Max-Planck-Institut
für
Astrophysik

Annual Report 2011

Contents

1 General Information

1.1 A brief history of the MPA

The Max-Planck-Institut für Astrophysik, called the MPA for short, was founded in 1958 under the directorship of Ludwig Biermann. It was first established as an offshoot of the Max-Planck-Institut für Physik, which at that time had just moved from Göttingen to Munich. In 1979, in the course of plans to move the headquarters of the European Southern Observatory from Geneva to Garching, Biermann's successor, Rudolf Kippenhahn, relocated the MPA to its current site. The MPA became fully independent in 1991. Kippenhahn retired shortly thereafter and this led to a period of uncertainty, which ended in 1994 with the appointment of Simon White as director. The subsequent appointments of Rashid Sunyaev (1995) and Wolfgang Hillebrandt (1997) as directors at the institute, together with adoption of new set of statutes in 1997, allowed the MPA to adopt a system of collegial leadership by a Board of Directors. The Managing Directorship rotates every three years, with Wolfgang Hillebrandt in post for the period 2009-2011. In 2007 Martin Asplund arrived as a new director but, because of personal reasons, returned to The Australian National University in 2011, but he remains to be linked to the institute as external Scientific Member, in addition to the other external Scientific Members: Riccardo Giacconi, Rolf Kudritzki and Werner Tscharnuter. In 2012 Eiichiro Komatsu from the University of Texas will arrive as a new director and will further strengthen the institute's investigations of the beginnings and the evolution of the universe.

The MPA was founded specifically as an institute for theoretical astrophysics. Its original goal was to develop the theoretical concepts and numerical algorithms needed to study the structure and evolution of stars (including the sun), the dynamics and chemistry of the interstellar medium, the interaction of hot, dilute plasmas with magnetic fields and energetic particles, and the calculation of transition probabilities and cross–sections for astrophysical processes in rarefied media. These efforts led to broad international cooperation and were clearly differentiated from the observational and instrumental activities carried out in other Max-Planck institutes. From its inception the MPA has had an internationally-recognized numerical astrophysics program that is unparalleled by any other institution of similar size.

In recent years, activities at the MPA have diversified. They now address a much broader range of topics and include a variety of data analysis activities while still maintaining a substantial emphasis on theory and numerics. Resