offers a maximum degree of accuracy, a completely thermostated housing reduces system drift and thus increases reproducibility and long-term stability. Evacuation and backfilling with inert atmospheres removes any influences of humidity.

Climatic test chamber

The climatic test chamber allows one to observe through an optical window the shape deviations of optical surfaces within a temperature range from –70 °C to room temperature. This is done with a FISBA µPhase 2 HR Compact Interferometer (see Fig. IV.4.4).

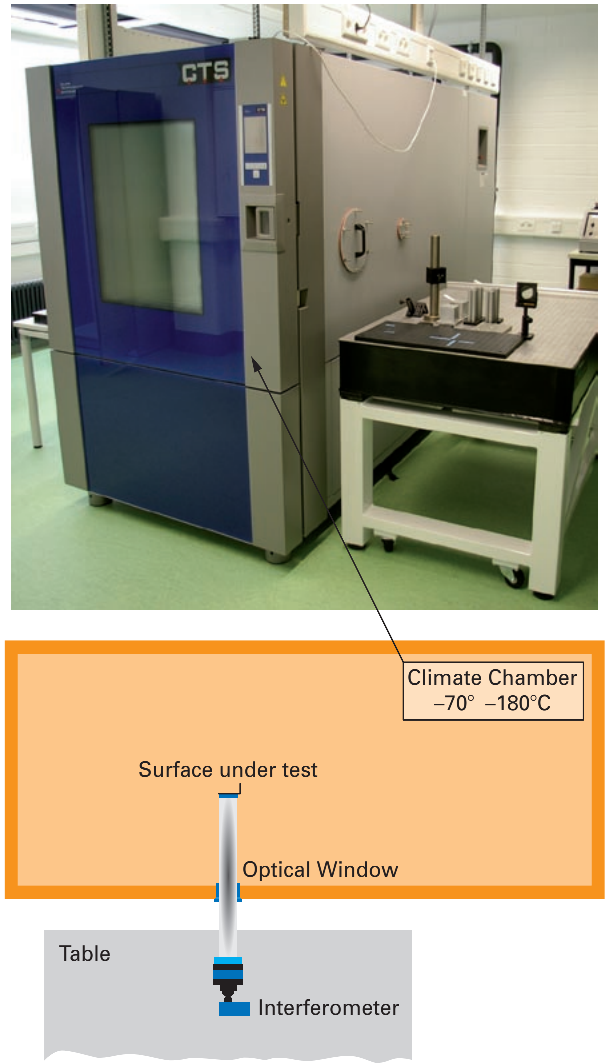
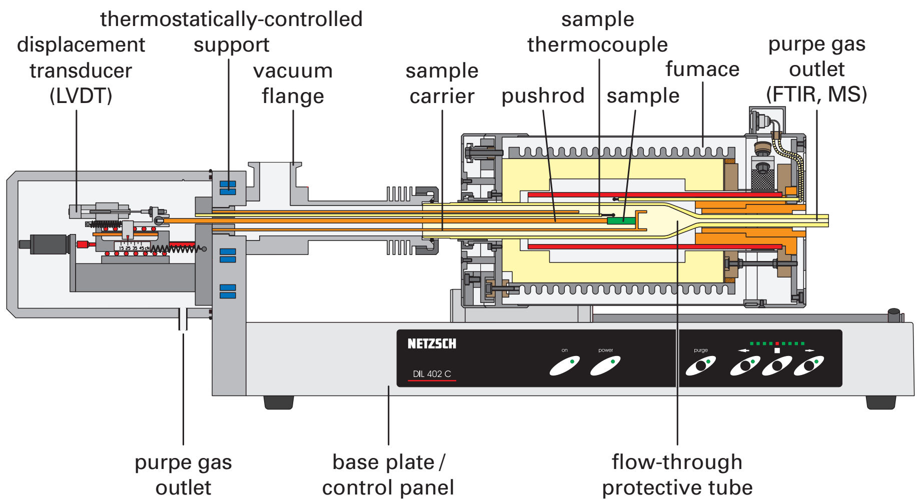


Fig. IV.4.4: Climatic test chamber with interferometer setup through an optical window.

Fig. IV.4.3: The low-temperature dilatometer DIL 402 C.



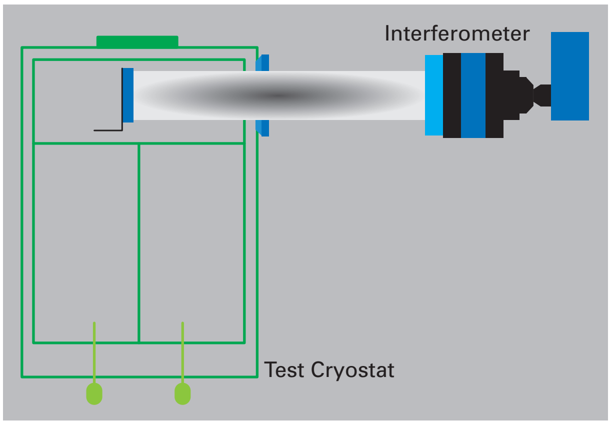


Fig. IV.4.5: Test cryostat (–180°C) with interferometer setup.

Test cryostat

A test cryostat (–180 °C) allows optical characterization of thermally induced strain under cryogenic conditions in vacuum. This test cryostat will be integrated into the FISBA interferometer setup in order to test the thermo-mechanical behavior of the material composites within the scope of cooling cycles (see Fig. IV.4.5).

Ralf-Rainer Rohloff, Veit Schönherr.

Cryo-cooling systems for infrared instrumentation

Most ground-based instruments for IR astronomy are enclosed in vacuum vessels. All optics, detectors and mechanics are hidden in a cryostat to cool them down to cryogenic temperatures. Each instrument has different requirements on the cryostat.

The most important requirements are size and temperature, but mechanical stability, window material etc. also play a role. The design of the cryostat and the choice of the cooling system depend on these requirements. Here we describe some recent solutions.

Cooling with LN_2: the cryostat for PANIC

One of the most common methods to cool an IR instrument is with liquid nitrogen (LN_2). Depending on the shielding, temperatures as low as 77 K at the cold optics and detector can be reached. This is sufficient for most near-infrared instruments. Many observatories supply LN_2 on the mountain and handling this cryogen is quite easy. Nitrogen is not toxic and the liquid needs a lot of energy to evaporate, making it an efficient coolant.

Currently, at the MPIA, we are building a liquid nitrogen cooled cryostat (Fig. IV.4.6) for PANIC, the "PAnoramic Near Infrared Camera" for Calar Alto. The instrument will be mounted at the 2.2 m telescope and has a maximum weight of only 400 kg, including all electronics and the liquid nitrogen. This leaves only 180 kg for the cryostat. To minimize weight, we designed a vacuum vessel with dished ends, which can be made much thinner than conventional flat ends. The optical path is folded three times so that it can be mounted on a round optical bench with a diameter of about 1 m. The bench is cooled by a nitrogen vessel with a shape similar to that of the vacuum vessel. To reduce the torque on the mounting flange, we placed the vessel between the optics and the telescope. Multilayer insulation reflects most of the room temperature heat radiation and therefore reduces the necessary volume of the vessel and its weight. The cryostat also has a separate, small nitrogen vessel to help maintain a constant detector temperature below 80 K. In addition, the detector array will have its own temperature control. As the telescope points to the horizon, the instrument is tilted. Therefore, the filling tubes of the vessels stop at the geometrical center, and they can only be filled half full.

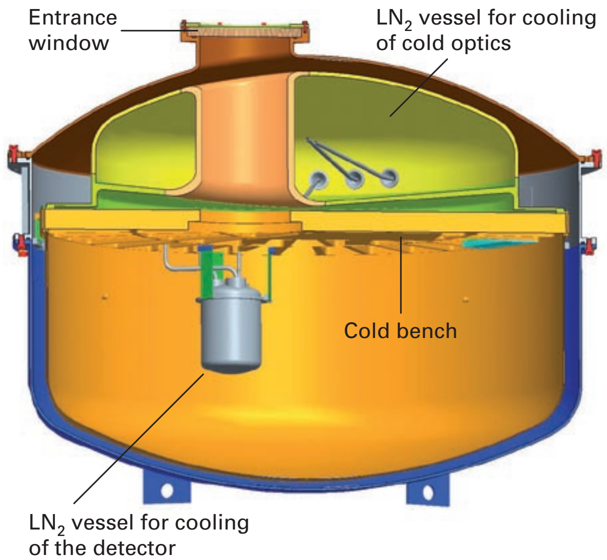


Fig. IV.4.6: Setup of the PANIC cryostat.

All parts of the cryostat were ordered in 2009; after delivery, which is expected in early 2010, they will be integrated and tested at MPIA.

Cooling with closed cycle coolers: the cryostat for LUCIFER

LUCIFER 1 is operating at the LBT since fall 2009. The cryostat of this instrument was built under the responsibility of the MPIA. Two powerful Gifford MacMahon (GM) refrigerators cool the instrument. GM coolers

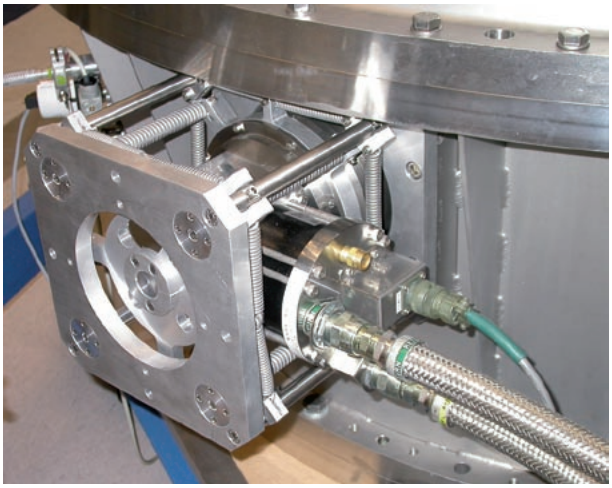


Fig. IV.4.7: One of LUCIFER's GM-coolers in its spring suspension mechanism.

use high-pressure helium supplied by a compressor as a coolant. This helium is expanded at the cold side of the cooler and compressed at the warm side. The big advantage of such a device over LN_2 is that you do not have to refill it with coolant.

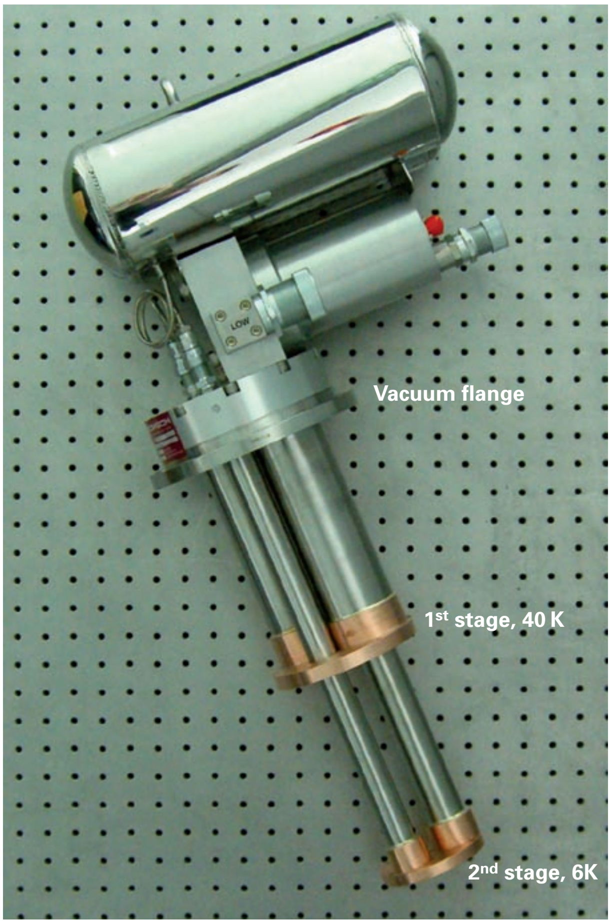
The disadvantage of GM coolers is vibration, which can disturb sensitive optical measurements. The LUCIFER coolers run with a pulse frequency of 1.2 Hz. This frequency dominantes the vibration spectrum. There are also some harmonics of the 1.2 Hz. To damp out these vibrations, the coolers are suspended on springs (Fig. IV.4.7), and the thermal coupling to the cold structure is achieved with flexible copper braids. Furthermore, the coolers are placed on opposite sides of the instrument and run in synchrony to be exactly in phase. This eliminates most of the lowest excitation frequencies. The coolers are not the only source of vibration. The compressor, which supplies the high-pressure helium, is also a source. At the LBT, the helium compressors are placed one level below the telescope in a room built on a different foundation from the telescope. The flexible gas hoses reach about 40 m from the compressor to the instrument. The route passes along the wall of the building, over a loop to the telescope, along the rim of the mirror cell to the instrument platform, and through a cable rotator to LUCIFER.

LUCIFER 2 will be integrated and tested at MPIA in 2010. Its installation at the telescope is foreseen for early 2011.

A combination of cooler and LN_2: the MATISSE cryostat

MPIA was the PI institute for the ESO VLTI instrument MIDI, which operates at mid-IR wavelength. Its successor, MATISSE, is now in the design and test phase. MPIA is responsible for the cooling system. Unlike MIDI, MATISSE will work in the *L* and *M*-bands as well as in the *N*-band. Therefore, we will have two different detectors and two separate cold optics. This requires two separate cryostats with similar geometry, but with different thermal requirements. For the *L* and *M* bands, the cold optics and detector could work at temperatures up to 80 K, for which LN_2 cooling is sufficient. The *N* band needs an optics temperature below 40 K and a detector temperature of about 6 K. This requirement brought us to a cooling concept quite similar to that deveoped for MIDI. To reduce the heat load from the environment to a minimum, a radiation shield cooled by LN_2 encloses the complete optical bench. For MIDI, a GM cooler with a moving displacer was used to cool the cold optics. For MATISSE, a pulse tube (PT) cooler is planned. This type of cooler (Fig. IV.4.8) vibrates less because it does not have a moving displacer. To damp out the remaining vibrations, we adapted an existing damping system to this large cooler. The force introduced by the central bellows under vacuum is compensated by four small bellows, pulling in the opposite direction. This results in a soft moving damper, even under vacuum. Cooling the optics and detector to 40 K and 6 K, respectively, drives

Fig. IV.4.8: The PT-cooler for MATISSE is tested.



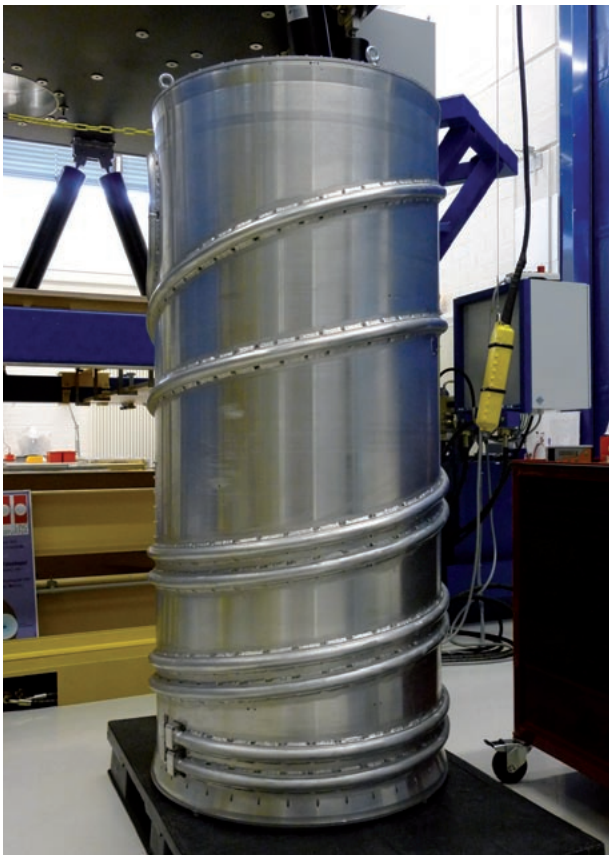
the cooler to its limit. We therefore have to carefully test the cooler performance as well as the efficiency of the thermal coupling.

The MATISSE cooler will be the first PT cooler ever used at the VLT. One cooler is already in house and has been tested by the MPIA and the ESO teams.

Cooling with a coolant loop: the LINC-NIRVANA cryostat

A unique cooling system is used for the LINC-NIRVANA cryostat at the LBT. The cooler recipient will not be mounted to the instrument cryostat. Instead, it will be located far away from the instrument, one level below the telescope platform, like the compressors for LUCIFER. Here, a high capacity industrial Stirling type cooler is used which cools helium gas down below 60 K. Vacuum insulated lines transport the cold gas to the instrument, where it flows through a heat exchanger. The heat exchanger (Fig. IV.4.9) is a large aluminum cylinder with a helium line welded on its out-side surface. The cold optics and the detectors are mounted to the inside of the cylinder. Even though the cryostat is very large, we need only about a quarter of the available cooling power for the cryostat. About the same amount is needed to compensate for the heat loss in the lines. Thus, we have approximately twice the cooling power we need. This extra cooling power allows for rapid initial cooling of LINC-NIRVANA.

Fig. IV.4.9: Heat exchanger of the LINC-NIRVANA cryostat.



The LINC-NIRVANA cooling system and cryostat are now completely integrated at MPIA, together with a pair of test lines. We are currently testing and optimizing the gas flow in the lines to reduce noise and vibration as much as possible.

As far as we know, no such system has ever been used in astronomy. The performance and experience gained from this cooling system will probably be a first step toward cooling systems for the huge cryostats of future instruments.

Werner Laun, Harald Baumeister,
Peter Bizenberger, Armin Huber,
Michael Lehmitz, Ralf-Rainer Rohloff.

Infrared detector systems

The development of infrared detector systems is one of the major technical activities at the MPIA. We have a specialized expertise in infrared detector systems that brings together engineers from different technical departments. This is needed, because infrared detector systems consist of three different key elements: read-out electronics, software, and of course the detectors themselves. Harmony between these components is achieved by a joint optimisation of the entire system.

Read-out electronics and science camera software

The newly developed MPIA read-out electronics (ROE) can handle single or multiple detector systems with up to 144 input channels. They feature high-speed data transfer and low power dissipation, and are simultaneously small and lightweight. This makes them (Fig. IV.4.10) ideal for relatively large focal plane arrays. The first instruments running with the new read-out electronics will be PANIC (the Panoramic Near Infrared Camera) at the 2.2 m telescope on Calar Alto and the LBT beam combiner LINC-NIRVANA.

The new ROE meets special requirements and interface implementations which allow it to realize new capabilities for the currently available IR-detectors. The ROE includes important features such as fast data path verification directly at the instrument and frame data protocol with check-sum embedded into the data flow. It will exploit all the advanced capabilities of the HAWAII-RG-type Teledyne detectors. With the implementation of the requirements by the Infrared Software Interface, the control of the clocking pattern of the detector allows it to react to current needs of astronomical IR-instruments.

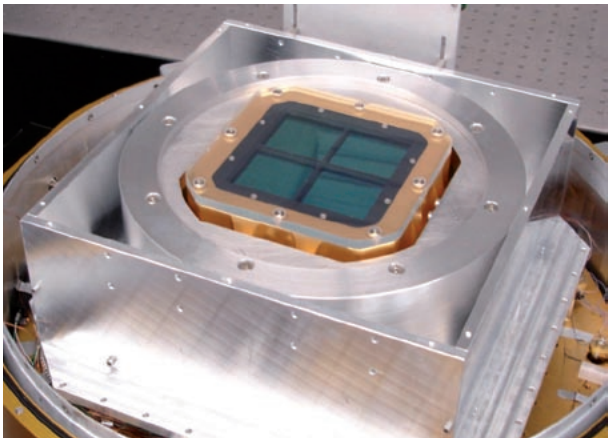


Fig. IV.4.10: The HAWAII-2RG detector mosaic for PANIC,

In order to minimize persistence effects in IR detectors, the new ROE pattern logic offers different idle-clocking patterns and modes, which can be selected and switched on demand according as needed. Idle clocking is automatically done when the detector is not used for some time, thereby prevent saturation of detector pixels by incoming light. New clocking schemes for the HAWAII-1 and -2 detectors of Teledyne, the generation before the RG-types of HAWAII detectors, will also be possible with the new MPIA ROE. Besides MPIA's read-out-modes, which offer almost 100 percent integration efficiency for repeated image cycling, we will also be able to combine this pattern logic to modify other important read-out modes like 'Fowler-Sampling', and thereby increase the detector integration efficiency.

Some advantages of the HAWAII-RGs 'Window Readout Mode' can now be emulated with the new ROE in order to achieve similar capabilities as the RGs available with earlier HAWAII detectors.

Infrared Detector Characterization

An infrared detector cannot operate alone: as a complex unit of a measuring system, it serves as a connection between the readout electronics and the software. The characterization process allows understanding of how the detector works and how it behaves, and it is the key to guarantee the best performance of an instrument during operation.

The MPIA has the ideal equipment and laboratories necessary for efficient detector characterization, together with revolutionary readout electronics and modern software. The measurement of important parameters, such as readout noise, dark current, gain, linearity, sensitivity, etc., are only some of the tasks that the MPIA has been carrying out in this area. Additional tests include the verification of detector functionality and fine-tuning and optimisation. The results of which are reflected in the performance of the instrument.

Ralf Klein, Ulrich Mall,
Vianak Naranjo, José Ricardo Ramos,
Clemens Storz, Karl Wagner.

V People and Events

V.1 MPIA Conferences

In the year under review, numerous meetings and conferences were once again organized by the Institute and its employees. Again, they took place in a number of venues, and not only in MPIA's home city of Heidelberg. This column provides a brief overview of some of the conferences.

In addition to small, yet important workshops about the MPIA's instrumentation projects, there were again larger scientific conferences which always give junior scientists the opportunity to present results and network with other scientists.

IMPRS Summer School

This is especially true for the annual summer school of the International Max Planck Research School for Astronomy and Cosmic Physics at the University of Heidelberg (IMPRS-HD), which was held at the Max Planck House in Heidelberg from August 10th to 14th, 2009 with the topic "Statistical Interferences from Astrophysical Data". Once again, excellent speakers were obtained, with David Hogg (New York University), Ian McHardy (University of Southampton) and William H. Press (University of Texas, Austin). They spoke on issues such as handling large volumes of information, numerical simulations and tackling problematic data sets and had question and answer sessions with the students. These discussions between established scientists and juniors from different fields of research are very valuable for sharing ideas and improving the quality of research. As part of the summer school, the 100-odd participants once again had the opportunity to take part in a special guided tour through the Max Planck Institute for Astronomy.

Fig. V.1.1: The summer school of the International Max-Planck Research School for Astronomy and Cosmic Physics in the Max-Planck-House in Heidelberg.

Fig. V.1.2: PhD students from all over the world are coming to the IMPRS of Heidelberg.

International Conferences

Two international conferences were held at Ringberg Castle, a venue owned by the Max Planck Society overlooking the beautiful lake Tegernsee. November 15th to 18th saw a gathering with the extragalactic theme of "The Gaseous Evolution of Galaxies", at which the discussions among the 35 internationally acclaimed scientists included the observations that will soon be possible using new telescopes (e.g. the extended IRAM Plateau de Bure interferometer, Expanded VLA and ALMA).

Some 40 scientists were invited to a workshop entitled "The Astrophysics of the Magnetorotational Instability and Related Processes" from April 14 to 18. They presented and discussed results and methods of theoretical research into the processes of protoplanetary disks. These processes are essential to the formation of planets, a topic covered by the international conference "Planet formation and Evolution: The Solar System and Extrasolar Planets", held in Tübingen from March 2nd to 6th with about 150 delegates, where much of the discussion and presentation focused on observational results. This conference was jointly organized by Tübingen University's Institute for Astronomy and Astrophysics and the research group of the German Research Foundation (DFG), "The Formation of Planets: The Critical First Growth Phase", in which MPIA is represented.

Other MPIA involvement through our collaboration in scientific committees included "The Second SUBARU International Conference" in Hawaii in March and the ESO/MPS meeting "From Circumstellar Disks to Planetary Systems" held in Garching in November.

MPIA colleagues helped to organize the splinter meeting "The E-ELT – Status, Timeline and Instrumentation" at the fall conference of the Astronomische Gesellschaft (AG) in Potsdam, where the discussion embraced the role of German astronomy in this most ambitious telescope project of all times.

Events at Königstuhl

A special congress was organized along with Heidelberg State Observatory (LSW/ZAH): On the occasion of the retirement of Max Camenzind (LSW) and Hermann-Josef Röser (MPIA), a celebratory scientific symposium was held in the MPIA auditorium on November 26th with prominent speakers who are also colleagues of the retirees. The speakers, who frequently brought entertaining personal anecdotes about Camenzind and Röser into their scientific talks, also included Immo Appenzeller and Rudolf Kippenhahn. Entitled “From Disks to Jets – from Stars to Quasars”, the symposium did justice to the wide scientific field that the retirees had studied both together and separately.

The “Legacy Survey Workshop”, held with staff from the Calar Alto Observatory (CAHA) in the MPIA auditorium on April 24th, had a very specific theme. It was held on the occasion of the annual CAHA colloquium which alternates between Grenada and Heidelberg, and aimed to gather ideas for a Survey using the PMAS/PPAK Integral Field Unit with the 3.5-meter telescope.

The Institute's biennial internal scientific symposium, where students and postdocs in particular from all departments get to present their projects, was held on February 18th. And the “Work and Family”– network held a congress at the Institute on November 12th, attended by representatives of the City of Heidelberg. MPIA is strongly committed to improving the balance between professional careers and family life – an issue of special importance for many scientists.

Finally, the MPIA Board of Trustees paid their annual visit to the Institute on September 18th. This body representing science, industry, politics and the media once again held fruitful discussions about current and future projects of relevance to scientific and media policy.

Klaus Jäger.

V.2 Activities to mark the "Year of Astronomy"

The International Astronomy Union (IAU) had declared the year 2009 to be the »Year of Astronomy«. Institutions around the world – from research institutes to public observatories, from planetariums to amateur clubs – were called upon to carry our fascinating science into the public arena with the aid of events which were to be as manifold and interesting as possible. The MPIA was also strongly committed to this, of course.

In view of the numerous things that the MPIA has been doing for many years in the field of public outreach, the IAU's call in relation to our Institute was a little like the famous saying of "carrying coals to Newcastle". Our annual activities alone, which also focus particularly on motivating pupils, would in themselves have been sufficient to count as an attractive program for the Year of Astronomy.

Examples include the very successful 2009 lecture series "Astronomy on Sunday Morning", the various events for Girls' Day and the professional and academic orientation for pupils at grammar schools (BOGY), the well over 30 guided tours through the Institute, and the numerous popular science talks by MPIA scientists throughout Germany. The Institute also showed a strong presence in the media with numerous press releases, interviews, and TV appearances.

Nevertheless, these public outreach activities, which have been continuously expanded over the years, experienced even further growth in 2009: on the one hand, of course, due to the motivation provided by the Year of Astronomy and, on the other, mainly by the increase in activities centered on the "Haus der Astronomie" (literally House of Astronomy, HdA). After the program and the financial and political basis for this unique institution had been laid over several years, 2009 saw not only the start of the actual construction work with the groundbreaking ceremony on the grounds of the MPIA; the core staff was also able to start work (details can be found in Chapter V.3). The new team went to work immediately providing support for the organization of the Open Day, whose success, and the success of so many of the Institute's events, was again only made possible by the high level of dedication of all the staff. It is exactly this commitment that will be a pillar for the HdA, as well in the future, and it was a significant, convincing argument at the political level that the projects of the HdA can be carried out without having to create a huge amount of new positions.

Open Day

The Open Day on May 17 was beyond doubt the highlight of our public events. Thousands of visitors again thronged to the Königstuhl mountain under perfect skies to gain an insight into the research and instrumentation projects at the MPIA, and to obtain an impression of the varied activities at the Institute. Outside and inside, almost all areas were open to visitors, and Institute staff were available to answer visitors' questions at a total of 31 stations.

Fig. V.2.1: Stream of visitors in front of the main entrance to the MPIA on Open Day.

The guests were thus able to learn how and under which conditions modern observatories, such as the Very Large Telescope (VLT) and Large Binocular Telescope (LBT), use adaptive optics and interferometry to surpass the image quality of a space telescope, on the one hand, and on the other, why new space telescopes, such as Herschel and JWST, are nevertheless necessary. They were able to see how great the technical challenges were that had to be met in order to successfully construct cameras and spectrographs for modern telescopes. And of course the visitors were also able to directly experience what and how the astronomers at the observatories actually observe and which scientific issues are behind this. With the aid of a video conference it was possible to watch live the work of the observers in the control room of the Large Binocular Telescope on Mount Graham in distant Arizona, or experience how a modern telescope records data at the Institute's own 70-cm telescope.

As on earlier Open Days, a special children's program was offered in order to provide the youngest visitors with basic knowledge on astronomy in a playful way. In addition to all the demonstrations and experiments – many of them hands-on – there was a non-stop lecture program that was offered in three lecture halls in parallel. There were also presentations in English for the first time. Our neighbour institute on the Königstuhl, the State Observatory (Landessternwarte), was also involved and offered guided tours of their historical telescopes, for example. And, finally, we also made sure that our guests did not go hungry.

Visit by the Mayor and the City Council

Immediately after Open Day, Heidelberg's Mayor Dr. Eckart Würzner, accompanied by the City Council, visited the MPIA at the invitation of the Institute Management for a talk and special guided tour of the laboratories. Due to the good relationship between the City of Heidelberg and the MPIA, the idea of establishing a Haus der Astronomie on the Königstuhl also found support from the very beginning by the Mayor, who had always shown great interest in the activities of the Institute even during earlier events on the Königstuhl. The guided tour on May 19, 2009 offered a pleasant opportunity for those members of the Council who had so far not been at the Institute to become more familiar with the activities on the mountain.

Supra-institutional public outreach

The Year of Astronomy also provided the opportunity for two "supra-institutional public outreach" events. The first was the series "Seven views of the cosmos – astronomy at the Max Planck Society" in which seven Max Planck institutes involved in astronomy (for Astronomy, Astrophysics, Extraterrestrial Research, Gravitational Physics, Nuclear Physics, Radioastronomy and Solar System Research) each introduced themselves by means of a comprehensive article on a current research topic. The articles were initially published in the regular monthly issues of the magazine "Sterne und Weltraum" and then collated into a special issue. This was accompanied by the corresponding teaching material to deal with these topics in class which was developed for "Wissenschaft in die Schulen!" (Science into schools!). This material was initially available for free in the Internet and then published as a special issue. The special issue was designed for graduating seniors who faced the choice of their field of study at university, and is used by the seven institutes as part of their public relations work for schools.

Fig. V.2.2: The Heidelberg City Council in the Institute's laboratories. Left in the foreground Mayor Dr. Eckart Würzner (see also interview on Page 118).

Fig. V.2.3: These two special issues were published for the Year of Astronomy and represented the fruits of the "supra-institutional public outreach work".

The nine-part series "Galileo and the others. Background to a Revolution in Astronomy" was produced in close cooperation with the Max Planck Institute for the History of Science in Berlin, where this topic is an important research focus. This series also appeared in the Year of Astronomy as a special issue and achieved a wide circulation.

Activities outside the Institute

The Heidelberg activities, which were designed specifically for the Year of Astronomy, started back in October 2008 with the lecture series "Galileis erster Blick durchs Fernrohr und die Folgen heute" (Galileo's first look through the telescope and the consequences for today), which was organized jointly by the University and the MPIA as part of the General Studies program. This event, which continued into February 2009 and enjoyed large public appeal, thus started three months before the ceremonial opening event in Berlin, which the Institute supported in terms of funding and content.

Other external events were also used and supported by the Institute as part of the Year of Astronomy. These included the exhibition "Himmlisches in Büchern" (The sky in books) by the Center for Astronomy in the library of the University of Heidelberg, for example, which continued into 2010, and also the involvement with the Science Express, the exhibition train of the Max Planck Society and the Ministry for Education and Research. When the train stopped in Heidelberg for three days in October 2009, the MPIA organized an accompanying evening with lectures in the new University auditorium on the topic of Extrasolar Planets and the Herschel Space Telescope.

The activities of the MPIA during the Year of Astronomy, which are described in summary here (for further examples see Chapter V.3), showed that public interest in the exploration of space is still strong. Although the Institute had organized numerous events in the years before as well, at no time did it have the impression that the public's interest would diminish in the face of the greatly enhanced offer. On the contrary. And this means that the successful start of the Haus der Astronomie on the campus of the MPIA is taking place under a lucky star.

Klaus Jäger, Jakob Staude, Markus Pössel.

V.3 Haus der Astronomie
Heidelberg's Center for Astronomy Education and Outreach

On December 10, 2008, plans for the creation of the "Haus der Astronomie" (literally "House of Astronomy"), a new Center for Astronomy Education and Outreach, had been announced at a press conference at the headquarters of the Klaus Tschira Foundation. On October 13, 2009, a ceremonial groundbreaking ceremony signalled the start of construction. The core team of the Center has been taking shape throughout 2009, and the Center has gone public with its first activities.

On January 1, 2009, the Center's head, Markus Pössel, took up his job. Pössel came to Heidelberg from New York, where he had served as Senior Science Advisor to the World Science Festival, and he has a strong record of previous work as an outreach scientist for the Max Planck Institute for Gravitational Physics in Potsdam – notably during the Einstein year 2005. In spring, Cecilia Scorza joined the team: Co-founder of the organization Astronomieschule e.V. at Heidelberg Observatory and an outreach scientist for the Deutsche Sofia Institute (DSI) Stuttgart, Scorza is a highly experienced outreach astronomer specializing in outreach to a younger audience, including children.

In December, Olaf Fischer took up a permanent position at the HdA. This position was created at the Stiftung Jugend & Wissenschaft ("Foundation Youth and Science") and seconded to the HdA by the City of Heidelberg as the city's main contribution to the project. Fischer, a specialist in physics and astronomy education who gained his "Habilitation" degree (the peculiarly German qualification for teaching at a university) in Jena, is the long-term leader of the "Wissenschaft in die

Fig. V.3.1: Virtual view towards the Haus der Astronomie from the North. The "central bulge" houses the lecture hall with the dome for the digital projection tilted to the East. The spiral arms are hosting on the ground floor of the entrance hall with ample room for exhibitions (*right part*) and seminar rooms (*left part*). The offices are located in the first floor of the spiral arms (Bernhardt & Partner).

Schulen!" (WiS!, literally "Science into the schools!") project. In close cooperation with our "resident astronomy magazine" *Sterne und Weltraum*, this project has been providing classroom-ready material dealing with cutting-edge astronomical research since 2004. WiS! is going to be a key HdA offering for secondary school students and teachers.

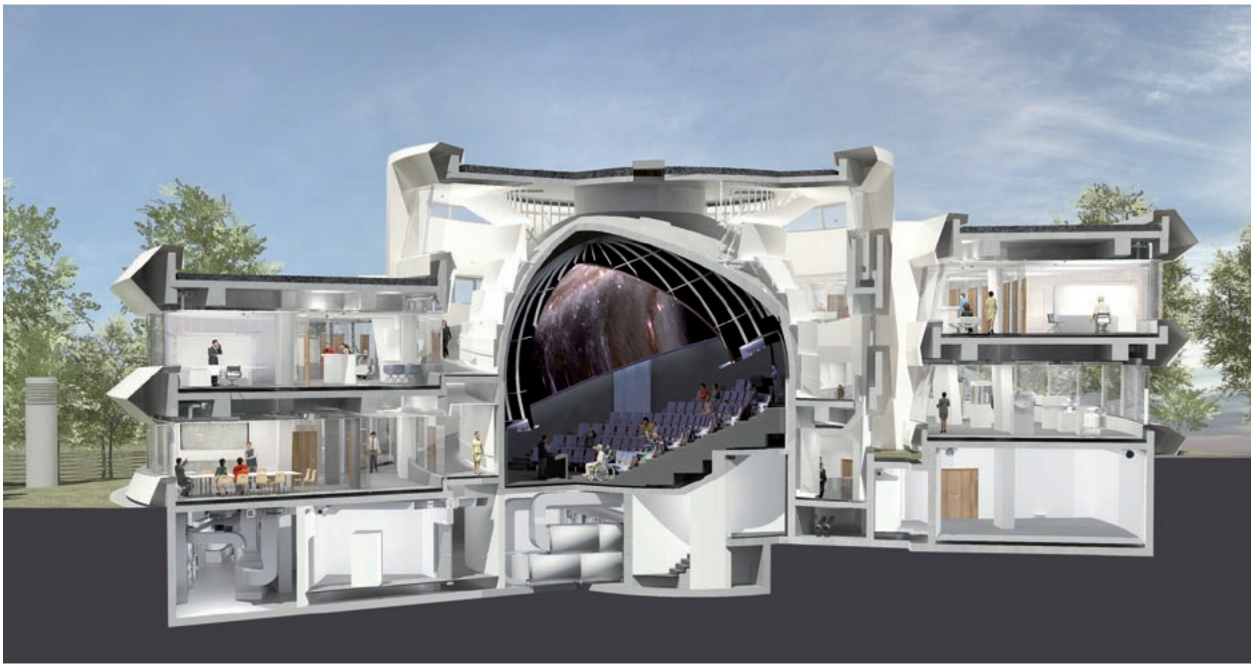
By the close of 2009, another HdA staff position had been established. This position, part of Heidelberg University's Center for Astronomy and seconded to the HdA, is initially financed by the Klaus Tschira Foundation and Baden-Württemberg's ministry for science and research. It has been filled by Carolin Liefke, who had just finished her PhD work in astronomy in Hamburg, but had already worked with high-school students and has extensive experience with small telescopes of the kind the HdA will use for public observations. Together with Jakob Staude, who developed key parts of the HdA concept, the HdA now has a core team of five staff members. In its work of building the HdA, this core team is ably supported by MPIA staff, notably by MPIA director Thomas Henning, MPIA's scientific coordinator Klaus Jäger, its chief of administration, Mathias Voss, and Frank Witzel as representative of the institute's technical services department.

Thus staffed, the HdA has started its outreach work in earnest. True to its mission to build on existing Heidelberg outreach activities, the HdA contributed to MPIA's Girls' Day and its series popular Sunday astronomy talks, and organized activities for children at the MPIA's Open Day in May. On June 13 – 17, the HdA participated in *Explore Science*, a yearly educational event celebrating natural science in Mannheim's Luisenpark, organized and produced by the Klaus Tschira Foundation.

In addition, the center developed new formats, which are to form an integral part of future HdA activities: As part of the International Year of Astronomy (IYA), the center contributed to the "Kepler Days", a three-day program for the general public, with a particular focus on families, high-school students, and teachers, which included talks, workshops and a cultural program. In October, the HdA presented an astronomy exhibition at Frankfurt's international book fair. During the "Week of school astronomy" in November, part of Germany's nationwide activities for the IYA, the HdA both organized a teacher's workshop on "Astronomy: Teaching meets cutting-edge research", in cooperation with the state of Baden-Württemberg's department of education, and hosted that year's workshop for the teacher network of the German SOFIA Institute (DSI).

While a number of activities are up and running, HdA work is definitely set for further expansion. Throughout 2009, behind-the-scenes work included developing audio/video production and visualization projects, both test developments and productions that are slated for publication/public use at a later date. In addition, the HdA took major steps towards the acquisition of crucial tools for the center's future work. In this respect, the undoubted highlights were MPIA's acquisition of a new 50 cm telescope for the Western Dome of the Elsässer laboratory, which is to be the main instrument for future public observation events on the Königstuhl. For observations with high-school students, the HdA successfully applied for a major grant from the W. E. Heraeus Foun-

Fig. V.3.2: Sectional view from the North (east-west cut) of the Haus der Astronomie. Housing technology and laboratories are located in the basement (Bernhardt & Partner).



dation, which has paid for 15 4-inch telescopes, including equipment for solar observations and simple spectroscopic measurement.

For an institution like the HdA, networking with other key actors in the astronomy outreach/education scene is essential. To this end, the HdA presented itself at conferences such as the AG Meeting in Potsdam, the "astronomy" meeting dedicated to astronomy and the new media in Leiden, the "Conference on the Inspiration of Astronomical Phenomena" (INSAP VI) in Venice, the Baden-Württemberg Science Academy in Adelsheim, and at a poster session of the IAU's general assembly in Rio de Janeiro. Also, 2009 saw the start of heightened cooperation with one of the world's prime astronomical institutions: The HdA is now the German node of the *Eso Science Outreach Network*, that is the German node for the outreach activities of the European Southern Observatory.

Naturally, a major focus point of HdA development has been the center's trademark, galaxy-shaped future home. For the building, most of 2009 saw the intense participation of the HdA team in putting the final touches to the construction plans – from the presentation of an exhibition concept for the foyer to the requirements for the digital planetarium to making sure that the building's workshop rooms and multimedia facilities are optimally laid out for the intended use. October 13, 2009 marked the beginning of the construction phase, with a festive groundbreaking ceremony attended by, among others, Heidelberg's mayor Dr. Eckart Würzner, representatives of the Klaus Tschira Foundation, the University and the Max Planck Society. Construction work has been progressing swiftly, and the Königstuhl featured a large, galaxy-shaped construction pit by the end of the year. The tangible changes on the Königstuhl and the new activities leave little room for doubt: the "Haus der Astronomie" has become reality!

Markus Pössel, Jakob Staude,
Olaf Fischer, Carolin Liefke, Cecilia Scorza,
Thomas Henning, Klaus Jäger,
Mathias Voss, Frank Witzel.

V.4 Prizes and Awards

As in previous years, 2009 saw the awarding of a number of prizes and fellowships to scientists at the MPIA. They again included the Otto Hahn Medal.

Otto Hahn Medal for Dominik A. Riechers

The Max Planck Society awards the Otto Hahn Medal every year to up to 40 young scientists for their outstanding research work. The awarding of the Medal, which was established in 1978, is intended to motivate particularly talented young scientists to continue their university or research work. The award, which also has a monetary component, is traditionally presented at the Annual Meeting of the Max Planck Society, which in 2009 took place from June 16 to 19 in Mainz.

The MPIA's *Dominik A. Riechers*, whose doctoral thesis made a significant contribution to extra-galactic research, was one of this year's recipients of the honor. In his thesis entitled "The Molecular Interstellar Medium of Quasar Host Galaxies in the Early Universe" he investigated the properties of molecular gas and its mass distribution in those galaxies which already possessed extremely massive black holes in the infant phase of the universe. Molecular gas is the matter from which the stars are formed – its investigation in these quasar host galaxies (QSO hosts) is therefore crucial for our understanding of how young galaxies developed in the early universe. However, such investigations are also very difficult as quasars are extremely distant (spatial resolution!) and the active nucleus also outshines the host galaxy in many wavelength ranges (contrast!). Dominik Riechers used observations in the radio and millimeter region to carry out a detailed study of some of the most important properties of the molecular interstellar medium in the quasars. He was able to measure high-resolution spectra of the CO($J = 1 \rightarrow 0$) line for the first time to determine the total mass of the molecular gas at this high redshift and, with further observations, double the number of the molecules known to have existed in the early universe. All these data provided intrinsically consistent star formation rates in the quasars and (together with two other studies) found a higher star formation efficiency than in other galaxies. This is probably owed to a higher average gas density in these objects. Using complex interferometric measurements, it was possible for the first time to spatially and dynamically resolve QSO host galaxies at $z > 4$ and to detect substantial structures in the molecular clouds, as well as to determine dynamic masses in order to investigate the known relation between the mass of the black hole and the mass of the bulge, as it is known from the local universe.

Fig. V.4.1: Domink A. Riechers

Patzer Prize for Min Fang, Aday Robaina and Adam Leroy

The Ernst Patzer Prize is also intended to support junior scientists. It was donated by the art-lover and philosopher Ernst Patzer and established by his widow.

The Foundation wishes to support science and research particularly in the field of astronomy and awards its prizes to young researchers at the MPIA and other institutes in Heidelberg. The prizes are presented annually for the best publications produced in the course of doctoral studies or in the postdoc phase, and have been published in a refereed journal. A selection committee comprising two MPIA scientists and one external scientist from Heidelberg decides who is to receive the awards.

This year, the awards were presented to two doctoral students, Min Fang and Aday Robaina, and the postdoc fellowship holder Adam Leroy.

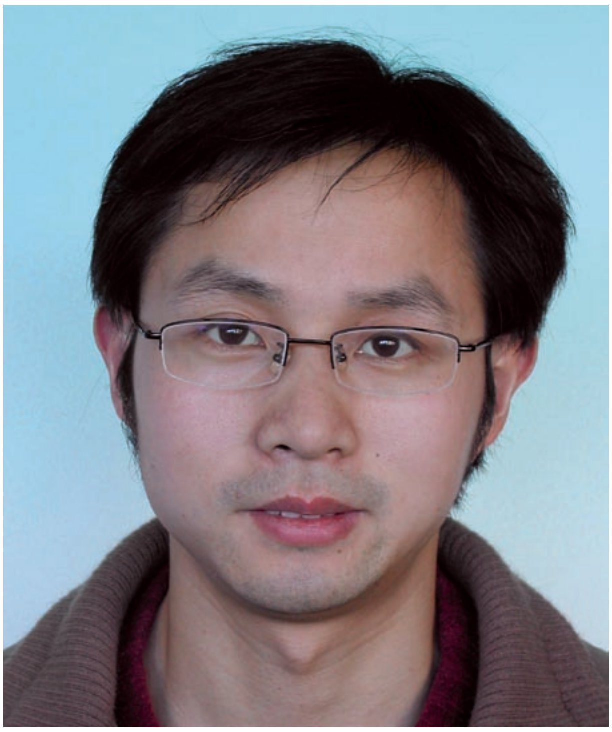


Fig. V.4.2: Min Fang

Fig. V.4.3: Aday Robaina

Min Fang was honored for his publication "Star and protoplanetary disk properties in Orion's suburbs" (published in Astronomy & Astrophysics 504, No2, 461). This publication investigates the development of circumstellar accretion disks by means of a large spectroscopic and photographic survey of young stars in Orion. VLT/VIMOS spectra, optical imaging and the combination with 2MASS, SPITZER IRAC, and MIPS data were used to determine spectral energy distributions between 0.4 and 24 µm, to calculate atmospheric models, and to determine masses and ages, as well as line widths and accretion rates. In addition to the discovery of a large number of new stars with "transition disks" (i.e. protoplanetary disks in an advanced phase of evolution) he was able to show that the proportion of stars with transition disks that exhibit significant accretion activity is relatively small compared to stars with optically thick disks, but that similar accretion rates exist. Furthermore, through his investigation he was able to more or less exclude gravitational interactions between the disks and twin stars, or gravitational instabilities as the mechanism for the formation of transition disks, and show that the lifetime of disks in cluster environments is shorter than in the field.

Aday Robaina received his prize for the publication entitled "Less than 10 percent of star formation in $z \sim 0.6$ massive galaxies is triggered by major interactions". This was published in Astrophysical Journal 704 (2009), p. 324 and concerns the effect of interaction or even merging events of large, gas-rich galaxies on the star formation activity of these galaxies and, in particular, the significance of such events for the average rate of star formation in the universe. He used photometric redshifts, masses, star formation rates and HST-based morphological studies to investigate the increase in the star formation rate as a function of the separation of galaxies in the redshift range $0.4 < z < 0.8$. As was to be expected, the interacting or merging galaxies exhibited the highest star formation. The rate exceeds that of non-interacting galaxies by only a factor of 1.8, however, in good agreement with hydrodynamic simulations of gravitational interactions, which predict strong but short-lived bursts of star formation. Averaged over the whole interaction period the values are also rather moderate here, too. The contribution of such strong interactions to the overall star formation at $0.4 < z < 0.8$ amounts to only 10 percent. Such events have therefore not really been important for the formation of the total stellar mass since $z = 1$ – a surprising result and one which is important for our understanding of the cosmological evolution of the galaxies.

Finally, *Adam Leroy* received the prize for his publication in the Astronomical Journal 136, p. 2782, “The star formation efficiency in nearby galaxies: Measuring where gas forms stars effectively”. In his paper he determines the star formation efficiency and the star formation rate in 23 nearby galaxies and compares these values with the predictions resulting from known physical laws. He uses charts of the neutral, atomic hydrogen from data of the HI Nearby Galaxy Survey (THINGS), on the one hand, and charts of molecular hydrogen which originate from the HERA CO-Line Extragalactic Survey and the Berkeley-Illinois-Maryland Association Survey of Nearby Galaxies, on the other.

Abb. V.4.4: Adam Leroy

The star formation rate was determined by combining charts of the Galaxy Evolution Explorer (GALEX) in the far UV, charts from the SPITZER Infrared Nearby Galaxies Survey (SINGS) at 24 μm, star density profiles from the SINGS Survey at 3.6 μm, as well as kinematic data from the THINGS Survey. Free-fall times, gas pressure and stability examinations of gas disks were included in the determination of the star formation efficiency. For H_2 alone, the star formation efficiency was measured as almost constant in spiral galaxies (at a spatial resolution of around 800 parsec). Where the interstellar matter consists mainly of HI, however, a decline in the star formation efficiency with increasing distance from the center could be determined. This result applies to spiral galaxies and also to dwarf galaxies, and enables the conclusion to be drawn that the formation of large molecular clouds depends greatly on the environment. Furthermore, the ratio of molecular to atomic gas seems to be subject to a »soft« dependence on the radius, the star density and the pressure, and the radius-dependent decline in the star formation efficiency is too strong to be explained by free-fall times or orbits alone. Moreover, the disks of the galaxies are relatively stable on larger scales and thus there is no simple link between large-scale instabilities and the decline in the star formation efficiency.

Fellowships for MPIA scientists

MPIA scientists were again successful in gaining special research fellowships.

Christoph Mordasini received a two-year Humboldt research fellowship for postdocs, while Viki Joergens was awarded a Margarete-von-Wrangell fellowship for postdoctoral lecturing qualification from the Federal State Ministry for Science, Research and the Arts, Baden-Württemberg. Furthermore, Jörg-Uwe Pott was awarded a research fellowship of US$ 13 000 by NASA for an observational project with the Keck telescope.

Klaus Jäger.

V.5 Astronomical developments in the Max Planck Society

Reminiscences of Reimar Lüst

Professor Lüst has promoted astronomy most effectively within the Max Planck Society. On the occasion of the 40th anniversary of work starting at the MPIA on January 1, 1969 we asked him about the events at that time and their consequences today.

Question: *Prof. Lüst, seven Max Planck Institutes are now dedicated to the exploration of the universe, using all conceivable kinds of experimental and theoretical methods – from the MPI for Solar System Research, which explores the surface of Mars with robots, for example, the MPIs for Astronomy, Astrophysics, Radio Astronomy, Extraterrestrial Physics and the Astroparticle Physics Department at the MPI for Nuclear Physics, through to the MPI for Gravitational Physics, which is about to achieve the first direct detection of cosmic gravitational waves. How do you feel about the situation nowadays?*

Reimar Lüst: I think it's great. In reality they are even eight Institutes, because the MPI for Physics in Munich conducts particle physics beyond the standard model, searches for dark matter or investigates very high energy gamma rays – all this is also quite crucial for astrophysical issues. No-one could have foreseen at the outset that astronomy would achieve such an important position in the Max Planck Society. In the very beginning it was the vision of Werner Heisenberg who, in 1947 as the Director of the Göttingen MPI for Physics, appointed Ludwig Biermann after his release from prisoner-of-war camp as the Head of a new department at his institute which was to focus on astrophysics. I think this was the starting point of astronomy at the MPG – although there had been efforts before the Second World War to establish a Kaiser Wilhelm Institute for Astronomy.

The starting point was initially the addition of an astrophysics department, then headed by Ludwig Biermann, to the MPI for Physics, and the relocation of the Institute to Munich. It was recognized that astrophysics would become a Sub-Institute, and thus Biermann became Co-Director with Heisenberg, and the Institute was called the "Max Planck Institute for Physics and Astrophysics". In 1963 a further Sub-Institute was founded from the main Institute, i.e. for extraterrestrial physics, which I was allowed to head. And in the next stages, which soon included the foundation of the MPI for Astronomy, I was personally involved to some extent.

In 1983 on the occasion of your 60th birthday, Hans Elsässer, the Founding Director of our Institute, described in a short text entitled "*Astronomical Recollections*" *and published in Sterne und Weltraum (Stars and Space) the first promising discussion with Adolf Butenandt, the then President of the Max Planck Society, in May 1964: You were instrumental in helping Elsässer to have this discussion and accompanied him to visit Butenandt?*

RL: Yes. Soon after his appointment as Director at the Landessternwarte (State Observatory) in Heidelberg, in 1962 Elsässer was involved by the Council of German Observatories in the efforts to establish an astronomical observatory in the Southern hemisphere. Initially he put out feelers to the Federal Ministry of the Interior. But there were soon discussions as to whether it was allowed to become active in this direction at all, because it was not really responsible for research. Elsässer then turned to me to see whether I couldn't arrange a discussion with Butenandt. This led to the discussion in the Munich Residenz, where the President of the MPG then resided.

But shortly before there had also been a meeting of the Council of German Observatories, where the subject was radio astronomy. The discussions had been very heated: The astronomers were actually against a central MPI for radio astronomy, and also against an MPI for optical astronomy. They were afraid that the Max Planck Institutes would draw the good scientists away from the universities. It was mainly because there was such dispute over radio astronomy that Butenandt proposed during the visit of Elsässer's and myself that the Science Council should comment.

The Science Council "*had the task of drawing up recommendations on how the content and structure of universities, science and research should develop, and advising Federal Government and Federal States on these issues*"*. You were then a member of this commission?*

RL: Yes, I had been a member of the Science Council since 1965. And so in May 1966 I became Chairman of a small working group to draw up a letter of recommendation in respect of the foundation of two Max Planck institutes, one for radio astronomy and one for optical astronomy. Apart from the government representatives and myself, this working group included the astronomers Bengt Strömgren from Copenhagen, Jan Oort from Leiden and Otto Heckmann from Hamburg, the Director of Eso since its foundation in 1962.

Initially the focus was on radio astronomy. There were discussions with Sebastian von Hoerner, Heinrich Siedentopf's successor to the Tübingen chair of astronomy. He wanted to build a large radio telescope, for which the VW Foundation had already promised its support. Mr. von Hoerner proposed that this should occur within the framework of a new Max Planck Institute for Radio Astronomy in Tübingen.

Otto Hachenberg at the astronomical institute in Bonn had developed similar plans. It was therefore initially decided to establish an Max Planck Institute for Radio Astronomy in Tübingen, headed by Sebastian von Hoerner, and to appoint Otto Hachenberg to the Tübingen chair – the two of them together were to build the large radio telescope. But in view of the fact that radio astronomy had already been brought forward strongly by the State of North Rhine-Westphalia, Hachenberg felt obliged to remain in Bonn and pleaded for this solution.

The Science Council thus consulted the working group initially about radio astronomy. In 1966 it recommended siting radio astronomy not in Tübingen, but in Bonn. This resulted in a very angry letter from Mr. von Hoerner, who withdrew from everything in a very angry state of mind. And this is how the Max Planck Institute for Radio Astronomy in Bonn was founded. Hachenberg was called back to Bonn as the Founding Director, and was soon joined by Peter Mezger and Richard Wielebinski as Directors. A short time later the working group then also wrote the Science Council's recommendation to establish an MPI for optical astronomy with the far-reaching task of establishing two optical observatories, a northern one in the Mediterranean and one in the southern hemisphere. Otto Heckmann was not very happy about this, however.

And why not?

RL: Otto Heckmann and Hans Elsässer did not get on, and Heckmann also had doubts that a national southern observatory was necessary in addition to the European southern observatory in Chile which had been established only a short time before. I still remember that a decisive meeting of the Science Council took place in Berlin in July 1967. I needed the agreement of my astronomy colleagues to the far-reaching recommendations of the working group, which I had to present to the Science Council, and obtained it from Bengt Strömgren and Jan Hendrik Oort by telephone during a break in the meeting. But I flew extra from Berlin to Hamburg and back the same day to see Heckmann and to literally wrest the signature from him.

You have achieved an enormous amount with this, however ...

RL: I am still a little proud that it was possible to get both radio astronomy and optical astronomy up and running. The 100-m radio telescope in Effelsberg went into operation on May 12, 1972, Hans Leussink was Research Minster at the time. When the building of the Institute for Optical Astronomy was opened in Heidelberg in 1975, I was President.

Fig. V.5.1: Reimar Lüst.

And afterwards the astronomical landscape within the MPG continued to develop apace.

RL: Jürgen Ehlers had joined Biermann at the Max Planck Institute for Physics and Astrophysics in 1971 and had set up the research group on the theory of relativity. And in 1975 Kippenhahn joined as Biermann's successor. When the Berlin Wall came down in 1989, astrophysics got into a difficult situation because Kippenhahn's succession became imminent, and since no suitable successor was in sight, consideration was given to moving all the astrophysics to Potsdam. The Astrophysics staff was against this, of course. In 1990, Jürgen Ehlers proposed establishing a Max Planck Institute for Gravitational Physics in Potsdam. This came about in 1995 with the Albert Einstein Institute and Ehlers as Founding Director. And in Garching the Max Planck Institute for Physics and Astrophysics was split into three independent institutes in 1991 – for physics, astrophysics and extra-terrestrial physics.

In 1957 the MPI for Nuclear Physics had already been founded in Heidelberg under the direction of Wolfgang Gentner. Gentner had a strong interest in cosmic chemistry, i.e. in the analysis of extraterrestrial rock samples with atomic and nuclear physical methods, and thus explored issues which concerned the early development of the Solar System. Nowadays, this Institute investigates the complete interplay of particle physics and astrophysics.

And finally the MPI for Solar System Research in Katlenburg-Lindau, which is soon to move to Göttingen: It was incorporated into the Max Planck Society in 1957 as the MPI for Aeronomy, its research focusing on the Earth's upper atmosphere. In the years that followed more and more areas of our solar system were added: Comets, planets, the Sun and the heliosphere. An early highlight of this development was the Giotto mission to Halley's comet in 1985, Esa's first large scientific space mission, the institute's contribution being the construction of a camera under the direction of Hans Ulrich Keller. Keller was also a student of Ludwig Biermann, who had himself made a decisive contribution to comet research.

When you now look at this whole development of astronomy in the Max Planck Society – has it really had a positive effect on the astronomy at the State institutes and universities?

RL: Oh yes. When I see that, whether it be Munich and Garching or Heidelberg or the radio astronomy in Bonn – the junior scientists always came jointly from the universities and the Max Planck Institutes. Take Reinhard Genzel, for example; he did his doctoral studies in Bonn in radio astronomy. And all the directors were university lecturers at the same time. All the young scientists in extraterrestrial research came primarily from Garching. The universities were concerned that the Max Planck Institutes would weaken the research at the universities, but the opposite happened because of the Max Planck Institutes – the attraction of astronomy and astrophysics, in particular, has increased for the young scientists everywhere. And the collaboration between the MPIs and the university institutes is becoming increasingly closer.

The attraction of astronomy is felt beyond its own boundaries. In Heidelberg all physics students in the first semester were recently asked what moved them to study physics in Heidelberg in particular. One third stated their interest in high energy physics and quantum physics, but two thirds said it was astronomy and cosmology.

RL: I also think that this fascination which emanates from astronomy benefits all natural sciences. Astronomy should therefore have the chance to blossom as early as school. Think of the Netherlands: This small country is active and successful in all sciences, and it is particularly strong in astronomical research. It has produced a quite astonishing, disproportionate number of outstanding astronomers. Astronomy is an independent discipline in Dutch schools. This certainly also explains the strength of Dutch astronomy. But, moreover, our science has a far-reaching effect from which benefit all sciences.

The interview was conducted by Jakob Staude.

Reimar Lüst,
was born in 1923 in Barmen near Wuppertal; after military service as an officer in the engineers he began to study theoretical physics and mathematics while a British prisoner-of-war, completing his studies in 1949 in Frankfurt. He was granted his doctorate in 1951 by Carl Friedrich von Weizsäcker with a thesis on "The development of a gas mass orbiting about a central body", i.e. on the fundamental properties of proto-planetary disks. After his first post at the MPI for Physics in Göttingen and a teaching and research residency in New York he obtained his post-doctoral lecturing qualification in 1960 at the University of Munich and became a Scientific Member of the MPI for Physics and Astrophysics, which by then had relocated to Munich and expanded. In 1961 he took over the coordination of the science program of the European Space Research Organization (Esro), in 1963 he became Director of the new Extraterrestrial Physics Department at the MPI for Physics and Astrophysics. Between 1969 and 1972 he was the Chairman of the Science Council, which was then concerned with the expansion and establishment of new universities and research institutes. From 1972 until 1984 he was President of the Max Planck Society, held the post of Director General of Esa in Paris until 1990, and then until 2000 was President of the Alexander von Humboldt Foundation for the support of highly qualified foreign researchers. Reimar Lüst was also decisively involved in the planning and development of the private 'International University Bremen' (IUB, now: Jacobs University) which was founded in 1999. Presently he lives in Hamburg and makes intense use of his office in the Max Planck Institute for Meteorology.

V.6 "The Haus der Astronomie is a dream come true"

A conversation with Eckart Würzner, the mayor of the city of Heidelberg, about the beginnings of the MPIA, Heidelberg as a science city, and the latest activities on the Königstuhl.

Question: *Mr. Würzner, around 1970 there was a rumour at the Landessternwarte, the State Observatory (LSW), that the mayor at the time, Reinhold Zundel, was instrumental in bringing the MPIA to the Königstuhl. Back then, many in the city council would have preferred to site the institute at Neuenheimer Feld. What do you know about the role played by Mr. Zundel?*

Eckart Würzner: That's correct. That's just how it was. The first thing that can be said is that Reinhold Zundel was very far-sighted back then and didn't see Heidelberg simply as a city with the oldest university, a famous castle and a beautiful medieval city centre. He was very forward-thinking and also wanted to establish new research facilities in Heidelberg. As far as the location of the MPIA was concerned, a significant aspect for him was of course good observing conditions, which are of great importance to institutes which also operate their own local telescopes. This is the case for the Königstuhl mountain.

A counterargument was that, at the time the Institute was being established, there was already a plan to position the new large telescopes in Southern Europe, meaning the Königstuhl, as an observation site, wasn't quite so important. But didn't the fact that the Landessternwarte was located on the mountain also played an important role?

EW: Yes, the site already had an observatory – This was a sort of a nucleus. It offered the astronomers of the MPIA the best conditions for a close collaboration, even though it is not conveniently located, otherwise. However, given that scientists like to retreat from the world a bit in order to be able to pursue their research in peace, a city-centre location is not always the ideal solution. In this respect, the decision about the site of the European Molecular Biology Laboratory (EMBL) was a comparable one. On the other hand, the other disciplines were nevertheless located at Neuenheimer Feld and also on the New Campus, which we are currently realising in the Bahnstadt district of the city, as they provide an easier cooperation between the researchers – on an interdisciplinary level, as well.

You mentioned the arguments back in those days, namely the advantage of the Königstuhl site for astronomers, and also the somewhat isolated position that was good for retreating. Do you see this as a problem now? From today's perspective, do you think the institutes located on the Königstuhl are cut off from the rest?

EW: Back then, it was still a world that was rather secluded. It wasn't yet possible to communicate via Internet in the way we do as a matter of course today.

Despite Internet and new media it is, of course, important to maintain personal contact and this is true for interdisciplinary aspects as well. But I see Heidelberg as one large campus. And on this large campus nothing is very far away, and people can get in direct contact by bike, public transport or on foot and can discuss things – at cultural events as well, of course, which the city offers in abundance.

We also have the impression you want to strengthen people's perception of Heidelberg as a city of science, and also further increase international cooperation.

EW: Yes, absolutely. In the past, Heidelberg's image abroad was characterised mainly by the castle and the medieval city centre, a romantic city. This image is now being increasingly expanded so as to draw attention to Heidelberg as a city of research and science. This is largely owed to the important national and international institutions here, such as, for example, the MPIs, the EMBL, the German Cancer Research Centre (DKFZ) or the national centre for tumour therapy, and the world-famous Ruprecht-Karls-University. Heidelberg provides great prospects for all researchers who come here to work. Just like artists, who look for an artists' colony, scientists too search out special places where they can find optimum working conditions, an excellent international environment and good opportunities for discourse with colleagues. We want to expand these further and also improve our contacts to foreign countries. Many international institutes or even research sites have great interest in collaborating with our international research institutes.

Heidelberg is one of the most important locations for astronomy in Germany. This discipline can be found at a total of 6 institutes, either as a main subject or in conjunction with others. What does this mean for the city, in your view?

EW: Heidelberg's astronomy is internationally renowned and thus an advertisement for the city. Moreover, astronomy is the only science where one can connect with young people, in particular, with great success. Who doesn't remember when they were young, sitting with their friends on the meadow outside their tent at night and

Fig. V.6.1: Eckhart Würzner.

looking up to the skies and thinking: What's up there? Who's responsible for it? How did the universe, the stars and Earth form? Astronomy arouses this natural curiosity in a particularly powerful way – and this fire needs to be kindled more fervently. It's a fascinating research field and I find it very encouraging that Heidelberg is such an international nucleus for it.

We train not only astrophysicists but technicians and craftspeople as well, of course. The instruments built at our Institute provide a direct link between basic research and industry.

EW: I find it fascinating that we not only conduct research in this field, but also develop and build the instruments needed for this research directly in Heidelberg. Anyone who's been to Königstuhl montain and has seen and experienced how complex optical, mechanical and electronic instruments reliably operate at temperatures of minus 260 degrees Celsius over a period of many years, has to be completely enthralled. For me, these are key experiences that are very important and that represent a terrific example of scientific findings being put into practice. Such high-tech instruments are not mass-produced articles. But the know-how gained is later utilized in very different ordinary instruments. It's crucial that young people, in particular, understand that the work doesn't only involve theory, but also has very practical applications.

Do you think these aspects must be more strongly conveyed to the public? Do the local institutes do enough in this respect?

EW: I believe a great deal is already being done on this front in Heidelberg. The Science in our Explo or the involvement of school classes in relevant research projects are good examples.

But one also has to state quite openly that some in Heidelberg still don't know that there is such an institute up here. Just as some have never heard of the EMBL or don't know that one of the largest medical centres is located at Neuenheimer Feld. Some have only a very vague idea. And this, of course, presents us with the task of making this treasure of ours visible. This also generates understanding for the fact how important these institutions are for Heidelberg. Especially countries such as Germany, which are basically lacking in natural resources, have to depend almost exclusively on education, research and technological development. This is our future. This is the message we must get across; this is what people must be able to experience, and this is exactly what we want to do in Heidelberg.

This leads us directly to the next issue: The founding director back then, Dr. Elsässer, was almost visionary in that he brought not only research but also another aspect to the montain – something which people then hardly gave a second thought to, but which is now highly topical – scientific public outreach. Even before the MPIA was founded he initiated the journal Sterne und Weltraum (Stars and Space) which now, fifty years on, is blossoming and thriving, and which recently formed the basis of our school project. The Haus der Astronomie (HdA) is now being created from this school project and our numerous public outreach activities over the years. Are the above-mentioned reasons also why you followed and supported this plan from the outset?

EW: Yes, and I have to say the Haus der Astronomie is a dream come true. The idea behind it – to make scientific findings intelligible, to enable people to experience and witness them – is very significant, as I have said before, especially for the younger generation. If we fill young people with enthusiasm, we won't have a problem finding the young scientists who are interested in black holes and who want to know how stars and galaxies form, or how the new drive technologies work in automotive engineering, or which processes occur in a cell. With our experimental learning within Explo, our 'Exploratorium', we are already active in the field of microbiology. And with the HdA Heidelberg will become another important location for extracurricular learning.

It's important that science, in this case gazing into space, can be experienced and made tangible. It strengthens the mind and the motivation; it helps to revive the urge to conduct research. And it's basically very simple to do: Those special places, where fascination can be experienced first hand, must simply have to be provided. I myself didn't study geology and geography by chance. My interest was aroused through many fascinating questions, such as the origin of the earth. The HdA is a meeting place for people of all ages who are eager for knowledge – which is something new for Heidelberg. The concept is educationally sound, and the location on the MPIA campus also offers young people the opportunity to get to know "real" researchers and to look over their shoulder as they work.

So do you also think it will have a sustainable future?

EW: Yes, I believe the HdA is a stimulating *and* sustainable project. The right partners have recognised this and are working together here. We were determined to support this process – financially, too – by participating in the HdA through our 'Exploratorium'. For the city it is important to support the extra-curricular places of learning as a partner, and to promote networking with other important organising bodies. It's fantastic that the ambitious idea of an HdA has been turned into a reality thanks to the tremendous financial commitment made by Klaus Tschira, a very successful entrepreneur who has remained a scientist at heart. And, by the way, the extraordinary architecture in the shape of a galaxy – which has also never been realised before – as well as the construction and development of the building statics, all represent great innovations, even before the building goes into active use – which is something we are all looking very forward to, of course!

The interview was conducted by Klaus Jäger and Jakob Staude.

Eckart Würzner,
born 1961 in Goslar/Germany, studied geography at the universities of Mannheim and Heidelberg and was awarded his doctorate in 1993 for the thesis "Comparative Case Study on Possible Influences of Noxious Agents in the Atmosphere on Mortality in Agglomerations" in the conurbations of the Federal Republic of Germany and the metropolitan area of Paris, which was supported by the graduate funding programme of the state of Baden-Württemberg.

From 1988 until 1991 he worked as an environmental consultant for the city of Heidelberg before taking over the management of the Technical Environmental Protection Division. He then headed the Environmental and Energy Management Division (1997 – 1999) and afterwards was named director of the Office for Environmental Protection, Energy and Health Promotion, before taking over the office of deputy mayor for environment and energy of the city of Heidelberg in 2001.

In 2006 Eckart Würzner was elected mayor of the city of Heidelberg. In addition, he is also chairman of a number of regional and supraregional bodies, such as the "Meeting of Shareholders of the Technologiepark Heidelberg GmbH" and the "European Energy and Climate Task Force".

Mr. Würzner has visited the MPIA several times over recent years on various occasions and has always followed the activities of the Institute with great interest. From the outset, he was very keen on the HdA idea and was instrumental in paving the way for the city of Heidelberg to now actively support this institution as a partner.

V.7 Obituaries

Frithjof Brauer

Frithjof Brauer came to our institute in the early summer of 2005 to start a PhD project on the first stages of planet formation. Coming from a background in theoretical physics, he was the right person to tackle the mathematical problem of the evolution of size distributions of solid particles in the gaseous disks surrounding young stars. He turned out to be very successful in designing new computational methods to overcome various difficulties arising from the huge dynamic range of this problem, which spans more than thirty orders of magnitude in mass from sub-micron size dust particles all the way up to kilometer size planetesimals. His breakthroughs in this field made it possible for the first time to model the evolution of the dust population in protoplanetary disks, covering their entire spatial range and lifetime. Models of this kind were highly anticipated and necessary, since in recent years the quality and volume of observational data taken at infrared and millimeter wavelengths have grown dramatically. Yet no good models of dust evolution were available to interpret these data. Frithjof Brauer's models filled that gap, and his work quickly became highly cited. Much of the theoretical dust evolution research that is currently being done at the MPIA is based on this groundbreaking work. In early 2009, Frithjof defended his thesis, receiving the highest possible ranking: summa cum laude. He won the Ernst Patzer Prize for the main paper arising out of his thesis, and he was awarded the MPG Reimar Lüst Fellowship which, allowed him to continue his research for two more years as a postdoc.

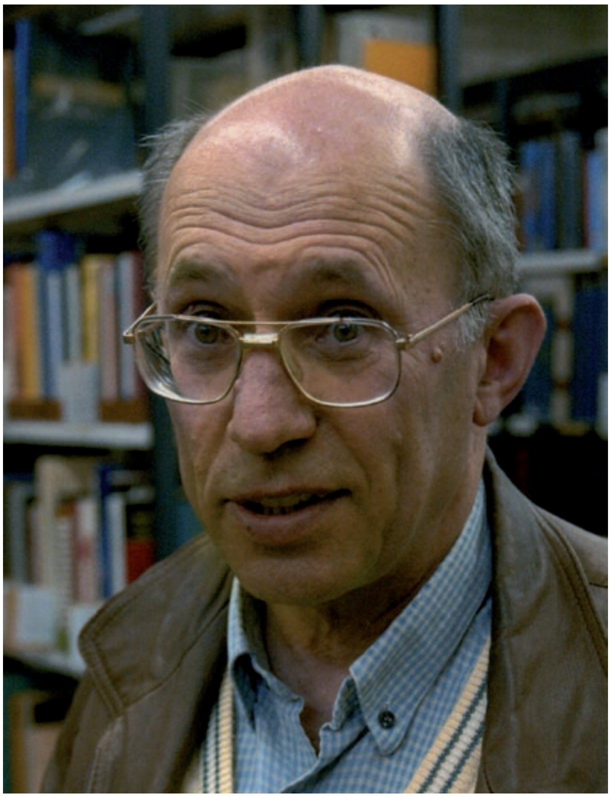
Unfortunately, during his time as a PhD student, Frithjof became gravely ill with cancer. Despite gruelling medical treatments and a gloomy perspective, Frithjof persisted in writing what became an impressive thesis, all the while keeping his sense of humour and his will for life. But at last, on September 19, 2009, he lost the battle. He passed away at the age of 29.

We remember Frithjof as a person of great warmth, who, even during his illness, was always willing to help others. He had a broad range of interests, and it was always a pleasure to discuss with him issues such as philosophy, music, and science in general. He had a passion and great talent for piano playing, often improvising beautiful music as he went along. Most importantly, it was a great pleasure to hang out with him.

He is very much missed. Frithjof Brauer still had lots of plans for his future, but life was too short.

Cornelis Dullemond, Thomas Henning.

Kurt Birkle



Kurt Birkle, Director of the Calar Alto Observatory for many years, passed away on January 1, 2010. A tragic traffic accident snatched him from his active life only a few days before his 71st birthday.

Kurt Birkle was born on January 8, 1939 in Freiburg/Germany. He completed his study of physics in 1966 with a Diploma thesis at the Fraunhofer Institut in Freiburg – the future Kiepenheuer Institute for Solar Physics – on the behavior of the photospheric granulation in the cycle of solar activity. After a further year at the Fraunhofer Institute, in which he researched the structure of the chromosphere, he arrived at the Landessternwarte Heidelberg-Königstuhl at the beginning of 1968 as a doctoral student in order "not to be labeled a solar physicist" – as Wolfgang Mattig, his fellow traveler back then remembered. Kurt Birkle later moved with his doctorate supervisor Hans Elsässer to the newly founded MPIA.

The establishment of the MPIA was based on the realization that only an institute with direct access to an observatory with powerful large telescopes would be able to compete on the international stage. Such an observatory, which was intended to provide astronomers at German institutes with the opportunity to conduct observation, still had to be established.

Kurt Birkle was one of those who blazed a trail for the success of this ambitious project. He contributed significantly to the search of several years' duration for suitable locations for the planned observatories – one in the northern and one in the southern hemisphere. The station in the northern hemisphere was to be located in Europe for a number of reasons; climatological and geographical initial investigations had limited the choice of suitable locations to narrow areas in southern Greece and the southeastern part of Spain. The only possible sites for the southern station were Chile, which was known to offer good conditions, and South West Africa, now Namibia.

The title of Kurt Birkle's doctoral thesis, which he submitted in 1973 at the Ruprecht Karl University of Heidelberg, reveals his contributions to the search for the location: "Comparative measurements of the astronomical seeing in Greece, Spain, South West Africa and Chile". With the support of his colleagues E. Böttcher, W. Hormuth and M. Wensch he built simple observation stations on the 1805-meter high Pirgaki in the Parnon mountains on the Peloponnese, and also on the 2168-meter high Calar Alto, the highest part of the Sierra de los Filabres north of the Spanish coastal town of Almeria. In Namibia he used the station that Thorsten Neckel had built on the 2350-meter high Gamsberg at the edge of the Namib Desert.

In spring 1968 in Greece, and in spring 1970 in Spain, Kurt Birkle began to measure the seeing, extinction and meteorological data. Today, one can hardly imagine what this pioneering work, far away from any type of infrastructure, involved in terms of personal hardship. Only someone with Kurt Birkle's character could have mastered these challenges so well. He did not mind living in makeshift accommodation and, if need be, sometimes even having to find lodgings in a bare shelter belonging to the passing shepherds. The ability to withstand loneliness, to have the rhythm of his life determined by professional requirements, to value personal needs less than the joy of his work – these were characteristics that distinguished the person Kurt Birkle. The measurements he obtained under these conditions finally clinched matters for the choice of location: the observatory for the northern hemisphere was to be constructed on the Calar Alto.

Kurt Birkle began conducting seeing measurements on the Gamsberg in October 1970, and one year later on La Silla in Chile as well. Although there was already a wide range of seeing data available for the Chilean location, they had been obtained with different methods and different definitions of the measured value so that a reliable comparison of the data was scarcely possible. Kurt Birkle's measurements showed that the good average seeing conditions for the Gamsberg were the same as for La Silla; the proportion of nights with very good seeing was even higher on the Gamsberg. The then still uncertain political future of South West Africa was the main reason why the Max Planck Society decided to affiliate the 2.2-meter telescope planned for the southern hemisphere with the Eso observatory on La Silla.

After the decision on the location in the northern hemisphere had been made in favor of the Calar Alto, Kurt Birkle, together with Spanish colleagues, oversaw the construction of the German-Spanish Astronomical Center (DSAZ) there with its four large telescopes. Its official opening in 1979 marked the establishment of a national observatory – the dream of German astronomy for half a century. The road to this goal was very arduous. First of all, the complete infrastructure had to be provided. The team was housed in living and work containers for a good few years. Managing all of this needed someone with not only great organizational talent, but also diplomatic skills in order to solve problems with local authorities or even prevent them occurring in the first place. As the local director, Kurt Birkle was able to motivate his co-workers despite often adverse conditions. When there were problems with staff, which occurred due to the different mentalities, his quiet and reconciling manner meant they were settled in a matter-of-fact atmosphere.

Kurt Birkle can claim the crucial credit for the good relations with Spanish astronomy and also for the contacts to the local science institutions and local authorities. He played a decisive role in the upturn of Spanish astronomy during the last 35 years. Publicly, Kurt Birkle may have often stood in the shadow of his doctorate supervisor and MPIA Founding Director Hans Elsässer, but every astronomer who observed on the Calar Alto and learned a lot from him appreciates how much credit is owed to Kurt Birkle.

In addition to the construction of the observatory and its organization, Kurt Birkle also spent time on his own research, of course. His special interest was comets, on the one hand, and active galaxies, on the other. The instrumentation that was introduced during his work on the Calar Alto ranged from photographic plate cameras for direct images via image convertor cameras for the near infrared region, multi-stage image amplifiers, various spectrographs and CCD cameras, through to modern infrared cameras and adaptive optics.

The observations in the early days were conducted with photographic plates, and Kurt Birkle became a specialist in this field. He tested methods to make them more sensitive and experimented with pre-exposures and various development methods in order to get as much as possible from the plates – work which made a crucial contribution to the outstanding quality of the direct images and spectral plates. His meticulousness and attention to detail are particularly evident in the outstanding images with the Schmidt-Telescope, which were widely disseminated.

As an observer, Kurt Birkle conformed to the typical image of the traditional astronomer. Equipped with winter-proof clothing and accompanied by classical music, one of his other passions, he spent long nights, even at subzero temperatures, at the eyepiece, as »autoguiders« were then still unheard of. Nevertheless, he would be on his feet again the next morning to devote himself to administrative issues, or to look after guest observers from the Königstuhl and other German and Spanish research institutes.

In 1998 Kurt Birkle returned to the Königstuhl and devoted himself completely to his scientific research. He remained active even after his retirement in 2003. In 2005 he began to compile an electronic archive together with Holger Mandel and other colleagues of the Landessternwarte and also with the financial support of the Klaus Tschira Foundation, in order to preserve the photographic material which had been obtained over the years on the Königstuhl and the Calar Alto for later generations, and to make it available for long-term studies. By the end of 2009 this database – Heidelberg Digitized Astronomical Plates (≠P) – comprised a total of 6160 digitized photographic plates, which had been produced since 1900 with the Bruce double astrograph of the Landessternwarte, and since 1982 with the Schmidt-Telescope on the Calar Alto. This database can be freely accessed via the website of the GAVO Data Center at http://dc.zah.uni-heidelberg.de.

On the last day of 2009 as well, Kurt Birkle had been on the Königstuhl working on the digitalization project. Time was of no consequence to him. And so, as the world around him celebrated the beginning of a new year, he was on the road again, as he had traveled hundreds of thousands kilometers before, unimpressed by other customs and traditions. This time, however, his journey reached its end before he reached his destination near Freiburg. Kurt Birkle is survived by his Spanish wife, Pilar Duro, and both daughters Irene and Sylvia.

Kurt Birkle was never one for the limelight. The few honors he was awarded included the naming of the planetoid (4803), discovered in 1989, after him. He and his life achievements will remain in the grateful memory of all who knew him.

Uwe Reichert, Ulrich Thiele.

Staff

Directors: Henning (Managing Director), Rix

Scientific Coordinator: Jäger
Public Outreach: Staude (Head)
Administration: Voss (Head)
Haus der Astronomie: Pössel

Scientists: Afonso, Bailer-Jones, Bell (until 31.7.), Balog (since 1.8.), Bertram, Beuther, Borelli, Bouwman, Brandner, Dannerbauer (until 30.9.), De Bonis, De Jong, Dullemond, Dumas, Dziourkevich, Elias (until 30.9.), Feldt, Fendt, Fischer (1.12. until 31.12.), Fried, Gallazzi, Gässler, Goldman (since 1.2.), Goto (since 1.4.), Gouliermis, Graser, Gredel, Hennawi (since 15.6.), Hennemann (until 31.10.), Herbst, Hippler, Hofferbert (parental leave since 14.1.), Inskip, Huisken, C. Jäger, K. Jäger, Jahnke, Jester (until 31.5.), Joergens, Klaas, Klahr, Klement, Köhler, Krause, Kürster, Launhardt, Leipski (since 1.9.), Lenzen, Linz, Liu, Marien, Meisenheimer, Möller-Nilsson, F. Müller, Mundt, Nielbock, Pavlov, Peter, Pössel (since 1.1.), Pott (since 1.6.), Rodriguez (since 1.10.), Röser (until 30.9.), Sandor, Sargent, Scheithauer, Schinnerer, Schreiber, Scorza (since 1.6.), Semenov, Setiawan, Sicilia-Aguilar, K. Smith, Staude (until 31.12.), Steinacker (1.3. until 31.8.), Stilz, Trowitzsch, Tsalmantza, van Boekel, van de Ven (since 15.8.), van den Bosch (until 15.4.), Walter

PhD Students: Anguita (until 31.3.), Arold, Behera (until 14.10.), Bergfors, Besel (since 1.12.2008), Bicanski (until 28.2.), Birnstiel, Bocchi (until 20.2.), Boley (since 1.9.), Boudreault (until 19.11.), Brasseur (since 1.9.), Burtscher, Cacciato (until 31.7.), Cisternas, Csak, Crnojevic, Da Rio, De Rosa, Dettenrieder (until 31.8.), Dopke (since 15.6.), Downing (since 15.6.), Ernst (until 31.7.), Fallscheer, Fang, Federrath, Flock, Follert, Foyle, Gan, Geißler (until 30.9.), Gennaro, Golubov (since 1.8.), Grootes (since 1.10.), Holmes, Hormuth, Jäger (since 1.9.), Juhasz, Karim, Kern (since 1.5.), Koposov (until 30.11.), Kudryavtseva (since 1.4.), Kuiper, Lefa (since 1.4.), Liu (since 1.11.), Lu (since 1.7.), Ludwig (since 1.10.), Meyer, Mignone (until 30.4.), More (until 31.7.), Moster, Moyano, A. Müller (until 28.2.), Natale, Nicol (until 11.5.), Nikolov, Nugrohu, O'Sullivan (until 31.3.), Pedaletti (until 31.7.), Pitann, Porth, Raettig (since 1.5.), Robaina, Roccatagliata, Rochau, Rodon (until 30.11.), Ruhland, Rodriguez, Schmalzl, K. B. Schmidt, T. Schmidt, Schruba, Schulze-Hartung (since 1.5.), Skelton, Steglich, Stumpf, Sturm, Tackenberg (since 1.10.), Uribe, Uelzhöffer (since 1.12.), Valente, Van der Laan (since 1.3.), Vasyunin, Vasyunina, Wang, H., Weise, Zechmeister, Zeidler (since 1.3.), X. Zhang (since 1.11.), Zhao-Geisler, Zsom, Zub

Diploma Students and Student Assistants (UH): Bestenlehner (until 31.5.), Conrad (until 31.1.), Fiedler (since 28.9.), Hoffmann (until 31.10.), Lendl (until 30.9.), Potrick (since 1.3.), Raettig (until 30.4.), Schewtschenko (since 1.6.), Schmiedeke (since 17.8.), Schnupp (since 16.3.), Wylezalek (since 1.4.)

Diploma and Master Students (FH): Bideaux (since 1.9.), Blanco (since 1.9.), Dittkrist (since 1.9.), Fischer (until 30.6.), Keilbach (until 28.2.), Pfannschmidt (until 28.2.)

Postdoctoral Stipend Holders: Arold (since 14.4.), Bik, Blindert (until 31.5.), Boudreault (until 19.11.), Brauer (deceased on 20.9.), Cacciato (since 1.8.), Carson, Commercon (since 15.10.), Decarli (since 1.11.), Fan, Fedele, Fontanot (until 30.4.), Goldman (until 31.1.), Goto (until 31.3.), Greve, Gustafsson (until 30.11.), Kainulainen (since 1.6.), Kang, Kim (until 30.6.), Kurk (until 30.6.), Labadie, Leroy (until 30.9.), Li (since 15.9.), Lyra (5.4. until 30.9.), Ma (19.3. until 31.7.), Macciò, Martin, Martinez-Sansigre (until 31.8.), Martinez-Delgado (since 1.12.), Matthews (until 31.3.), Maulbetsch (until 30.4.), Meidt (since 15.8.), Mordasini, More (1.8. until 31.10.), Morganson (since 15.8.), Mosoni (until 28.2.), Nicol (12.5. until 31.12.), Nilsson (until 31.3.), Ormel (since 1.11.2008), Pasetto (until 31.8.), Pasquali, Peng (9.5. until 9.7.), Ragan (since 15.12.), Rodriguez (1.7. until 30.9.), Sandstrom (since 15.9.), Skibba (until 31.7.), Stutz (since 1.8.), Thalmann, Tremonti (until 31.5.), van der Wel, Vasyunin (since 1.12.), Wang Wei, Yang (since 12.8.), Zatloukal (until 28.2.), Zhukovska, Zibetti

Interns: Abel (since 1.9.), Brezinski (since 1.9.), Christmann (since 1.3.), Ehret, Franke (until 24.7.), Haude (2.2. until 20.3.), Lechner (since 1.9.2008), Merx, Messer (1.3. until 31.8.), Neidig, Peterlick (5.8. until 30.9.), Roeske (1.3. until 31.8.), Verellen (29.6. until 14.8.), Wipfler (since 1.9.2008), J. Zimmermann (until 30.9.)

Public Outreach: Staude (Head), Pössel, Quetz

MPIA Observatories: Gredel

Technical Departments: Kürster
Mechanics Design: Rohloff (Head), Baumeister (Deputy), Blümchen, Ebert, Huber, Münch, Schönherr (since 1.6.)

Precision Mechanics Workshop: Böhm (Head), W. Sauer (Deputy), Euler (until 31.8.), Heitz, Maurer, Meister, Meixner, Stadler; trainees, interns, student assistants: Abel (since 1.9.), Brezinski (since 1.9.), Christmann (since 1.3.), Ehret, Franke (until 24.7.), Merx, Neidig, Wipfler (since 1.9.2008)

Electronics: Wagner (Head); Mohr (Deputy); Adler, Alter, Bieler (since 1.10.), Ehret, Klein, Lehmitz, Mall, Mohr, Ramos, Ridinger, Westermann (until 30.9.), Wrhel; trainees, interns, student assistants: Bideaux (since 1.9.), Blanco (since 1.9.), Fastner (since 1.9.), Keilbach (until 28.2.), Messer (1.3. until 31.8.), Pfannschmidt (until 28.2.), Roeske (1.3. until 31.8.)

Instrumentation-Software: Briegel (Head); Storz (Deputy), Berwein, Borelli, Kittmann (Guest of the University of Cologne), Leibold (until 30.6.), Möller-Nilsson, Neumann, Pavlov, Trowitzsch; trainees, interns, student assistants: Fischer (until 30.6.)

Engineering and Project Management: Marien (Head), Bizenberger (Deputy), Bertram, Brix, De Bonis (Guest of the University of Cologne), Gässler, Graser, Laun, Meschke, Naranjo, Peter

Administrative and Technical Service Departments:
Administration: Voss (Head); Apfel, Anders, Baier, Beckmann, Heißler, Hölscher, Schleich, S. Schmidt, Scheerer (since 15.11.), Zähringer; trainees: Lechner, J. Zimmermann (until 30.9.)

Library: Dueck

Data Processing: Richter (Head), Piroth (Deputy), Hiller, Bestenlehner (until 31.5.); Student Assistant: Schewtschenko (since 1.6.)

Photographic Lab: Anders

Graphic Artwork: Quetz (Head), Meißner, Müllerthann

Secretaries: Bohm, Janssen-Bennynck, Koltes-Al-Zoubi (maternity leave since 22.10.), Seifert, Witte-Nguy (since 14.9.)

Technical Services and Cafeteria: Zergiebel (Head), F. Witzel (Deputy), Behnke, Drescher, Jung, Lang, Nauss, B. Witzel, E. Zimmermann

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

Freelance Science Writer: Thomas Bührke

Guests: Y. Serena Kim, Univ. Arizona, 1. Sep. 2008 – 30. June; Xiaohui Fan, Steward Obs., 1. Sep. 2008 – 30. June ; Bernhard Sturm, 1. Dec. 2008 – 31. Jan.; Francesco Pierfederici, NOAO/LSST, 4. – 31. Jan.; Markus Janson, Univ. Toronto, 6. – 8. Jan.; Steven Balbus, Ecole Norm. Sup. Paris, 14. – 16. Jan.; Guillaume Laibe, Cral ENS Lyon, 14. – 17. Jan.; Amy Stutz, Univ. Arizona, 14. – 16. Jan.; Jon Braithwaite, CITA Toronto, 14. – 16. Jan.; Jouni Kainulainen, 14. – 15. Jan.; Andrea Stolte, Univ. Köln, 21. – 23. Jan.; Benjamin Hussmann, Univ. Köln, 21. – 23. Jan.; Adam Bolton, IfA Hawaii, 25. – 28. Jan.; Yuko Kakazu, IOP Paris, 26. – 28. Jan.; Joseph Hennawi, UC Berkeley, 27. – 30. Jan.; Eric Gawiser, Rutgers Univ., 1. – 3. Feb.; Maria Khramtsova, Urals State Univ., 2. – 20. Feb.; Domenico Tamburro, München, 4. Feb.; Simon Huegelmeyer, Göttingen, 2. – 5. Feb.; Thomas Puzia, HIA Victoria, 3. – 8. Feb.; Natalia Noel, Univ. Edinburgh, 3. – 8. Feb.; Ingo Thies, Univ. Bonn, 4. – 5. Feb.; Pavel Kroupa, Univ. Bonn, 4. – 5. Feb.; Joe Crocker, Oxford Univ., 8. – 10. Feb.; Sandra Savaglio, MPE, 8. – 9. Feb.; Eric Emsellem, Univ. Lyon, 9. – 10. Feb.; Brant Robertson, KICP Chicago, 9. – 11. Feb.; Rychard Bouwens, UC Santa Cruz, 10. – 12. Feb.; Klaus Dolag, MPA, 11. – 12. Feb.; Pamela Klaassen, ESO, 11. – 12. Feb.; Mariska Kriek, Princeton Univ., 14. – 18. Feb.; Stelios Kazantzdis, Ohio State Univ., 15. – 18. Feb.; Juan Carlo Munoz, AIP, 16. – 27. Feb.; Glenn van de Ven, Inst. For Adv. Studies, 16. – 19. Feb.; Juan Carlos Munoz, AIP Potsdam, 16. – 27. Feb.; Jörg-Uwe Pott, Keck Observatory, 17. – 20. Feb.; Jose A. Caballero, Univ. Madrid, 18. – 21. Feb.; Gwendolyn Meeus, AIP Potsdam, 24. – 26. Feb.; Evan Skillman, Univ. Minnesota, 28. – 4. Feb.; Roderik Overzier, MPA Garching, 2. – 7. March; Koen Maaskant, Univ. Amsterdam, 2. – 13. March; Roberto Decarli, Univ. di Como, 9. – 11. March; Dmitry Vibe, Russ. Acad. Sci., 9. March – 9. Apr.; Nikolai Voshchinnikov, St. Petersburg State Univ., 12. March – 9. Apr.; Ficut V. Dana, Univ. Hertfordshire, 16. – 21. March; Simone Weinmann, MPA Garching, 23. – 27. March; Benjamin Hussmann, Univ. Köln, 25. – 27. March; Andrea Stolte, Univ. Köln, 25. – 27. March; Zsolt Regaly, Konkoly Obs. HAS, 29. March – 9. Apr.; Seyma Caliskan, Ankara Univ., 4. Apr. – 9. May.; Fuyan Bian, Steward Obs., 5. – 19. Apr.; Luciano Casarini, Univ. Milano, 14. Apr. – 5. May.; Christian Tapken, 16. – 18. Apr.; Raquel Salmeron, Mt. Stromlo Obs., 18. – 21. Apr.; Neal Turner, CalTech, 18. Apr. – 4. May.; Bernd Husemann, AIP Potsdam, 200. – 25. Apr.; Jesus Maldonado, Univ. Madrid, 20. Apr. – 20. July; Joseph Hennawi, UC Berkeley, 23. – 29. Apr.; Daniel Mortlock, London, 26. – 29. Apr.; Olivier Schnurr, Univ. Sheffield, 27. – 29. Apr.; Rene Andrae, ITA HD, 27. Apr. – 8. May.; Mitesh Matel, Imperial College, 29. Apr. – 1. May.; Sylvain Veilleux, Univ. Maryland, 3. – 4. May.; Marco Spaans, Kapteyn Astr. Inst, 4. – 8. May.; Anders Johansen, Sterrewacht Leiden, 4. – 7. May.; Carole Mundell, Liverpool JM Univ., 4. – 7. May.; Aaron Boley, Univ. Zürich, 4. – 5. May.; Zsolt Regaly, Konkoly Obs., 4. May. – 30. June; Warrick Lawson, Univ. New South Wales, 5. – 9. May.; Johan Olofsson, Obs. Ujf Grenoble, 5. – 8. May.; David Delgado, IAC, 5. – 13. May.; Chien Peng, NRC Herzberg Inst., 9. May. – 9. July; Dan McIntosh, Univ. Missouri-Kansas, 16. May. – 6. June; Alan McConnachie, Herzberg Inst., 20. – 24. May.; Subhanjoy Mohanty, IC London, 27. – 29. May.; John Bally, Univ. Colorado, 29. May. – 3. June; Crystal Brasseur, ?, 1. – 2.

June; Estelle Bayet, Univ. Coll. London, 1. – 4. June; Mark Westmoquette, Univ. Coll. London, 1. – 4. June; Markus Janson, Univ. Toronto, 1. – 5. June; Yaroslav Pavlychenkov, Russ. Acad. Sci., 1. – 14. June; Andrey Zhilkin, Russ. Acad. Sci., 1. – 14. June; Natalia Zhilkina, Chelyabinsk State Univ., 1. – 14. June; Dylan Hatt, Haverford College, 1. June – 31. July; Chris Carilli, NRAO, 1. June – 15. Aug.; Claudia Marka, AIU Jena, 2. – 13. June; Greg Rudnick, Univ. Kansas, 8. – 12. June; Peter Abraham, Konkoly Obs., 8. – 18. June; Sonya Mollinger, Harvard University, 8. June – 7. Aug.; Blair Conn, ESO Santiago, 11. – 12. June; Caroline D'Angelo, ESO Garching, 15. – 16. June; Réné Plume, Univ. Calgary, 15. June – 31. July; David Hogg, NYU, 15. June – 15. Aug.; Ronin Wu, NYU, 16. June – 18. July; Dominik Riechers, Caltech, 22. – 27. June; Paul Boley, Ural State Univ., 22. June – 30. July; Uma Gorti, 23. – 26. June; Greg Rudnick, Univ. Kansas, 28. June – 31. July; Phil Marshall, Univ. California, 29. June – 3. July; Alberto Bolatto, Univ. Maryland, 1. – 2. July; Ignacio Ferreras, King's College Lond, 1. – 14. July; Glenn van de Ven, IAS Princeton, 3. – 12. July; Yan-Mei Chen, MPA Garching, 3. – 29. July; Ravi Sheth, Univ. Pennsylvania, 5. – 19. July; Mariangela Bernardi, Univ. Pennsylvania, 5. – 19. July; Takaya Nozawa, Univ. Hokkaida, 5. July – 1. Aug.; Benjamin Weiner, Univ. Arizona, 8. – 28. July; Bronson Wacker, Univ. Kansas, 10. July – 1. Aug.; MacLow Mordecai-Mark, AMNH, NY, 11. July – 22. Aug.; Steven Balbus, Ecole Norm. Sup., 12. July – 3. Aug.; Caroline Terquiem, Univ. Curie, Paris, 12. July – 3. Aug.; Dustin Lang, NY Univ., 14. July – 16. Aug.; Jo Bovy, NY Univ., 19. July – 15. Aug.; Mauro Giavalisco, UMASS, 19. July – 4. Aug.; Daniela Calzetti, UMASS, 19. July – 4. Aug.; Mark Pitts, Honolulu, 19. July – 28. July; Thomas Cox, 21. – 24. July; Warrick Lawson, Univ. New S.Wales, 26. July – 6. Aug.; Anna Brylyakova, 27. July – 13. Aug.; Mark Swain, JPL, 27. July – 30. Aug.; Martin Zintl, LMU München, 29. – 30. July; Takashi Kozasa, Univ. Hokkaida, 29. July – 30. Aug.; Christian Wolf, 29. July – 5. Aug.; Ralf Kissmann, Univ. Tübingen, 30. – 31. July; David Martinez-Delgado, IAC, 1. – 31. Aug.; Miriam Peterlick, 3. Aug. – 30. Sep.; Julianne Dalcanton, Univ. Washington, 6. – 11. Aug.; Susana Iglesias-Groth, IAC, 6. – 27. Aug.; Rafael Rebolo, IAC, 6. – 27. Aug.; Pierre Cox, 9. – 11. Aug.; Emanuele Daddi, 10. – 11. Aug.; Peter Kurczynski, 12. – 14. Aug.; Emanuele Daddi, 10. – 11. Aug.; Gerrit van der Plas, Univ. Amsterdam, 10. – 13. Aug.; Peter Kurczynski, 12. – 14. Aug.; Torsten Boeker, ESA/ESTEC, 15. – 30. Aug.; Ute Lisenfeld, IAA, 15. – 30. Aug.; Linda Watson, Ohio State Univ., 24. – 28. Aug.; Paul Martini, Ohio State Univ., 24. – 28. Aug.; Jakob Walcher, ESA, 24. – 27. Aug.; Nadine Neumeyer, ESO, 24. – 28. Aug.; Connie Rockosi, UCO/Lick Obs., 22. Aug. – 16. Sep.; Bradford Holden, 22. Aug. – 16. Sep.; Riccardo Smareglia, INAF-OATS Trieste, 24. Aug. – 4. Sep.; Cynthia Knight, Brigham Y. Univ., 25. Aug. – 3. Dec.; Xiangxiang Xue, 30. Aug. – 18. Sep.; Jose A. Caballero, Univ. Madrid, 1. – 3. Sep.; Daniel Zucker, Macquarie Univ. Sydney, 7. – 11. Sep.; Michael Gladders, Univ. Chicago, 7. – 11. Sep.; Matt Bayliss, Univ. Chicago, 7. – 11. Sep.; Dan Zucker, Macquarie Univ., 7. – 11. Sep.; Nikoletta Sipos, 8. Sep. – 7. Oct.; Ray Sharples, Univ. Durham, 10. – 11. Sep.; Tom Shanks, Univ. Durham, 10. – 11. Sep.; Andrew Walsh, James Cook Uni. Townsville, Australia, 11. – 15. Sep.; Cesar E. Garcia Dabo, ESO, 11. Sep.; Stephen Marsden, Anglo-Austr.Obs., 10. – 11. Sep.; Ramon Skibba, Steward Obs., 14. – 19. Sep.; Andre Müller, MPIA/ESO, 29. Sep. – 2. Oct.; Gang Zhao, 30. Sep.; Michael Cooper, Steward Obs., 3. – 27. Oct.; Amir Asgharsharghi, 4. – 9. Oct.; A. Martinez-Sansigre, Oxford Univ., 8. – 9. Oct.; B. Ramkumar, Univ. Düsseldorf, 9. Oct.; Brice Menard, CITA, 12. – 13. Oct.; Dan Weisz, Univ. Minnesota, 11. – 14. Oct.; Ranjan Gupta, IUCAA Pune, 18. – 21. Oct.; Sascha Quanz, ETH Zürich, 18. – 22. Oct.; Jesus F. Barroso, IAC, 25. Oct.– 1. Nov.; Nikoletta Sipos, 26. Oct.– 2. Nov.; Olivier Guillois, CEA-CNRS, 26. Oct.– 7. Nov.; Zsolt Regaly, Konkoly Univ., 28. Oct.– 15. Nov.; P.G. Prada Moroni, Univ. Pisa, 2. – 7. Nov.; Emanuele Tognelli, Univ. Pisa, 2. – 7. Nov.; Ilaria Pascucci, STSI, 7. – 12. Nov.; Genevieve Graves, UC Berkeley, 8. – 12. Nov.; Konrad Tristram, MPI Bonn, 9. – 10. Nov.; Patrick Ruoff, Univ. Tübingen, 10. – 13. Nov.; Gabriel Brammer, Yale Univ., 13. – 17. Nov.; Ruud Visser, Leiden Obs., 15. – 17. Nov.; Nikoletta Sipos, 15. Nov. – 18. Dec.; Stehen Hansen, Dark Cosm.Center, 16. – 18. Nov.; Igor Zinchenko, Russ. Acad. Sci., 17. Nov. – 11. Dec.; Xiaohui Fan, Univ. Arizona, 20. – 24. Nov.; Mariko Kato, Tokyo Inst. Techn., 21. Nov. – 5. Dec.; Zahorecz Sarolta, ELTE Astron. Dept., 23. – 24. Nov.; Erika Verebelyi, ELTE Astron. Dept., 23. – 24. Nov.; Gabor Marton, ELTE Astron. Dept., 23. – 24. Nov.; Andrea Stolte, Univ. Köln, 23. – 27. Nov.; Benjamin Hussmann, Univ. Köln, 23. – 27. Nov.; Nadia Kostogryz, NAO, 25. – 27. Nov.; Marco Spaans, Univ. Groningen, 25. – 28. Nov.; Markus Schöller, ESO, 26. Nov.; Simone Weinmann, MPI Astrophysik, 30. Nov. – 4. Dec.; Timo Anguita, PUC Chile, 30. Nov. – 4. Dec.; Regis Lachaume, PUC Chile, 30. Nov. – 4. Dec.; Zsolt Regaly, Konkoly Obs., 1. – 17. Dec.; Tim van Kempen, Cfa, 3. – 4. Dec.; Greg Herczeg, Caltech, 3. – 4. Dec.; Julio Navarro, Univ. Victoria, 4. Dec.; Warrick Lawson, Univ. New South Wales, 4. – 11. Dec.; Ryan Quadri, Leiden Obs., 6. – 10. Dec.; Rachel Somerville, STSI, 9. – 12. Dec.; Michael Williams, Oxford Univ., 15. – 16. Dec.

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

Calar Alto Observatory Almeria, Spain

Astronomy Coordination: Thiele (Deputy)
Telescope Technology and Data Processing: W. Müller

Departments

Department: Planet and Star Formation
Director: Thomas Henning

Infrared Space Astronomy: Oliver Krause, Zoltan Balog, Marc-André Besel, Stephan Birkmann, Jeroen Bouwman, Helmut Dannerbauer, Örs Hunor Detre, Ulrich Grözinger, Martin Hennemann, Ralph Hofferbert, Rory Holmes, Ulrich Klaas, Hendrik Linz, Friedrich Müller, Markus Nielbock, Jan Pitann, Silvia Scheithauer, Jürgen Schreiber, Amy Stutz

Star Formation: Thomas Henning, Aurora Aguilar Sicilia, Adrianus Bik, Paul Boley, Xuepeng Chen, Min Fang, Davide Fedele, Markus Feldt, Mario Gennaro, Dimtrios Gouliermis, Miwa Goto, Attila Juhasz, Jouni Kainulainen, Serena, Kim, Huabai Li, Ralf Launhardt, Rainer Lenzen, Owen Matthews, Laszlo Mosoni, André Müller, Christian Ormel, Diethard Peter, Sarah Ragan, Veronica Roccatagliata, Boyke Rochau, Markus Schmalzl, Tim Schulze-Hartung, Dmitri Semenov, Bernhard Sturm, Roy van Boekel, Antonin Vasyunin, Tatiana Vasyunina, Wei Wang, Mathias Zechmeister, Svitlana Zhukovska

Brown Dwarfs / Exoplanets: Reinhard Mundt, Carolina Bergfors, Boudreault, Steve, Wolfgang Brandner, Joseph Carson, Kerstin Geißler, Bertrand Goldman, Felix Hormuth, Viki Joergens, Natalia Kudryavtseva, Victoria Rodriguez Ledesma, Johny Setiawan, Christian Thalmann, Patrick Weise

Theory (SP): Hubertus Klahr, Andrej Bicanski, Frithjof Brauer, Bennoit Commercon, Frank Dettenrieder, Natalia Dziourkevitch, Mario Flock, Sebastian Kern, Rolf Kuiper, Christoph Mordasini, Nathalie Raettig, Ana Uribe

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

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

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

Emmy-Noether-Group: "The Formation of Massive Stars": Henrik Beuther, Cassandra Fallscheer, Javier Rodon, Jochen Tackenberg, Yuan Wang

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

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

Department: Galaxies and Cosmology
Director: Hans-Walter Rix

Star Populations and Star Formation: Coryn Bailer-Jones, Thomas Herbst, Steve Boudreault, Christian Elting, Jelte de Jong, Kester Smith, Carola Tiede, Paraskevi Tsalmantza

Structure and Dynamics of Galaxies: Hans-Walter Rix, Glenn van de Ven, Kelly Foyle, Coryn Bailer-Jones, Rainer Klement, Sergey Koposov, Nicolas Martin, David Martinez-Delgado, Eric Morganson, Stefano Pasetto, Anna Pasquali, Stefano Zibetti

Star Formation and Interstellar Medium: Eva Schinnerer, Fabian Walter, Roberto Decarli, Gisella de Rosa, Min Fang, Thomas Greve, Alexander Karim, Sharon Kurk, Adam Leroy, Alejo Martinez-Sansigre, Sharon Meidt, Mark Sargent, Tessel van de Laan, Hsiang-Hsu Wang

Observational Cosmology: Eric Bell, Joe Hennawi, Hermann-Josef Röser Kris Blindert, Anna Galazzi, Sebastian Jester, Marie-Helene Nicol, Christine Ruhland, Kasper Borello Schmidt, Christina Tremonti, Arjen van der Wel

Active Galactic Nuclei: Knud Jahnke, Klaus Meisenheimer, Leonard Burtscher, Mauricio Cisternas, Fontanot, Katherine Inskip, Chrisitan Leipski, Kim Nilsson

Modelling: Christian Fendt, Rachel Somerville, Frank van den Bosch, Marcello Cacciato, Lucas Labadie, Andrea Maccio, Surhud More, Benjamin Moster, Oliver Porth, Ramin Skibba

Instrumental Developments: Josef Fried, Thomas Herbst, Jörg-Uwe Pott, Rory Holmes, Roman Follert, Eva Meyer, Xianyu Zhang

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

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

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

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

Teaching Activities

Winter Term 2008/2009

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

Summer Term 2009

C. Bailer-Jones: Applications of Machine Learning in Astronomy (Lecture)
C. Bailer-Jones: Statistical Methods (Lecture)
E. Bell, H. W. Rix: Galaxies (Lecture)
E. Bell, H. W. Rix: Exercises on Galaxies (Exercises)
H. Beuther: Star Formation (Lecture)
H. Beuther: Massive Star Formation (Seminar)
C. Dullemond: Tutorial on Computational Fluid Dynamics (Exercises)
C. Dullemond: Computational Fluid Dynamics (Lecture)
Ch. Fendt, H.-J. Röser: Introduction to Astronomy and Astrophysics III (Seminar, with J. Heidt, LSW/ZAH)
Ch. Fendt, C. Dullemond: Current Research Topics in Astrophysics (IMPRS Seminar, with A. Quirrenbach, LSW/ZAH)
Ch. Fendt: Workshop (IMPRS Seminar, with A. Just, ARI/ZAH)
Th. Henning: Physics of Star Formation (Lecture)
F. Huisken: Clusters and Nanoparticles (Lecture, FSU Jena)
F. Huisken: Laboratory Astrophysics (with H. Mutschke, Lecture, FSU Jena)
H. Klahr: UK-Numerics (Block Lecture, with R. Banerjee. ITA/ZAH)
N. Martin: The Local Group as a cosmological probe, IMPRS block course (Guest Lecture)
N. Martin: The structure of faint Local Group dwarf galaxies, IMPRS summer school (Guest Lecture)
K. Meisenheimer: Colloquium at MPIA and LSW (with S. Wagner, M. Camenzind, LSW/ZAH)
K. Meisenheimer: Group Exercises on Experimental Physics II (Exercises)
R. Mundt: Introduction to Astronomy and Astrophysics III (Seminar)
H.-W. Rix: Galaxien (Block Lecture)
B. Rochau: Physical Practicals IIA (Practicals)
H.-H. Wang: Computational Fluid Dynamics (Exercises)

Winter Term 2009/2010

H. Beuter, Ch. Fendt: Introduction to Astronomy and Astrophysics I (Lecture)
H. Beuther, Ch. Fendt, L. Burtscher: Introduction to Astronomy and Astrophysics I (Exercises)
Ch. Fendt, K. Meisenheimer: Workshop (IMPRS Seminar, with T. Lisker, ARI/ZAH
Th. Henning: Physics of Star Formation (Seminar)
F. Huisken: Clusters and Nanoparticles: Part I (Clusters) (Lecture, FSU Jena)
K. Meisenheimer: Colloquium at MPIA and LSW (with S. Wagner, LSW/ZAH)
K. Meisenheimer: Astrophysical sources of high energy radiation (Seminar, with S. Wagner, LSW/ZAH, J. Kirk, MPIK)
O. Porth: Introduction to Astronomy (Exercises)
B. Rochau: Physical Practicals IIA (Practicals)
H. W. Rix: Observing the Big Bang (Lecture)

Service in Committees

Cristina Afonso: Member of the S-TAC at the MPIA; Member of the Strategy Survey Working Group of PAN-STARRS1; Member of the scientific community and working group of the Plato Space Mission Concept
Coryn Bailer-Jones: Member of the PhD Advisory Committee at the MPIA; Manager of the Subconsortium "Astrophysical Parameters" in the GAIA Data Processing and Analysis Consortium; Member of the GAIA Data Processing and Analysis Consortium Executive; Member of the Scientific Organizing Committee of Commission 45 (Stellar Classification) of the IAU
Henrik Beuther: Member of the APEX program committee; Member of the ESO OPC; Member of the IRAM program committee
Wolfgang Brandner: Member of the Calar Alto Scientific Advisory Committee (SAC); Member of the FP7 E-ELT Preparation Group (ESO); Member of the METIS Science Team; Member of the PhD Advisory Committee at the MPIA; Member of the selection committee of the Astronomical Colloquium Heidelberg
Leonard Burtscher: Speaker of the PhDnet (PhD-Student Network of the MPG), deputy speaker of the IMPRS-HD
Cornelis P. Dullemond: Mitglied des PhD Advisory Committee am MPIA
Christian Fendt: Member of the Graduation Committee of the Faculty of Physics and Astronomy, Heidelberg
Kelly Foyle: IMPRS representative
Wolfgang Gässler: Member of the LBT First Light AO review commitee; Member of the IAU Working Group on Optical Interferometry Data Standards
Bertrand Goldman: Member of the PANIC science team; Member of the PAN-STARRS1 SPOC; Member of the PAN-STARRS1 KPAT committee

Roland Gredel: Member of the ELT Site Selection Advisory Committee; Member of the ELT Science and Engineering Committee; Head of the Dome C (Antarctica) site quality assessment; Head of the OPTICON board; Member of the OPTICON telescope directors forum

Thomas Henning: Head of Lange Binocular Telescope Beteiligungsgesellschaft; Member Representative of the LBT Board; Member of the CAHA Executive Committee; Member of the PS1 Board of Directors, Member of the Appointment Committee of the MPI for Solar System Research; Visiting Committee for Physics, University of Innsbruck; Search Committee, ESO Director of Programs (Head); ESO Council (Vice President), Member of the SOFIA Science Council; Member of the Advisory Council of the Kiepenheuer Institute for Solar Physics, Freiburg, and of the Thüringen State Observatory, Tautenburg; Member of the Selection Committee of the Dutch Academy Professorship Programme

Tom Herbst: Principal Investigator for LINC-NIRVANA; Member of the Science and Technical Committee (STC) for the Large Binocular Telescope; Member of the ESO Science Strategy Working Group and Science and Technical Committee; Chairman of the E-ELT Science and Engineering Committee; Head of the WP3 “Operations” for MICADO; Member of the PhD Advisory Committee at the MPIA

Klaus Jäger: Board Member of the Astronomische Gesellschaft (PR officer) (since September 2009); Member of the Scientific Advisory Board of the International Summer Science School Heidelberg (ISH); Collaborator of the Rat Deutscher Sternwarten (RDS) and the LBT-Beteiligungsgesellschaft (LBTB)

Knud Jahnke: Member of the ESO Panel, Periode 85

Viki Joergens: Member of the PhD Advisory Committee at the MPIA

Hubert Klahr: Referee of the NASA Origins Review Panel, Member of the Appointment Committee at the MPIs for Physics, for Extraterestrial Physics and for Solar System Research, Member of the Phd Advisory Commitee at the MPIA, Member representative in the Section CPT of the MPG

Martin Kürster: Member of the ESO OPC Panels

Ralf Launhardt: Member of the S-TAC at the MPIA; Jury Member for the Scientific Ernst Patzer Prize (until May); Project scientist at ESPRI

Reinhard Mundt: MPIA representative in the German-Spanish CARMENES team

Hans-Walter Rix: Member of the Scientific Advisory Council of the Astrophysical Institute Potsdam; Head of the PS1 Science Consortium; Board Member of the LBT Beteiligungsgesellschaft; Member of the NIRSPEC Science Team; Member of the BMBF Referees Committee “Astrophysics and Astroparticle Physics”; Member of DFG Fachkollegien; Member “at large” of the ASTRONET Infrastructure Roadmap Working Group

Jakob Staude: Member of the National Selection Committee for the Contest “Jugend forscht”

Glenn van de Ven: Member of the PhD Advisory Committee at the MPIA; Jury Member for the Scientific Ernst Patzer Prize

Fabian Walter: Member of the JWST MIRI European consortium; Member of the IRAM Program Committee; Member of the PAN-STARRS Science Council

Further Activities

Girls’ Day, held at the Institute on April 23, was organized by Cristina Afonso, Vianak Naranjo, Alexander Karim and Silvia Scheithauer. Klaus Jäger gave a talk on “The sky in the computer – virtual planetaria”.

On May 17, the MPIA threw open its doors and more than 5000 visitors took up this invitation to visit the Institute on top of the Königstuhl.

The series of 8 lectures “Astronomy on Sunday Morning” in June–July was organized by Klaus Jäger, Markus Pössel, Axel M. Quetz and Jakob Staude.

The Institute’s Board of Trustees met on September 18.

On October 13, the first official groundbreaking ceremony was held for the Haus der Astronomie (House of Astronomy) on the grounds of the MPIA in the presence of Prof. Kurt Roth (Pro-Vice Chancellor of the University of Heidelberg), Manfred Bernhardt (Architects Bernhardt + Partner, Darmstadt), Beate Spiegel (Klaus Tschira Foundation), Prof. Herbert Jäckle (Vice President of the Max Planck Society) and Dr. Eckart Würzner (Mayor of Heidelberg).

The BOGy practicum for school pupils on Oct 26–27 was organized by Leonard Burtscher, Klaus Jäger, Klaus Meisenheimer and Silvia Scheithauer. Klaus Jäger gave a talk on “Galaxies and Terabytes–Optical Astronomy in the Age of Modern Large Telescopes”.

Over the year, a total of 680 visitors in 32 groups were taken on a tour of the Institute (Axel M. Quetz, Natalie Raettig and others).

There were 19 press releases and staff gave many radio and TV interviews (Klaus Jäger, Markus Pössel, Axel M. Quetz, Jakob Staude and others).

Cristina Afonso held the office of Equal Opportunities Commissioner at the MPIA and is the Equal Opportunities Commissioners’ representative of the CPT Section at the MPG.

Wolfgang Brandner taught 4 study units on the topic of the “Solar System” during researchers’ day at Baldham primary school (June 26) and manned the stand “Adaptive Optics and Astronomy” at the “Highlights of Physics” event in Cologne (September 20–24).

Leonard Burtscher manned the astronomy stand at the Frankfurt Book Fair (17 October).

Cornelis Dullemond organized the “Miniforschung” (Miniresearch) for students in the lower semesters.

Thomas Henning was a panelist at the opening event for the “International Year of Astronomy” on January 20 in Berlin.

Tom Herbst undertook a research residency at the Herzberg Institute of Astrophysics in Victoria, British Columbia, Canada (September 1–December 22) to collaborate with the instrumentation teams of the Gemini Telescope, the Canada-France-Hawaii Telescope (CFHT) and the Thirty Meter Telescope (TMT).

Stefan Hippler supervised Experiment F36 "Wave front analysis" in the advanced practical training for physicists.

Klaus Jäger arranged special guided tours of the Institute with accompanying lectures for Heidelberg City Council, the IMPRS, the Rhein-Neckar newspaper and others. He was a guest on the talkshow "Zur Sache" (Brass Tacks) broadcast by Rhein-Neckar television (December 18), put together a video / audio trailer for the MPIA, contributed to the editing of the book "Unendliche Weiten – Weltraum erleben im Planetarium Mannheim" (a book on the infinite vastness of space written to commemorate the 25th anniversary of Mannheim Planetarium), and was involved in the opening event for the "International Year of Astronomy" on January 20 – 21 in Berlin, the exhibition "Himmlisches in Büchern" (The sky in books) in the library of Heidelberg University (with A. M. Quetz) and the "Science Express" science train of the MPG (with A. M. Quetz).

Alexander Karim was involved in the particle physics show of the University of Bonn at the KIP, Heidelberg (December 4 – 6).

Ulrich Klaas was the Chairman of the Library Committee.

Reinhard Mundt was the Ombudsman of the MPIA.

Jörg-Uwe Pott was the postdoc spokesman at the MPIA.

Axel M. Quetz was involved in the editing and design of the 48th volume of the magazine "Sterne und Weltraum" (Stars and Space).

Boyke Rochau supervised two students at the DAAD RISE (Research Internships in Science and Engineering) from June 8 – August 7.

Christine Ruhland and Markus Schmalzl were the student spokespersons at the MPIA.

Eva Schinnerer was an evaluator at the (E)VLA/VLBA of the NRAO.

Johny Setiawan was involved in supervising the "Jugend forscht" (Young researchers) project undertaken by the State prize winners Julyan Petrasch and Lennart Schlieder at the MPIA's 70-cm KING telescope (February 1 – 7).

Jakob Staude was involved in the publication of the 48th volume of the magazine "Sterne und Weltraum". Between October 2008 and March 2009 he organized and managed the series of 14 lectures for the General Studies component at the University of Heidelberg entitled "Galilei's first look through the telescope and the consequences for today".

Jürgen Steinacker has been a visiting professor at the Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (LERMA) des Observatoire de Paris since September.

Christian Thalmann instructed the members of the NACO Large Program in data reduction (December).

Awards

The Otto Hahn Medal of the Max Planck Society for outstanding achievements by junior scientists was presented to Dominik A. Riechers for pioneering work on the properties of molecular gas and mass distribution in those galaxies which already had extremely massive black holes when the universe was in its infancy.

This year's prizes from the Wissenschaftliche Ernst-Patzer-Stiftung (Scientific Ernst Patzer Foundation) were awarded to the doctoral student Min Fang for his publication "Star and protoplanetary disk properties in Orion's suburbs", the doctoral student Aday Robaina for his publication "Less than 10 percent of star formation in $z \sim 0.6$ massive galaxies is triggered by major interactions" and to the postdoc fellowship holder Adam Leroy for his publication "The star formation efficiency in nearby galaxies: Measuring where gas forms stars effectively".

Jörg-Uwe Pott was awarded a research grant of US $ 13 000 by NASA for an observation project with the Keck telescope.

Christoph Mordasini received a two-year Humboldt research fellowship for postdocs.

Kelly Foyle was presented with the "Best talk by students award" at the CASCA Conference, Toronto, Canada, in May.

Viki Joergens was awarded a Margarete-von-Wrangell fellowship for postdoctoral lecturing qualification from the Federal State Ministry for Science, Research and the Arts, Baden-Württemberg.

Johny Setiawan was honored by the Embassy of the Republic of Indonesia, Berlin.

Compatibility of Science, Work, and Family

The MPIA has been increasing its efforts to improve the compatibility of science, work, and family for a great many years. Scientific work, in particular, presents a very special challenge when trying to make these issues compatible. Since 2005, important steps have been introduced at the MPIA to provide both outstanding research conditions and important solutions to improve the work-life balance. The MPIA has so far put the following measures into practice: MPIA International Office to support staff in finding living accommodation, suitable childcare facilities and schools, and other administrative matters; allotted places at day nurseries in Heidelberg with long opening hours for children under three years of age; baby office and childcare room at the Institute; childcare at congresses; an external family service to advise staff on issues related to the improved compatibility of career and care of family members; flexible working hours and location; support of professional careers during 'time out' taken for family reasons; cooperation in the Dual Career

Network of the scientific establishments in Heidelberg, and cooperative ventures in the Heidelberg company networks in order to be involved in improving the framework conditions for science.
The services we provide for childcare, flexible working, the compatibility of work and care, and the service for dual career couples are extremely important for science. A family-friendly staff policy can greatly improve the daily working life of scientists and also of staff in other areas.

The Max Planck Society with its 80 institutes was awarded the "Beruf und Familie" (Career and family) certificate in June by the Ministry for Family Affairs. This created a supra-institutional standard for the whole MPG in the area of work-life balance.
The MPIA has firmly integrated the issue of compatibility of science, work and family as an integral economic component for science, and as a future-oriented staffing concept in order to thereby continue to promote the competitiveness of the Institute on an international level.

Cooperation with Industrial Companies

2m Theater- und Veranstaltungstechnik, Wülfrath
3B Scientific GmbH, Hamburg
A & F Deutschland GmbH, Hannover
Aachener Quarz-Glas, Aachen
Acrylics, Niederfischbach
ADCO GmbH, Aachen
ADDITIVE GmbH, Friedrichsdorf
adlus GmbH, Elchingen
Adolf Pfeiffer GmbH, Mannheim
ADR S.A., Thomery
Advanced Office Products GmbH, Bochum
Agilent Technologie, Böblingen
Air Liguide GmbH, Leipzig
Air Liquide Deutschland GmbH, Oberhausen
AktivShop im MBO Verlag GmbH, Rheine
Alcatel, Wertheim
Allcom GmbH, Oldenburg
Alternate Computer Versand, Linden
AMERICA II EUROPE GmbH, Mönchengladbach
American Institute of Physics, Melville NY 11747-4502
ANDUS ELECTRONIC GMBH, Berlin
Aqua Technik Gudat, Neulußheim
AquaDuna, Sternenfels
Argenta Elektronik, Solingen
ARLT, Magstadt
Arrow Central Europe GmbH, Dreieich
Arte & More GmbH, Raunstein
asknet AG, Karlsruhe
AstroMedia-Versand, Neustadt in Holstein
ASYS, Dornstadt
Atomic Softek, Hamilton, Ontario
ATP Messtechnik GmbH, Ettenheim
Auer Paul GmbH, Mannheim
Aufzug-Service M. Gramlich GmbH, Ketsch
Austerlitz Electronic GmbH, Nürnberg
Autobus Oberbayern, Bad Wiessee
Autohaus Krauth GmbH&Co.KG, Meckesheim
Avnet Abacus Dortmund, Holzwickede/Dortmund
AVNET EMG GmbH, Poing
B.E.S.T., Forst
B+S Express Transport GmbH, Weinheim
Baader Planetarium GmbH, Mammendorf
bacuplast GmbH, Remscheid
Baier Digitaldruck, Heidelberg
Baker & Harrison, München
Bastisch EDV Zubehör, Mannheim
BDK, Sonnenbühl
Bechtle GmbH & Co.KG, Mannheim
Bechtle ÖA Direkt, Neckarsulm
Bernhardt Nutzfahrzeuge GmbH, Heidelberg
Bethge Joachim, Mauer
Betten Fürstenberger, Wiesloch
Billettfabrikation+Druckerei, Ketsch
Binder Elektronik GmbH, Sinsheim
Bleher-Folientechnik, Heimerdingen
Blitz Button+Wagner Werbung GmbH, Dielheim
Börsig GmbH, Neckarsulm
BRADY GmbH, Egelsbach
Bundesanzeiger, Köln
Bürklin OHG, München
Bürma Büromarkt, Stuttgart
Büro-Mix GmbH, Mannheim
Büro-Taxi GmbH, Kamp-Lintfort
Büromarkt Böttcher AG, Jena
Buster Altöl GmbH, Mannheim
CADFEM GmbH, Grafing
Cadmus Journal Services, Charlotte, NC 28275-1903
CAMCenter GmbH, Nidderau
Camfil KG, Reinfeld
CANCOM NSG GmbH, Jettingen-Scheppach
Carbon Vision GmbH, Unterschleißheim
Carl Zeiss Industrielle Messtechnik, Oberkochen
Carl Zeiss Jena GmbH, Jena
Carl Zeiss Optronics GmbH, Oberkochen
CDS Copy und Digital Druck GmbH, München
CGB-Carbon Grossbauteile, Wallerstein
Coating-Plast GmbH, Schriesheim
Coda KG, Waldkirch
Coherent Europe B.V., KL Utrecht
Colordruck, Leimen
Comarch Systemintegration GmbH, München
Compumess Elektronik GmbH, Unterschleissheim
Computacenter AG & Co oHG, Stuttgart
COMTRONIC GmbH, Wilhelmsfeld
Conatex Didactic Lehrmittel GmbH, Neunkirchen
Conrad Electronic GmbH, Hirschau
Conrad Electronic SE, Wernberg-Köblitz
Contag GmbH, Berlin
Container Weis, Leimen
Cornelsen Experimenta GmbH&Co, Berlin
CreaSo GmbH, Gilching
CRYO Anlagenbau GmbH, Wilnsdorf
Cryophysics GmbH, Darmstadt
Cryovac Gesellschaft fuer, Troisdorf
Cyberport GmbH, Dresden

Cyclotron Computervertrieb e. K., Wiesbaden
D.H. Frank GmbH, Nußloch
Dastex GmbH & Co. KG, Muggensturm
Data Translation GmbH, Bietigheim-Bissingen
dataTec GmbH, Reutlingen
DATOS-Computer GmbH, Wuppertal
db electronic Daniel Böck GmbH, Ehringshausen
DDC Elektronik GmbH, München
DELL-Computer GmbH, Frankfurt
DELTA-V GmbH, Wuppertal
DELTRIC GmbH, Frankfurt am Main
Deltronix Enterprises, Mission Viejo
Denios AG, Bad Oeynhausen
Der Dekoladen LTD, Mannheim
Deti GmbH, Meckesheim
Deutsche Telekom AG, Darmstadt
Dewit Industrial Sensor GmbH, Witten
Dicronite U.T.E. Pohl GmbH, Iserlohn
Digi-Key c/o US Bank Minneapolis, Enschede
Distrelec Schuricht GmbH, Bremen
DMG Stuttgart Vertriebs+Service Gmb, Leonberg
DMV, Halle-Queis
Dobritzsch, Maintal
DPS Vakuum, Großrinderfeld
DPV Elektronik Service GmbH, Eppingen
Dräger Safety AG & Co.KGaA, Lübeck
Draht Mayr GmbH, Dielheim
Drahtwaren-Driller, Freiburg
Drucker Druck, Bietigheim
DVS Dekont Vakuum Service GmbH, Erfurt
dynarep Electronic Vertriebs GmbH, Gauting
EBJ, Ladenburg
EDICO-Equipment GmbH, Nürnberg
Edmund Optics GmbH, Karlsruhe
EKZ. Bibliotheksservice GmbH, Reutlingen
Elblinger Elektronik GmbH, Salzgitter
Electronic Product Services Limited, Düsseldorf
electronic sensor+resistor GmbH, Ottobrunn
Elektro-Steidl, Weinheim
EMF 97 GmbH, Worms
ERNI Electronics GmbH, Adelberg
ERSA GmbH, Wertheim
European IT Storage Ltd., Filderstadt
Excel Technology Europe GmbH, Darmstadt
Faber Industrietechnik GmbH, Mannheim
Farben Specht, Bammental
Farnell GmbH, Oberhaching
FAST ComTec Communication, Oberhaching
Faulhaber GmbH & Co KG, Schönaich
FEISOL Inc., Aachen
Fels Fritz GmbH Fachspedition, Heidelberg
FILCON Electronic GmbH, Taufkirchen
FISBA Optik AG, St. Gallen
Fischer Elektronik GmbH & Co. KG, Lüdenscheid
Fleige-Optik, Holm-Wedel/Hamburg
FLIR Systems, Frankfurt
FlowCAD EDA-Software Vertrieb, Feldkirchen
FOLIT GmbH, Kornwestheim
FOP Faseroptische Produkte GmbH, Crailsheim
fotoversand24.de, Schwerin
FPS-Werkzeugmaschinen GmbH, Warngau
Friedrich Wolf GmbH, Heidelberg
Fritz Zugck, Leimen
FTU-Fortbildungszentrum für Technik, Karlsruhe
Füssener Astro-Lehrmittel, Füssen
G+H Schallschutz, Ludwigshafen
Gaerner GmbH, Frankfurt
Ganter GmbH, Walldorf
Gartenwelt Bumb GmbH, Karlsruhe
GCE GmbH, Eppelheim
Gebr. Kassel GmbH, Gondelsheim
Geier Metall-u.Stahlhandel GmbH, Mannheim
Geier Metall-u.Stahlhandel GmbH, Mannheim
Geiger Alois Söhne GmbH & Co.KG, Sandhausen
Gerwah Präzision GmbH, Grosswallstadt
Gimahhot GmbH, Hamburg
Glas Hlawatsch GmbH, St. Leon-Rot
Gleich GmbH, Kaltenkirchen
Glenair Electronic GmbH, Steinbach
Göbel, Horst, Ludwigshafen
Grating Solver Dev. Company, Allen
Großversandhaus-Bader, Pforzheim
Grothues Elektrotechnische Geräte G, Leimen
Grulms Pneumatik GmbH, Grünstadt
Gummispezialhaus Körner, Eppelheim
Güniker + Heck, Mannheim
Günter Jacobi GmbH, Griesheim
Gutekunst & Co. Federnfabrik, Metzingen
Gutruf Werner, Meckesheim
Haarländer GmbH, Roth
Hach GmbH, Pfungstadt
Häcker GmbH, Weinsberg
Häfele, Roland, Schriesheim
Hagemeyer Deutschland GmbH &Co KG, Heidelberg
Hahn u. Kolb GmbH, Stuttgart
Hailo-Werk GmbH & Co.KG, Haiger
Hanhart Shop, Hamburg
Harmonic Drive AG, Worms
Hauck GmbH, Heidelberg
Haus des Blindenhandwerks, Esslingen
Hebmüller SRS Technik, Neuss
Hehr Rudolf, Heidelberg
HELUKABEL GmbH, Hemmingen
Hera Laborsysteme GmbH, Blaufelden
Herose GmbH, Bad Oldesloe
Heuser Friedrich GmbH, Heidelberg
Hewlett-Packard Direkt GmbH, Böblingen
Hilma-Römheld GmbH, Hilchenbach
Hilti Deutschland GmbH, Heidelberg
Hintze u. Kunick GmbH, Berlin
HM Industrieservice GmbH, Kronau
HMC H.Meyer & C0, Düsseldorf
Hoffmann, Göppingen
Hoffmann Nürnberg GmbH, Nürnberg
Holz Zentrum Schwab GmbH, Hockenheim
Holzland, Tübingen
Hommel Hercules-, Viernheim
Honsberg & Co.KG., Remscheid
Horiba Jobin Yvon GmbH, Bensheim
Horn, Stutensee
Hositrad Deutschland, Regensburg
HOT Electronic GmbH, Taufkirchen
HP GmbH, Böblingen
HSD Consult GmbH, Berlin
Huba Control AG, Walddorfhäslach
Huber + Suhner GmbH, Taufkirchen
Hummer + Rieß GmbH, Nürnberg
HY-LINE Power Components Vertr. GmbH, Unterhaching
IKEA, Walldorf
ILFA Feinstleitertechnik GmbH, Hannover
Industriebedarf Oberhausen, Ketsch
Ineltek GmbH, Heidenheim
Ing.H. Tafelmaier, Rosenheim

Ingenieurbüro Lopez, Jena
Ingenieurbüro M. Steinbach, Jena
Ingenieurbüro Castlemacher, Unterschleissheim
INNEO Solutions GmbH, Ellwangen
INOTEC electronics GmbH, Lauffen a.N.
inova Semiconductors GmbH, München
Integrate Computer, Frankfurt
Intercon Spacetec, Augsburg
INVENT GmbH, Braunschweig
Inwerk GmbH, Meerbusch
IOP Publishing Ltd., Bristol
ISOLOC Schwingungstechnik GmbH, Stuttgart
item Industrietechnik, Ulm
Jacobi Eloxal GmbH, Altlussheim
Jacobi Kunststoffbeschichtung, Altlussheim
Jenoptik Laser, Optik, Systeme GmbH, Jena
JUMO GmbH & Co. KG, Fulda
KA-WE GmbH, Schwetzingen
Kai Ortlieb Buchbinderei, Eppelheim
KAISER + KRAFT, Stuttgart
KAKO Elektro GmbH, Nußloch
Karl Scholl GmbH, Heidelberg
Katzer Printvision Gmbh, Sandhausen
Kaufmann, Horst W., Crailsheim-Wittau
Keil An ARM Germany GmbH, Grasbrunn
Kerb-Konus-GmbH, Amberg
KFK Verzinkerei GmbH, Sinsheim
Kistler Instrumente GmbH, Ostfildern 2 (Nellingen-)
Klar Heinrich GmbH, Wuppertal
Kniel GmbH, Karlsruhe
Kobold Messring GmbH, Hofheim/Taunus
KOCO MOTION GmbH, Dauchingen
kofferxpress.de, Ehingen
Kohlhammer W. Druckerei, Stuttgart
Konica Minolta Businesss, Mannheim
Krause + Hagmann GmbH, Heidelberg
Kroschke GmbH, Braunschweig
Kruse Sicherheitssysteme GmbH & Co., Stelle
Kühne & Nagel (AG&CO.) KG, Mannheim
KVB, Chemnitz
L.+H. Hochstein GmbH + Co., Heidelberg
L.Grandpair, Heidelberg
Lampenwelt GmbH, Schlitz
Landefeld GmbH, Kassel-Industriepark
Landig Deutschland, Bad Saulgau/Lampertsweiler
Lapp Kabel GmbH, Stuttgart
Laser-Zentrum-Hannover, Hannover
Laub GmbH+Co, Elztal-Dallau
Lemo Elektronik GmbH, München
Lenke Printware Großhandel, Jena
Leuchten u.Leuchtmittel Seidler, Hamburg
Leuchtmittel Markt, Forchheim
Liebert Mary Ann Inc.Publishers, New Rochelle
Linos Photonics GmbH, Göttingen
Lorenz Messtechnik GmbH, Altdorf
LPKF CAD/CAM Systeme GmbH, Garbsen
LTN Servotechnik GmbH, Otterfing
LZS Global Services,Inc., Fremont
M & L Montagetechnik Luck GmbH, Wasungen
Maas International GmbH, Bruchsal
maastrek SELECTION, Hildesheim
Mädler GmbH, Stuttgart
Maico, Villingen-Schwenningen
Malteser-Hilfsdienst e.V., Wiesloch
Maschinenbau Pelzer, Jena
Masterplatex, Berlin
Max Computer GmbH, Schönberg
MAXIM GmbH, Planegg
Mayer GmbH Omnibusbetrieb, Neckargemünd-Dilsberg
MDesign GmbH, Bochun
Mediaresort, Altena
Meilhaus Electronic GmbH, Puchheim
Mekentosj.B.V-, RA Aalsmeer, The Netherlands
Melitta Systemservice GmbH & Co.KG, Minden-Dützen
Memec Express, Unterhaching
Merz Johannes GmbH, Speyer
Metabowerke GmbH, Nürtingen
Metallbau GLAWION GmbH, Eberswalde
Metrofunkkabel-Union GmbH, Berlin
MGV Stromversorgung, München
MicroStaXX GmbH, München
MK Computer Electronic GmbH, Göppingen
Möller-Wedel Optical GmbH, Wedel b. Hamburg
Montronic GmbH & Co.Kg, Wentorf bei Hamburg
Mouser Electronics, Maisach-Gernlinden
MTM Power, Mellenbach
MTS Systemtechnik GmbH, Mertingen
Mundelsee Karlheinz, Nussloch
Mura, Metallbau, Viernheim
Murata Elektronik GmbH & Co, Nürnberg
Murrplastik-System-Technik, Oppenweiler
MWR/Christian Wirth, Rimbach
Neolab Laborbedarf - Vertriebs GmbH, Heidelberg
Neopost, Unterschleißheim
Netzsch-Gerätebau GmbH, Selb
Netzwerkartikel.de, Oberhausen
Neumann Druckerei, Heidelberg
Newport Spectra-Physics GmbH, Darmstadt
Nibler W. GmbH, Walldorf
Nies Elektronic GmbH, Frankfurt
Nikonians EMEA Ltd., Donaueschingen
Nimax GmbH – Astroshop.de, Landsberg
Noesse Datentechnik, Leverkusen
NOVOTEK GmbH, Böblingen
NU Horizons Electronics GmbH, München
Oerlikon, Köln
officeb2b GmbH, Aystetten
Olympus Deutschland, Hamburg
Omnilab GmbH, Berlin
Opal Ass. GmbH, Insel Reichenau
OpenStorage, Wiesbaden
Optical Society of America, Washington DC
Optima Research Ltd., Stansted
OptoPolymer, München
ORBITEAM SW-GmbH, Bonn
Otto Blumen GmbH, Mannheim
OWIS GmbH, Staufen
Panasonic, Holzkirchen
Pepperl + Fuchs GmbH, Mannheim
Pfeiffer & May, Heidelberg
Pfeiffer Vacuum GmbH, Asslar
Pfister Büro mit Maß und System, Leimen/St.Ilgen
Philipp Lahres GmbH, Weinheim
Phoenix Contact GmbH & Co., Blomberg
Photo-Center Kühnemann, Jena
Physik Instrumente (PI), Karlsruhe
Phytec Messtechnik, Mainz
Phytron-Elektronik GmbH, Gröbenzell
Phywe Systeme GmbH & CO.KG, Göttingen

Pink GmbH, Wertheim
Plambeck deko event, Tespe
Pneu-Therm Ltd., Newark, Nottinghamshire
POG – Präzisionsoptik Gera GmbH, Gera
Pollin Electronic GmbH, Pförring
Polytec GmbH, Waldbronn
Precision Plus Vacuum Parts, München / Kirchheim
Pro Media Concept GmbH, Konstanz
Pro-Com Datensysteme GmbH, Eislingen
PSS Projektions-Systeme-Schmitt e.K, Leimen
R. & S. Keller GmbH, Wuppertal
Radiall GmbH, Rödermark
Raiffeisen Lagerhaus EG Meckesheim, Bammental
Rapid Transportgeräte GmbH, Beckum/Westf.
Rasti GmbH, Haren
ratioform, Ladenburg
RAZ R.A. Zimmermann KG, Dietzenbach
Recom Electronic GmbH, Dreieich
Record Metall Folien GmbH, Mühlheim
redcoon GmbH, Aschaffenburg
Redlich-EDV, Jena
REEG GmbH, Wiesloch
Reichelt Elektronik, Sande
Reifen Stoll, Wiesenbach
Rhein-Neckar-Verkehr GmbH, Mannheim
Rhein-Neckar-Zeitung, Heidelberg
Rieche- Elektronik, Hitzhusen
Riekert & Sprenger, Wertheim
Rinnert GmbH, Kaast
Rittal GmbH + Co.KG, Herborn
RMG Metallfachhandel GmbH, Ladenburg
Rofin-Sinar Laser GmbH, Bergkirchen
Roth Carl GmbH & Co.KG, Karlsruhe
RS Components GmbH, Mörfelden-Walldorf
RUF Elektrohandel GmbH & Co.KG, Mannheim
Rufenach Vertriebs-GmbH, Heidelberg
Rutronik, Ispringen
Samtec Germany, Germering
Sanitär-Raess GmbH, Heidelberg
Sauter-Cumulus GmbH, Freiburg
Scantec GMBH, Germering
Schäfer Fritz GmbH, Neunkirchen
Schäfer Shop GmbH, Mannheim
Schaffland Detlef, Handelsvertretung, Leverkusen
Schäfter+Kirchhoff GmbH, Hamburg
Scheffel elektronischer Vertrieb Gm, Ditzingen
Schenker Deutschland AG, Mannheim-Rheinau
Schmidt Mess- und Regeltechnik, Spiesheim/Rhh.
Schmitt Stefan, Wiesloch
Schneider Günther GmbH, Sandhausen
Schreiber-Glas, Berlin
Schroff GmbH, Straubenhardt
Schulz H.u.G. Ingenieure, Heidelberg
SCHUPA Schumacher GmbH, Walldorf
Schuricht GmbH + Co KG, Bremen
SE Spezial-Electronic AG, Bückeburg
Seifert mtm Systems GmbH, Ennepetal
servo Halbeck GmbH & Co.KG, Offenhausen
Ses – Société Européene de, Aix-En-Provence Cedex 3
Sicon Socomec GmbH, Mannheim
Siemens Build.Technol.GmbH & Co.OHG, Mannheim
Sigmann Elektronik GmbH, Hüffenhardt
Sky Blue Microsystems GmbH, München
SLCR Lasertechnik GmbH, Düren
Sphinx Computer Vertriebs GmbH, Hemsbach
Sphinx GmbH, Laudenbach
Spiess Elektro Markt GmbH, Rauenberg
Stempel Bauer, St. Leon-Rot
StoCretec, Kriftel
Stumpf Jochen Schreinerei, Nußloch
Sumitomo, Elk Grove Village
Sunrise Netztech Transfer, Bornheim
SWS Edelstahl GmbH, Emmingen
Systerra Computer GmbH, Jena
T-E Klebetechnik, Hannover
Tautz Druckluft+Sandstrahltechnik G, Mannheim
Team Arrow, Neckarsulm
Technik Direkt, Würzburg
Teledyne Scientific & Imaging LLC, Thousand Oaks
Telemeter Electronic GmbH, Donauwörth
Telko GmbH Saalfeld, Saalfeld
Tetronik GmbH, Tanusstein-Wehen
The MathWorks GmbH, Ismaning
Theile Büro-Systeme, Speyer
Thermodyne GmbH, Osnabrück
Thorlabs GmbH, Dachau
ThyssenKrupp Schulte GmbH, Mannheim
Tischer Gastro, Heidelberg
Topcart International GmbH, Erzhausen
Torso-Verlag, Wertheim
Total Mineralöl GmbH, Fellbach-Schmiden
Total Walther GmbH, Ratingen
Tower Electronic Components GmbH, Dossenheim
tproneth GmbH & Co. KG, Puchheim
transtec AG, Tübingen
Trinos Vakuum-Systeme, Göttingen
Trumpf Laser GmbH, Leonberg
Typographus, Berlin
UHT Umschlag- und Hafentechnik GmbH, Eberswalde
UKP GmbH, Mainz
United Electronic Industries, Inc., Walpole
Vacom GmbH, Jena
Varian GmbH, Darmstadt
VAT Deutschland GmbH, Grasbrunn
Vereinigte Baustoff u. Eisen GmbH, Heidelberg
Verlag Europa-Lehrmittel, Haan – Gruiten
VWR International GmbH, Dresden
W.Niedergesess Holz, Sandhausen
Walter Bautz GmbH, Griesheim
Wamser Büro Service, Mannheim
Watlow GmbH, Kronau
Watterott electronic, Hausen
Wero-medical, Sandhausen
Westphalia, Hagen
WHD Wachdienst Heidelberg, Heidelberg
Wiesemann u. Theis GmbH, Wuppertal
Willi Stober GmbH & Co. KG, Karlsruhe
Winger Elektronics GmbH & Co.KG, Dessau-Roßlau
Witzenmann Rhein-Ruhr GmbH, Xanten
Wollschläger GmbH & Co. KG, Weinstadt-Endersbach
Würth Elektronik GmbH & CO.KG, Künzelsau
XP Power GmbH, Bremen
Zemax Dev. Corp., Bellevue, WA
Zimmermann Heizöl Total, Sandhausen

Conferences, Scientific, and Popular Talks

Conferences Organized

Conferences Organized at the institute:

Internel Symposium, MPIA, 18. Feb. (K. Jahnke)

Retreat "LBT Science Exploitation", Castle Edesheim, 12. – 13. Feb. (K. Jäger)

Workshop "CAHA Legacy Survey", MPIA, 24. Apr. (K. Jäger, Joao Alves (CAHA))

Meeting of the LBT-Beteiligungsgesellschaft (LBTB), MPIA, 28. Apr. (Th. Henning, R. Gredel, K. Jäger)

Stages Collaboration Meeting, MPIA, 19. – 20. May (K. Jahnke)

LN Science Case Meeting, 24. June (E. Schinnerer)

Argos Consortium Meeting, 30. – 31. July (W. Gässler)

IMPRS Summer School: "Statistical Inferences from Astrophysical Data", Heidelberg, 10. – 14. Aug. (H.-W. Rix, Chr. Fendt, St. Wagner (ZAH/LSW))

Meeting of the Board of Trustees of the MPIA, Heidelberg, 18. Sep. (K. Jäger, Th. Henning)

Meeting of the LINC-NIRVANA teams and LBT representativs, MPIA, 21. – 22. Sep. (M. Kürster)

Meeting of the LINC-NIRVANA Consortium, MPIA, 1. – 2 Oct. (M. Kürster)

Retreat of the PSF group, Mayschoß, 14. – 16. Oct. (K. Dullemond, N. Dzyurkevich, M. Nielbock)

Meeting "Career and family" at the MPIA, 12. Nov. (I. Apfel, K. Jäger)

Symposium "From Disks to Jets – from Stars to Quasars" on the occasion of the retirement of Max Camenzind and Hermann-Josef Röser, MPIA, 26. Nov. (K. Jäger, Chr. Fendt, K. Meisenheimer)

Other Conferences Organized:

Argos PDR, Garching, 16. – 17. Feb. (W. Gässler)

International Conference "Planet Formation", Tübingen, 2. – 6. March (C. P. Dullemond)

The Second SUBARU International Conference, Hawaii, 8.-13. March (Th. Henning)

IMPRS-Workshop Retreat, Brigach-Hirzwald, Schwarzwald, 11.–13. March (L. Burtscher, K. Foyle)

Ringberg Workshop "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14. – 18. Apr. (N. Dzyurkevich, H. Klahr, M. Flock, S. Balbus)

Jenam/NAM Meeting, Hatfield, UK, 20. – 23. Apr. (Th. Henning)

Meeting of the LINC-NIRVANA Consortium, Monte Porzio Catone, INAF, Rome, Italy, 7. – 8. May (M. Kürster)

ARENA Conference "An Astronomical Observatory at Concordia for the Next Decade", Rome, Italy, 11. – 15. May (Th. Henning)

6th MPIA Student workshop, Noorden, Netherlands, 25. – 31. May (Eva Meyer)

GAIA DPAC CU8 Meeting No. 7, Toulouse, 8.-10. June (C. Bailer-Jones)

MIRI Science Team Meeting, Washington, USA, 15. – 16. June (Th. Henning)

AO for ELT, Paris, France, 22. – 27. June (SOC) (W. Gässler)

IMPRS Summer School: "Statistical Inferences from Astrophysical Data", Heidelberg, 11. – 14. Aug. (H.-W. Rix)

Spinter meeting "The E-ELT – Status, Timeline, and Instrumentation", Autumn Meeting of the AG, Potsdam, 22. – 25. Sep. (Th. Henning, R. Gredel)

Coordination Meeting of the LINC-NIRVANA team and the LBT team, Tucson and Mt. Graham, Arizona, USA, 28. – 30. Oct. (M. Kürster)

PhDnet General Meeting, Jena, 28.-31. Oct. (L. Burtscher, with PhD students from Jena and other MPIs)

ESO/MPG Meeting "From Circumstellar Disks to Planetary Systems", Garching, 2. – 6. Nov. (Th. Henning)

Conference "The Gaseous Evolution of Galaxies", Ringberg Castle, 15. – 18. Nov. (F. Walter)

GAIA DPAC CU8 Meeting No. 8, Nizza, 17.-18. Nov. (C. Bailer-Jones)

Conferences and Meetings Attended, Scientific Talks and Poster Contributions

Cristina Afonso: Plato Space Mission Meeting, Aahrus, Denmark, 2.–3. Apr., Rome, Italy, 5. May, Belfast, Ireland, 11. June; Pan-Starrs Consortium Meeting, Boston, 29. Aug.–2. Sep. (Talk); Jenam Conference, Hertfordshire, 20.-23. Apr. (Poster)

Zoltan Balog: Workshop "HERSCHEL Data Reduction", ESA, Villa Franca, Spain, 14. – 16. Dec.; HERSCHEL SDP Initial Results Symposium, ESA, Universidad Politécnica de Madrid, Madrid, Spain, 17. – 18. Dec.

Carolina Bergfors: Conference "Planet formation and evolution: The solar system and extrasolar planets", Tübingen, 2. – 6. March (Poster); Conference "Pathways towards habitable planets", Barcelona, 14. – 18. Sep. (Poster)

Jürgen Berwein: Conference "Astronomical Data Analysis Software and Systems 2009", Sapporo, Japan, 4. – 8. Oct. (Poster)

Tilman Birnstiel: Conference "Planet Formation and Evolution", Tübingen, 2. – 6. March (Poster); Conference "Planetesimal Formation", Cambridge, 28. – 30. Sept. (Poster); Conference "From Circumstellar Disks to Planetary Systems", Garching, 3. – 6. Nov. (Poster)

Jeroen Bouwman: MIRI European Consortium Meetings: Leuven, Belgium, 21. – 23. Jan., Leicester, UK, 28. – 30. Apr., Copenhagen, Denmark, 8. – 10. Sep.; HERSCHEL Data Reduction Workshop, ESA, Villa Franca, Spain, 14. – 16. Dec.; HERSCHEL SDP Initial Results Symposium, ESA, Universidad Politécnica de Madrid, Madrid, Spain, 17. – 18. Dec.

Wolfgang Brandner: UK E-ELT Science Workshop "Exoplanets and Proto-stars with the European ELT", Edinburgh, UK, 2. – 3. Apr. (Talk); E-ELT Design Reference Mission and Science Plan, Garching, 26. – 28. Apr. (Talk); IAU Symposium 266: "Star Clusters", Rio de Janeiro, Brazil, 10.-14. Aug. (Poster); IAU Special Session 7: "Young Stellar Objects, Brown Dwarfs and Disks", Rio de Janeiro, Brazil, 11. – 14. Aug. (Talk); PanStarrs 1 Consortium Meeting, Boston, USA, 29. Aug. – 3. Sep.

Leonard Burtscher: IMPRS-Workshop Retreat, 11. – 13. March, Brigach-Hirzwald, Schwarzwald (Talk); Helmholtz Young Scientists Conference, Berlin, 19. May; Ringberg Workshop "Physics of Galactic Nuclei", Ringberg Castle, 15. – 19. June (Talk); Conference "The Many Faces of Centaurus A", Sydney, Australia, 28. June – 3. July (Talk); IMPRS-Summerschool "Statistical Inferences from Astrophysical Data", Heidelberg, 10. – 14. Aug.; 4th PhDnet Interdiscplinary Scientific Event "Science and Fiction: Crossing the boundaries", Leipzig, 4. – 6. Sep. (Talk)

Chris Carilli: Colloquium at MPIA and LSW, MPIA, 7. Aug. (Talk); Colloquium at MPI for extraterrestrial Physics, July (Talk)

Joseph Carson: AIP-Conference "Exoplanets and Disks: Their Formation and Diversity", Hawaii, USA, Feb. (Talk); Harvard-Smithsonian Center for Astrophysics, Cambridge, USA, March (Talk); European Southern Observatory, Santiago, Chile, Sep. (Talk)

Mauricio Cisternas: COSMOS Team Meeting, Ehime University, Matsuyama, Japan, 15. – 18. June (Poster); IAU Symposium 267, Rio de Janeiro, Brazil, 10. – 14. Aug. (Poster)

Nicola Da Rio: IAU Symposium 266: "Star Clusters – Basic Galactic Building Blocks Throughout Time And Space", Rio de Janeiro, Brazil, 10. – 14. Aug. (Poster)

Jelte de Jong: Conference "The Milky Way and the Local Group – Now and in the GAIA Era", Heidelberg, 31. Aug. – 4. Sep. (Poster)

Örs Hunor Detre: MIRI European Consortium Meetings: Leuven, Belgium, 21. – 23. Jan., Leicester, UK, 28. – 30. Apr., Copenhagen, Denmark, 8. – 10. Sep.

Cornelis P. Dullemond: Workshop "Doug Lin Fest", Firenze, Italy, 22. – 26. June

Gaelle Dumas: Conference "ALMA and ELTs – A Deeper, Finer View of the Universe", Garching, ESO, 24. – 27. March (Talk); "Journees Action Specifique ALMA", Grenoble, IRAM, Apr 6. – 7. Apr. (Poster); Conference "Physics of Galactic Nuclei", Ringberg, 15. – 19. June (Talk); Conference "SFR@50 filling the cosmos with stars", Spineto, Italy, 6. – 10. July (Talk); Conference "German ALMA community day", AIA, Bonn, 8. Oct. (Talk)

Natalia Dzyurkevich: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Poster); Ringberg Workshop "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14. – 18. Apr. (Talk); Conference "Dynamics of Discs and Planets", Isaak Newton Institute for Mathematical Sciences, Cambridge, UK, 17. – 21. Aug. (Poster); Workshop "MHD days", AIP, Potsdam, 8. – 9. Dec.

Min Fang: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Poster); Conference "From Circumstellar Disks to Planetary Systems", Garching, 3. – 6. Nov. (Poster)

Mario Flock: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets, Tübingen, 2.–6. March (Poster); Ringberg Workshop "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14.–18. Apr. (Talk); MPIA Student Workshop, Noorden, Netherlands, 25.–31. May(Talk); Conference "Dynamics of Discs and Planets", Isaak Newton Institute for Mathematical Sciences,Cambridge, UK, 17.–21. Aug. (Poster); Pencil Meeting, MPIA, Heidelberg, 24.–28. Aug. (Talk); Workshop "MHD days, AIP, Potsdam, 8.–9. Dec. (Talk)

Kelly Foyle: Conference "Unveiling the Mass", Kingston, Canada, June (Poster); Conference "Canadian Astronomical Society Annual Meeting", Toronto, Canada, May (Talk); Conference "Galaxies: Nature versus Nurture", Granada, Spain, May (Poster)

Wolfgang Gässler: ARGOS PDR preparation meeting, Tuscon, 15. – 16. Jan. (Talk); ARGOS PDR, Garching, 16. – 17. Feb. (Talk); LBT First Light AO review, Arcetri, Italy, 30. – 31. March (Talk); LINC-NIRVANA consortium meeting, Rom, Italy, 7. – 8. May (Talk); ARGOS consortium meeting, Arcetri, Italy, 18. – 19. March (Talk); AO for ELT, Paris, France, 22. – 27. June (Talk); ARGOS consortium meeting, Heidelberg, 30. – 31. July (Talk); LINC-NIRVANA consortium meeting, Heidelberg, 1. – 2. Oct. (Talk); LBT AO software meeting, Firenze, Italy, 20. – 22. Oct.; ARGOS consortium meeting, Tuscon, USA, 9. – 10. Nov. (Talk); ARGOS software meeting, Garching, 8. Dec.

Anna Gallazzi: IAU-Symposium No. 262: "Stellar Populations – Planning for the next decade", Rio de Janeiro, Brazil, 3. – 7. Aug. (Talk); Conference "Galaxy evolution and environment", Kuala Lumpur, Malaysia, 30. March – 3. Apr. (Talk); Meeting of the STAGES Collaboration, MPIA, 19. – 20. May

Mario Gennaro: IAU XXVII General assembly, Symposium 266: "Star Clusters: Basic Galactic Building Blocks Throughout Time And Space", Rio de Janeiro, Brazil, 3.–14. Aug. (Poster)

Bertrand Goldman: JENAM 2009, Hertfordshire, UK, 20. – 24. Apr. (Poster); PAN-STARRS1 collaboration meeting, Cambridge, MA, 29. Aug. – 2. Sep. (Talk); UKIDSS Workshop, London, UK, 12. – 15. Dec. (Talk)

Roland Gredel: 3. ARENA-Conference: "An astronomical observatory at Concordia (Antarctica) for the next decade", Frascati, Italy, 10. – 14. May (Talk)

Joseph F. Hennawi: Conference "The Gaseous Evolution of Galaxies", Ringberg Castle, 15. – 18. Nov. (Talk)

Martin Hennenmann: MIRI European Consortium Meetings: Leicester, UK, 28. – 30. Apr., Copenhagen, Denmark, 8. – 10. Sep.

Thomas Henning: International Workshop "Solving the Riddle of Turbulence: What, Why, and How", Göttingen, 6. – 9. May

Tom Herbst: Retreat of the Galaxy Group, MPIA, 5.–6. Feb.; Retreat MPIA, 12.–13. Feb.; ALMA/ELT Meeting, ESO, 24.–27. March; Retreat of the GC-Gruppe, Castle Neuburg, 5.–6. Feb.; Retreat MPIA Staff "LBT Generation 1.5 Instruments", "LBT Science Exploitation", Castle Edesheim, 12.–13. Feb.; Conference "European ELT Science and Engineering Committee Report", ESO, Garching, 23. Apr.; Conference "LBT News and LN Project Overview", Rom, Italy, 7. May; Conference "LBT News and LN Project Overview", MPIA, 1. Oct.; Conference "European ELT Science and Engineering Committee Report", Garching, 22. Oct.; Conference "LINC-NIRVANA Project Update", Tucson, USA, 28. Oct.

Stefan Hippler: Conference "Exoplanets and Disks: Their Formation and Diversity", Kailua-Kona, Hawaii, 9.–12. March; (Talk); METIS team meeting, KU, Leuven, Belgium, 4. Feb.; GRAVITY Adaptive Optics meeting, Observatoire de Paris, Paris, France, 16. Feb.; GRAVITY team meeting, MPIA, Heidelberg, 30.–31. March; METIS team meeting, ATC, Edinburgh, 19.–20. May; METIS team meeting, MPIA, Heidelberg, 30. June – 2. July; GRAVITY team meeting, LAO, Grenoble, France, 15.–161 Sep.; METIS team meeting, Sterrewacht, Leiden, Netherlands, 30. Sep.–1. Oct.; GRAVITY PDR Review, ESO, Garching, 14.–15. Dec.; METIS Phase A Study Review, ESO, Garching, 17.–18. Dec.

Rory Holmes: EUCLID Consortium Meetings: Garching, 2.–3. Feb., Barcelona, Spain, 1.–2. Apr; EUCLID Imaging Channels (EIC) Meeting, Rom, Italy, 4.–5. June; ESMATS (European Space Mechanisms and Tribology Symposium), Vienna, Austria, 23.–25. Sep.; Conference "Cosmic Vision", Paris, France, 30. Nov.–1. Dec.

Felix Hormuth: Seminar on Astrophysics, Observatory Hamburg, 25. June (Talk)

Friedrich Huisken: Photonik Colloquium, Faculty of Mathematics and Natural Sciences, University Potsdam, 5. May (Colloquium); European Silicon Days, Vienna, Austria, 20.–22. Sep. (Talk); Cluster Meeting, Herzogenhorn, 4.–9. Oct. (Talk)

Katherine Inskip: IAU symposium 267: "Evolution of Galaxies and Central Black Holes: Feeding and Feedback", Rio de Janeiro, Brazil, 10.–14. Aug. (Poster)

Cornelia Jäger: Max Planck Institut for Chemistry, Mainz, 27. May (Colloquium)

Klaus Jäger: Opening Ceremony of the "International Year of Astronomy", Berlin, 20.-21. Jan.; Meeting of members of the Board of the Astronomischen Gesellschaft (AG) and the Rat Deutscher Sternwarten (RDS), Institute for Astrophysics, Göttingen, 19. March; Board Meeting of the Rat Deutscher Sternwarten (RDS), Institute for Astrophysics, Göttingen, 20. March; Scientific Advisory Board Meeting of the "International Summer Science School Heidelberg", Palais Graimberg, Heidelberg, 14. Apr.; General Assembly of the Astronomische Gesellschaft "Deciphering the Universe through Spectroscopy", Potsdam, 20.–25. Sep.; Board Meeting of the Astronomische Gesellschaft, Potsdam, 25. Sep.; Meeting "Visualisierung astronomischer Inhalte", Planetarium Mannheim, 28. Sep.; Heidelberg Astronomers' Convention, Neuenheim Campus, University Heidelberg, 2. Oct.; Informational Event to the Programs of the Alexander von Humboldt-Foundation during the Awardee Meeting, University Heidelberg, 26. Nov.; Scientific Advisory Board Meeting of the "International Summer Science School Heidelberg", Palais Graimberg, Heidelberg, 22. Oct.; Board Meeting of the Astronomische Gesellschaft, Bonn, 17. Dez

Knud Jahnke: Autumn Meeting of the Astronomische Gesellschaft 2009, Potsdam, 21.-25. Sep. (Talk, Poster); IAU Symposium 267 "Evolution of Galaxies and Central Black Holes: Feeding and Feedback", Rio de Janeiro, 10.-14. Aug. (Poster); COSMOS collaboration meeting, Matsuyama, Japan, June (Talk); Sino German Frontiers of Science (Humboldt Foundation), Potsdam, May; STAGES Collaboration Meeting, MPIA, 19.–20. May

Viki Joergens: Conference "Recipes for making brownies: theory vs. observations, ESA Conference", Nordwijk, Netherlands, 9.–11. Sep. (Talk); Autumn Meeting of the Astronomische Gesellschaft: "The Cosmos at High Resolution", Potsdam, 21.-25. Sep. (Talk)

Jouni Kainulainen: Conference "The Many Faces of Centaurus A", Sydney, Australia, 28. June – 3. July (Talk)

Alexander Karim: COSMOS team meeting, University Ehime, Matsuyama, Japan, 15.–18. June (Talk); VIIth Marseille International Cosmology Conference, Marseille, France, 29. June – 3. July (Talk)

Sebastian Kern: Conference: "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14.-18. Apr.; IMPRS Summer School "Statistical Inferences from Astrophysical Data", Heidelberg, 10.–14. Aug.; Conference: "Pencil Code User Meeting 2009", 24.–28. Aug, MPIA; Conference: "Planetesimal Formation Workshop", Cambridge, UK, 28.–30. Sep. (Poster)

Hubert Klahr: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2.–6. March (Talk)

Rainer Klement: GAIA CU8 Meeting No. 7 and Java Workshop, CNE, Toulouse, France, 9.-12. June; Conference "The Milky Way and the Local Group – Now and in the GAIA Era", Heidelberg, 31. Aug.–4.Sept. (Talk); GAIA CU8 Meeting No. 8, Observatoire de Côte d'Azur, Nizza, France, 17.–18. Nov.

Oliver Krause: MIRI European Consortium Meetings: Leuven, Belgium, 21.–23. Jan., Leicester, UK, 28.–30. Apr., Copenhagen, Denmark, 8.–10. Sep.; EUCLID Consortium Meetings, Garching, 2.–3. Feb., Barcelona, Spain, 1.–2. Apr.; MPIA Internal Symposium, Heidelberg, 18. Feb.; SUBARU Science Conference, Kyoto, Japan, 17.–24. Ma1 (Talk); Space Cryogenics Workshop, Arcadia, Pasadena, USA, 23.–25. June (Talk); ESMATS (European Space Mechanisms and Tribology Symposium), Vienna, Austria, 23.–25. Sep. (Talk); Conference

"Cosmic Vision", Paris, France, 30. Nov. – 1. Dec.; HERSCHEL SDP Initial Results Symposium, ESA, Universidad Politécnica de Madrid, Madrid, Spain, 17. – 18. De. (Talk)

Natalia Kudryavtseva: GRAVITY science team meeting, Grenoble, France, 14. Sep. (Talk)

Martin Kürster: MPIA internal Symposium, MPIA, 18. Feb.; Meeting of the ESO-OPC-Panels, Ismaning, 26. – 28. May; LINC-NIRVANA science case meeting, MPIA, 24. June; Meeting of the ESO-OPC-Panels, Ismaning, 17. – 19. Nov.

Rolf Kuiper: Conference "ERASMUS-School: Supercomputing and Numerical Techniques in Astrophysics Fluid Flow Modelling", Evora, Portugal, 2. – 14. Feb.; Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March; Conference "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14. – 18. Apr. (Poster)

Ralf Launhardt: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", University Tübingen, 2. – 6. May (Poster); Conference "Millimeter and Submillimeter Astronomy at High Angular Resolution", Taipei, Taiwan, 8. – 12. June (Poster); AG-Tagung "Deciphering the universe through spectroscopy", AIP Potsdam, 21. – 25. Sep. (Talk)

Christian Leipski: Workshop "HERSCHEL Science Demonstration Phase Data Processing", Madrid, Spain, 14. – 16. Dec.; Workshop "HERSCHEL Science Demonstration Phase Initial Results", Madrid, Spain, 17. – 18. Dec. (Talk)

Dietrich Lemke: Meeting of the Astronomische Gesellschaft, Workshop History of Astronomy, Potsdam, 21. Sep.

Rainer Lenzen: METIS Technical Team Meeting, Leuven, Belgium, 4. – 5. Feb.; GRAVITY Meeting, Heidelberg, 30. – 31. March; METIS Meeting, Leiden, Netherlands, 21. Apr.; METIS Progress Meeting, ACT, Edinbourgh, UK, 19. May; METIS 3rd Team Meeting, Heidelberg, 30. June – 2. July; Gravity Consortium Review Meeting, Grenoble, 15.-16. Sept.; Meeting of the Astronomische Gesellschaft, Potsdam 21.-25. Sept.; METIS Technical Team Meeting, Leiden, Netherlands, 30. Sep.; ESO/CAUP Exoplanet Conference, Porto, Portugal, 19. – 23. Oct.; PDR GRAVITY Meeting, ESO, Garching, 14. – 15. Dec.; METIS FDR Meeting, ESO, Garching, 17. – 18. Dec.

Hendrik Linz: Conference "ALMA and ELTs: A Deeper, Finer View of the Universe", ESO, Garching, 24. – 27. March (Poster); HERSCHEL Data Reduction Workshop, ESA, Villa Franca, Spain, 14. – 16. Dec.; HERSCHEL SDP Initial Results Symposium, ESA, Universidad Politécnica de Madrid, Madrid, Spain, 17. – 18. Dec.

Chao Liu: Conference "The Milky Way and the Local Group – Now and in the GAIA Era", ZAH, Heidelberg, 31. Aug – 4. Sep. (Talk); LAMOST-PLUS meeting, NAOC, Peking, China, 22. Aug. – 25. Aug. (Talk); GAIA CU8 Meeting, CNES, Toulouse, France, 9. – 10. June (Talk)

Andrea V. Macciò: Conference "Open Problems in Galaxy Formation", Potsdam, 12. – 15. May (Talk); Conference "Distribution of Mass in the Milky Way Galaxy", Leiden, Netherlands, 13. – 17. July (Talk); Conference "The Milky Way in the GAIA era", Heidelberg, 1. – 4. Sep. (Talk)

Nicolas Martin: Meeting of the PAN-STARRS Collaboration, Harvard, USA, Aug. (Talk); Conference "The Milky Way and the Local Group: now and in the GAIA era", Heidelberg, Sep. (Talk); Conference "Distribution of mass in the Milky Way galaxy", Leiden, Netherlands, July (Talk); Conference "Overcoming Great Barriers in Galactic Archaeology", Palm Cove, Australia, May (Talk)

Eva Meyer: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Poster); MPIA Student workshop, Noorden, Netherlands, 25. – 31. May (Talk); Workshop "MAD and Beyond", ESO, Garching, 8. – 10 June; Conference "New Technologies for Probing the Diversity of Brown Dwarfs and Exoplanets", Shanghai, China, 19. – 24. July (Talk); Retreat of the PSF Group des MPIA, Mayschoß, 14. – 17. Oct.

Christoph Mordasini: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Poster); Conference "Bolides and Meteorite Falls", Prag, Czech Republic, 10. – 15. May (Talk); Conference "From Circumstellar Disks to Planetary Systems", Garching, 3. – 6. Nov. (Talk)

Friedrich Müller: MIRI European Consortium Meetings: Leuven, Belgium, 21. – 23. Jan., Leicester, UK, 28. – 30. Apr., Copenhagen, Denmark, 8. – 10. Sep.; ESMATS (European Space Mechanisms and Tribology Symposium), Vienna, Austria, 23. – 25. Sep.

Reinhard Mundt: Workshop "KH 15D", Middletown, USA, 22. – 23. June (Talk)

Marie-Helene Nicol: 213th American Astronomical Society Meeting, Long Beach, USA, 4. – 8. Jan. (Poster); Conference "Galaxy Evolution and Environment", Kuala Lumpur, Malaysia, 30. March– 3. Apr. (Poster); Space Telescope A 901/902 Galaxy Evolution Survey meeting, MPIA, 19. – 20. May (Talk)

Markus Nielbock: HERSCHEL/PACS ICC Meetings: Vienna, 12. – 13. Jan. (Talk), MPE, Garching, 1. – 3. Apr. (Talk), 29. – 30 June (Talk); HERSCHEL PV Phase Mid-Term Review, ESAC Villafranca, via Videocon, 1. Sep. (Talk); Retreat of the PSF Group des MPIA, Mayschoß, 14. – 16 Oct. (Talk); HERSCHEL SDP Initial Results Symposium, ESAC, Madrid, Spain, 17. – 18. Dec.

Nikolay Nikolov: Conference "JENAM" (Joint European and National Astronomy Meeting), University of Hertfordshire, UK, 20. – 23. Apr. (Poster)

Dading Nugroho: IAU Symposium 267 "Co-evolution of central black holes and galaxies: feeding and feedback", Rio de Janeiro, Brazil, 10. – 14. Aug. (Poster)

Christiaan W. Ormel: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Talk); Conference "Learning from starlight", Lorentz Center, Leiden, Netherlands, 16. – 20. March (Talk); Conference "Evolution of planetary and stellar systems", Monash Parto Center, Prato, Italy, 22. – 26. June (Poster); Conference "Planetesimal Formation", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, 28. – 30. Sep. (Poster); Winter workshop on planetary astrophysics, Kavli Institute for Astronomy and Astrophysics, University Peking, Peking, 12. – 19. Dec. (Talk)

Alexey Pavlov: ADASS 2009: "Astronomical Data Analysis Software and Systems XIX", Sapporo, Japan, 4. – 8. Oct. (Poster)

Oliver Porth: Workshop "Physics of Galactic Nuclei", Ringberg, 15. – 19. June (Poster); Conference "High Energy Phenomena in Relativistic Outfows", Buenos Aires, Argentina, 26. – 30. Oct.

Jörg-Uwe Pott: Physics of Galactic Nuclei", Ringberg Castle, 15. – 19.6., "From Circumstellar Disks to Planetary Systems", ESO Garching, 3. – 6. 11. (Talk)

Natalie Raettig: Conference "Planet Formation and Evolution", Tübingen, 2. – 6. March (Poster); Conference "The Dynamics of Discs and Planets", Cambridge, UK, 17. – 21. Aug. (Poster)

Hans-Walter Rix: External Retreat of the MPIA WBK, Obrigheim, 12. – 13. Feb.; Internal Symposium of the MPIA, Heidelberg, 18. Feb.; LAMOST Workshop, Peking, 27. May – 2. June; Conference "Tidal dwarf: Ghosts from structure formation, Bad Honnef, 25. May; Workshop "Galaxy Masses", Kingston, UK, 13. – 17. June; Conference "Galaxy Evolution", Marseille, France, 1. July; Workshop "Distribution of Mass in the Milky Way Galaxy", Leiden, Netherlands, 13. – 17. July; PS1 Collaboration Meeting, Center for Astrophysics, Cambridge, USA, 29. Aug. – 2. Sep.; Conference of the NIRSPEC science team, Oxford, UK, 9. – 11. Dec.

Aday Robaina: Conference "Galaxy Evolution and Environment", Kuala Lumpur, Malaysia, 30. March – 3. Apr. (Talk)

Boyke Rochau: Conference "Numerical Astrophysics and its role in Star Formation", Cardiff, UK, 19. – 23. Jan. (Poster); Conference "MAD and Beyond: Science with Multi-Conjugate Adaptive Optics Instruments", Garching, 8. – 10. June (Talk); IAU Symposium 266: "Star Clusters – Basic Galactic Building Blocks throughout Time and Space", 10. – 14. Aug. (Poster)

Maria Victoria Rodriguez Ledesma: Annual Argentinean Astronomical Meeting, La Plata, Argentina 21.-25. Sept. (Talk)

Christine Ruhland: Conference "Tidal Dwarf Galaxies", Bad Honnef, 25. – 29. May (Poster); Conference "The Milky Way and the Local Group", Heidelberg, 31. Aug. – 4. Sep. (Poster)

Mark Sargent: 213th AAS meeting, Long Beach, CA, USA, 4.-8. Jan. (Poster); Conference "Galaxies in Isolation: Exploring Nature vs. Nurture", Granada, Spain, 12.-15. May (Poster); COSMOS Team Meeting, Matsuyama, Japan, 15.– 18. June (Talk)

Silvia Scheithauer: MIRI European Consortium Meeting, Leuven, Belgium, 21. – 23. Jan.

Eva Schinnerer: Conference "ALMA and ELTs: A Deeper, Finer View of the Universe", ESO, Garching, 24. – 27. March (Poster); 214th AAS Meeting, COSMOS special session, Pasadena, 7. – 11. May; COSMOS Team Meeting, Matsuyama, 15. – 18. June (Talk); Conference "Spiral Arm Substructure in Nearby Galaxies", STScI, 29. Sep. – 1. Oct. (Talk); German ALMA community day, Bonn, 8. Oct.; Conference "The Gaseous Evolution of Galaxies", Ringberg Castle, 15. – 18. Nov. (Talk)

Markus Schmalzl: Conference "Dense Cores in Dark Clouds LXV", Newport, Rhode Island, USA, 21. – 23. Oct.

Jürgen Schreiber: HERSCHEL Data Processing Workshop, ESAC/Madrid, 24. – 25. March (Tutor)

Dmitry A. Semenov: Retreat of the Laboratory Astrophysics Group of the MPIA, Schlosshotel Eyba, Jena, 8. – 9. Feb.; Conference "Planet Formation", Tübingen, 1. – 6. March (Talk); Conference "Astrochemistry", ROC, Taipeh, Taiwan, 7. – 13. June (Poster)

Aurora Sicilia-Aguilar: Conference "Planet formation and evolution: The Solar System and Extrasolar planets", Tübingen, 2. – 6. March (Talk); Conference "From circumstellar disks to planetary systems", ESO, Garching, 3. – 6. Nov. (Poster)

Rosalind Skelton: Conference "Galaxy evolution and the environment", Kuala Lumpur, Malaysia, 30. March – 2. Apr. (Poster)

Kester Smith: Conference "The Milky Way, Now and in the GAIA Era", Heidelberg, 31. Aug. – 4. Sep. (Poster)

Jakob Staude: Annual Meeting of the Astronomische Gesellschaft, Potsdam, 21. – 25. Sep.

Micaela Stumpf: 213th Meeting of the American Astronomical Society (AAS), Long Beach, USA, 4.-9. Jan. (Talk)

Amelia Stutz: HERSCHEL Data Processing Workshop, Villafranca del Castillo, 14. – 16. Dec.; HERSCHEL SDP Initial Results Presentations, Boadilla del Monte, 16. – 17. Dec.

Christian Thalmann: 2nd SUBARU International Conference, Kona, Hawaii, March (Poster)

Paraskevi Tsalmantza: Conference: "GAIA DPAC Integration Testing Workshop", Genf, Schweiz, 30. Jan.; Conference: "7th GAIA CU8 Meeting", Toulouse, France, 8. – 10. June (Talk); Conference: "GAIA DPCC Java Workshop", Toulouse, France, 11. – 12. June; Conference: "The Milky Way and the Local Group – Now and in the GAIA Era", Heidelberg, 31. Aug. – 4. Sep.; Conference: "8th GAIA CU8 Meeting", Nizza, France, 17. – 18. Nov. (Talk); Conference: "GAIA GREAT meeting", Nizza, France, 19. – 20. Nov.

Ana Lucía Uribe: Conference "The Astrophysics of the Magnetorotational Instability", Ringberg Castle, 14. – 18. Apr.; Conference "12th MHD days", Potsdam, 8. – 9. Dec. (Poster)

Roy van Boekel: Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Poster); Retreat of the PSF Group

2009, Mayschoß, 14. – 16. Oct.; Conference "From circumstellar disks to planetary systems", Garching, 3. – 6. Nov. (Poster)

Glenn van de Ven: Conference "The Milky Way and the Local Group – Now and in the GAIA Era", Heidelberg, 31. Aug. – 4. Sep. (Talk)

Arjen van der Wel: Conference "Deep IR studies of the distant universe", Leiden, Netherlands, 2. – 6. Feb. (Talk); Science Day, MPIA, 18. Feb. (Talk); Conference "Joint European and National Astronomy Meeting", Hertfordshire, UK, 20. – 23. Apr. (Talk); Galaxy Coffee, MPIA, 30. Apr. (Talk); Conference "VIIth Marseille International Cosmoglogy Conference", Marseille, France, 29. June – 3. July (Talk); Galaxy Coffee, MPIA, 22. Oct. (Talk); Conference "Evolution of galaxies from mass selected samples", Leiden, Netherlands, 9. – 13. Nov. (Talk)

Anton I. Vasyunin: Retreat of the Laboratory Astrophysics Group of the MPIA, Schlosshotel Eyba, Jena, 8. – 10. Feb. (Talk); Conference "Astrochemistry", ROC, Taipeh, Taiwan, 7. – 13. June (Poster)

Fabian Walter: German ALMA community day, Bonn, Oct.; AAS meeting, Pasadena, USA, June (Poster); ESO workshop "ELTs and ALMA: A deeper, finer view of the universe", Garching, March (Talk)

Wei Wang: Conference "New Technologies for Probing the Diversity of Brown dwarfs and Exoplanets", Shanghai, China, 19. – 24. July (Poster); Conference "Evolution of Planetary and Stellar Systems", Prato, Italy, 21. – 26. June

Yuan Wang: Workshop "ALMA and ELTs: A Deeper, Finer View of the Universe", 24. – 27. March; Retreat of the PSF Group, Mayschoß, 14.-17. Oct.; ALMA training school "CASA Tutorial", Bonn, 5. – 7. Oct.

Svitlana Zhukovska: JENAM 2009, Hertfordshire, UK, 20. – 23. Apr. (Talk); Autumn Meeting of the AG, Potsdam, 21. – 25. Sep. (Talk); Seminar at the Institute for Astronomy, University Vienna, 14. Dec. (Talk)

Stefano Zibetti: IAU Symposium 262, "Stellar populations: planning for the next decade", Rio de Janeiro, Brazil, 3. – 7. Aug. (Talk); Workshop "Unveiling the Mass: Extracting and Interpreting Galaxy Masses", Kingston, Canada, 15. – 19. June (Talk); Conference "Galaxy evolution and environment", Kuala Lumpur, Malaysia, 30. March – 3. Apr. (Poster)

Invited Talks, Colloquia

Coryn Bailer-Jones: ELSA (European Leadership in Space Astrometry) workshop on The Techniques of GAIA, Heidelberg, Oct. (Talk); Joint European and National Astrononomy Meeting, Hatfield, UK, Apr. (Talk)

Henrik Beuther: Physik-Colloquium, University Kiel, 20. Jan.; Conference "Chemistry in star formation", University Tokyo, Japan, 5. March; Conference "ALMA vs ELT", Garching, 25. March; Colloquium "(Massive) star formation: Present and future", University Vienna, Austria

Jeroen Bouwman: University Amsterdam, Netherlands, 26. Feb. (Colloquium); Conference "The Dynamics of Disks and Planets", Cambridge, UK, 16. – 21. Aug. (Talk)

Leonard Burtscher: MPIA internal symposium, Heidelberg, 18. Feb. (Talk)

Joseph Carson: College of Charleston, Charleston, USA, March (Talk)

Cornelis P. Dullemond: Conference "IAU General Assembly", Rio de Janeiro, Brazil, 2. – 13. Aug. (Talk); Workshop "Planetesimal Formation", Cambridge, UK, 28. – 30. Sep. (Talk); Conference "From circumstellar disks to planetary systems", Garching, 3. – 6. Nov. (Talk); Workshop "Polarimetry of circumstellar disks", Utrecht, Netherlands, 18. – 19. Nov. (Talk); Colloquium "How to build a planet", Innsbruck, Austria, 1. Dec.

Natalia Dzyurkevich: MPIA Symposium, MPIA, 18. Feb.; Video Seminar "Early Stages of Planet Formation", MPIA, 18. June; University Tübingen, 3. Nov.; CEA, Parin, France, 2. Dec.

Markus Feldt: The 2nd SUBARU International Conference: "Exoplanets and Disks: Their Formation and Diversity", Keauhou, Hawaii, 9. – 12. March (Talk)

Mario Flock: Video Seminar "Early Stages of Planet Formation", 18. June (Talk); CEA, Paris, France, 2. Dec. (Talk)

Bertrand Goldman: Workshop "Voie Lactée", Besançon, France, 5. Nov. (Talk); Colloquium am MPE, Garching, 16. Dec.

Thomas Henning: University Uppsala, Sweden, Jan. (Colloquium); Conference "Planet Formation and Evolution: The Solar System and Extrasolar Planets", Tübingen, 2. – 6. March (Talk); The Second SUBARU International Conference, Hawaii, 8. – 13. March (Talk); University Leiden, 2. Apr. (Colloquium); University Grenoble, France, 25. June (Colloquium); Summer School "Young Stellar Objects: From Cool Stars to Exoplanets", El Escorial, University Madrid, 29. June – 3. July (Talk); Paderborn, 16. July (Colloquium); Opening Symposium GranTeCan, Teneriffa, Spain, 23. – 25. July (Talk); Conference "To the Edge of the Universe: 30 Years of IRAM", Grenoble, France, 28. – 30. Sept. (Talk); Workshop "Polarimetry of circumstellar disks", Utrecht, Netherlands, 18. – 19. Nov. (Talk); Leopoldina, Halle, 24. Nov. (Colloquium)

Tom Herbst: Inauguration of Prof. Alfred Krabbe at the SOFIA Institute, Stuttgart, 23 March (Talk); AO Coffee, HIA, Victoria, Canada, 18. Sep. (Talk); MPIA Galaxy Coffee, MPIA, 8. Oct. (Talk); IYA Science Tea, Victoria, Canada, 15, Oct. (Talk); HIA Colloquium, Victoria, Canada, 10. Nov. (Talk); HIA Instrumentation Coffee, Victoria, Canada, 2. Dec. (Talk)

Stefan Hippler: Colloquium "Optical Technologies", FH Münster, Münster, 14. Oct. (Talk)

Knud Jahnke: Heidelberg Joint Astronomical Colloquium, 10. Oct. (Colloquium)

Viki Joergens: ESA-Conference "Recipes for making brownies: theory vs. observations", Nordwijk, Netherlands, 9. – 11. Sep. (Talk); Conference "Heidelberg Astronomers' Convention", Heidelberg, 2. Oct. (Talk)

Hubert Klahr: Conference "The Astrophysics of the Magnetorotational Instability and Related Processes", Ringberg Castle, 14. – 18. Apr. (Talk); International Workshop "Solving the Riddle of Turbulence", Göttingen, 6. – 9. May (Talk); Department of Terrestrial Magnetism, Washington, USA, 26. May (Colloquium); Museum of Natural History, New York, USA, 2. June (Colloquium); Conference "Evolution of Planetary and stellar systems", Prato, Italy, 21. – 26. June (Talk); ASTRONUM 2009, 4th International Conference on Numerical Modeling of Space Plasma Flows, Chamonix, France, 29. June – 3. July (Talk); Observatorium Stockholm, Stockholm, 10. Sep. (Colloquium); Conference "Planetesimal Formation" Cambridge, UK, 28. – 30. Sep. (Talk); Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology (BTU), Cottbus, 18. Nov. (Colloquium); Isaac Newton Institute, Cambridge, UK, 1. Dec. (Colloquium); University of Exeter, 2. Dec. (Colloquium); Winter Workshop "Planetary Astrophysics" KIAA, University Peking, Peking, 12. – 19. Dec. (Talk)

Oliver Krause: Workshop "SN Ia Progenitors", University Princeton, USA, 17. – 18. Apr. (Talk); ESO, Garching, 7. Apr. (Colloquium); ESO, Santiago, Chile, 21. June (Colloquium); ESA/ESTEC Noordwijk, 19. Aug. (Colloquium)

Rolf Kuiper: Argelander Institut for Astronomy (AIfA), Bonn, 9. Jan. (Special Colloquium)

Ralf Launhardt: AIU Jena, 1. July (Colloquium)

Andrea V. Macciò: Dark Cosmology Center, Copenhagen, Denmark, 31. March (Colloquium); Conference "Particle Physics and Cosmology: From the Smallest Scales to the Largest", Copenhagen, Denmark, 1. – 3. Apr. (Talk); MPI for Astrophysics, Garching, 16. June (Colloquium); MPI for Nuclear Physics, Heidelberg, 24. Nov. (Colloquium); Institute for Theoretical Physics, University Heidelberg, 9. Dec. (Colloquium)

Nicolas Martin: Workshop "Calar Alto Legacy Survey", Heidelberg, Apr. (Talk); Conference "Tidal Dwarf Galaxies: Ghosts from Structure Formation", Bad Honnef, May (Talk); Workshop " Voie Lactée", Besançon, France, 5. Nov. (Talk); NRC Herzberg Institute for Astrophysics, Victoria, Canada, (Colloquium)

Christoph Mordasini: Conference "The Dynamics of Discs and Planets", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, 17. – 21. Aug. (Talk); Dipartimento di Astronomia, University Padua, Italy, 17. Dec. (Colloquium)

Jörg-Uwe Pott: IAA, Granada, seminar talk, 1.12

Hans-Walter Rix: Joint Astronomy Colloquium: "Do the Milky Way's Outskirts Live up to Expectations", ESO, Garching, 29. Jan. (Talk); Arizona Colloquium, Steward Observatory, Tucson, Arizona, USA, 12. March (Talk); NYU Colloquium, University New York, USA, 10. Apr. (Talk); University of Utah, Salt Lake City, Utah, 6 Oct. (Colloquium)

Boyke Rochau: University of Exeter, Astrophysics Group, Exeter, UK, 29 Oct. (Colloquium)

Jakob Staude: Conference "The Inspiration of Astronomical Phenomena", Venice, 18. – 23. Oct. (Talk)

Jürgen Steinacker: Observatoire de Paris, Paris, 13. Nov. (Talk); IAS, Paris, 9. Nov. (Talk); German Sofia Center, Stuttgart, 27. Oct. (Talk); IAS, Paris, 22. Oct. (Talk); Observatoire de Paris, Paris, 7. Oct. (Talk); ZAH/ITA, Heidelberg, 15. July (Colloquium); MPIA, Heidelberg, 6. May (Talk); Mannheim University, Mannheim, 2. Apr. (Colloquium); MPIA, Heidelberg, 27. March; MPIA und LSW Heidelberg (Colloquium)

Micaela Stumpf: Press Conference at the 213th Meeting of the American Astronomical Society (AAS), Long Beach, USA, 5. Jan. (Talk)

Roy van Boekel: AG Autumn Meeting 2009, Potsdam, 21. – 25. Sep. (Talk)

Fabian Walter: Workshop "First Star Formation", Heidelberg, Oct. (Talk); IRAM 30th anniversary, Grenoble, France, Sep. (Talk), Annual Meeting of the Astronomische Gesellschaft Potsdam, Sep. (Highlight Talk); Colloquium at the Lowell Observatory, Flagstaff, May; VLA-AOC, Socorro, USA, May (Talk)

Stefano Zibetti: IAU General Assembly 2009, "Diffuse light in galaxy clusters", Joint Discussion 02, Rio de Janeiro, Brazil, 6. – 7. Aug. (Talk); Università dell'Insubria, Como, Italy, 28. May (Colloquium)

Lecture Series

Viki Joergens: "Exoplanets around young stars: I. Radial Velocity", ASTROCAM School "Young stellar Objects: from Cool Stars to Exoplanets", San Lorenzo de El Escorial, Madrid, Spain, 29. Jun. – 3. July

Popular Talks

Henrik Beuther: Astronomy on Sunday Morning: "The Formation of the Stars", MPIA, 28. June; "The Formation of the Stars", Planetarium Mannheim, 6. Oct.

Wolfgang Brandner: "Brown Dwarfs – failed Stars or Superplanets?", Pollichia (Natural History Museum of the Palatinate), Bad Dürkheim, 6. Aug.

Leonard Burtscher: "One Night at the largest Telescope of the World", Gymnasium Penzberg/Sternwarte Penzberg e.V., 5. March; "In den Sternen die Zukunft erkennen? Eine kritische Auseinandersetzung mit der Astrologie", Sternwarte Gudensberg, 20. March; "Recognize the Future in the Stars? A critical discourse with Astrology", Observatory Heilbronn, 18. Sep.

Joseph Carson: "Discovering Astronomy", Nysmith School for the Gifted, Herndon, USA, March (Talk)

Christian Fendt: "Between Milliseconda and Billion Years – Time Scales in Astronomie", Study day "Time" at Hölderlin-Gymnasium, Heidelberg, 11. Nov.

Martin Hennenmann: “The difficult Birth of massive Stars”, Workshop Astronomy, Studium Generale, University Stuttgart, Stuttgart-Vaihingen, 24. June

Thomas Henning: “Astrophysics in the Laboratory: From Football Molecules, Nano Diamonds, and Star Dust”, Friedrich Schiller University, Jena, 17. Jan.

Klaus Jäger: “Deep Views, Sharp Eyes Time Maschine – 400 Years of Astronomy with Telescopes”, Planetarium Mannheim, 3. Feb; “Deep Views, Sharp Eyes Time Maschine”, Special Talk for pupils of the Salier-Gymnasium, Waiblingen, MPIA, 14. July; “Deep Views, Sharp Eyes Time Maschine”, Kepler Days at the MPIA, 18. July; “Mysterious Quasars – Answering a Riddle”, Geodatic Observatory Wettzell, Federal Office of Cartography and Geodesy (BKG) and Research Facility Satellite Geodesy (FESG), Wettzell, 19. Nov.; “Deep Views, Sharp Eyes Time Maschine”, Starkenburg Observatory, Heppenheim, 24. Nov.

Oliver Krause: “The European Space Telescope HERSCHEL”, Astronomy on Sunday Morning, MPIA Heidelberg, 26. June; “Spot into the Past – Time Travel to a Stellar Explosion of the 16th Century”, Observatory Trebur, 18. Sep.; “The Space Telescope HERSCHEL – Europes new Window into Space”, Science Express, University Heidelberg, 4. – 6. Oct.

Dietrich Lemke: “400 Years Astronomical Telescope – History and the Future of a Discovery Machine”, Observatory Starkenburg, 10. Feb.; “Are we alone in the Universe?”, Adult Education Center Schwetzingen, 7. Apr.; “400 Years Astronomical Telescope”, Astronomy on Sunday Morning, MPIA, Heidelberg, 21. June; “Infrared Space Telescope – Discoveries in the cold Cosmos”, Teacher's Training, MPIA, Heidelberg, 10. Nov.; “Back to the Moon”, Observatory Heilbronn, 11. Dec.

Hendrik Linz: “The largest Spece Telescope: HERSCHEL”, Space Science Day, SRH University, Heidelberg, 6. May

Markus Nielbock: “HERSCHEL and Planck – Europes new Spece Observatories”, Planetarium Mannheim, 31. March

Axel M. Quetz: “The Formation of Planetary Systems”, Schenk-von-Limpurg-Gymnasium Gaildorf, 24. March; “The Formation of Planetary Systems”, Adult Education Center Leimen, 15. Oct.; “The Formation of Planetary Systems”, Carl-Bosch-Gymnasium Ludwigshafen, 11. Nov.

Hans-Walter Rix: Talk at the Astronomical Society Weikersheim, Bad Mergentheim, 6. May; “Super Eyes looking into Space”, University Tübingen, Tübingen, 20. May

Maria Victoria Rodriguez Ledesma: “The formation of stars and brown dwarfs”, IYA (Argentinean node) talks, Salta University and National School Tucuman, August; “Extrasolar planets”, IYA (Argentinean node) talks, Normal High School and Tafi del Valle School, Sept.

Christine Ruhland: “Finding Clues to the Secrets of the Galaxies”, Immanuel Kant School, Rüsselsheim, 16. Nov.

Silvia Scheithauer: “The Infrared Eyes of the James Webb Space Telescope”, Children's University Bretten, 4. Nov.

Johny Setiawan: “The Search for Planets beyond our Solar System”, 5. Pupil's Symposium, Communication Center, DKFZ, Heidelberg, 13. May; “A Travel to the History of Planetary Systems”, Astronomical Talk Evening at the “Science Express”, University Heidelberg, 5. Oct.; Embassy of the Republic Indonesa, Berlin, 12. Sep.

Jakob Staude: “Quattrocento anni dopo. Galileo Galilei e la nascita del Sidereus Nuncius”, Festivaletteratura, Mantua, 10. Sep.

Jürgen Steinacker: “The unsolved puzzle of the giant stars”, MPIA, Heidelberg, 17. May

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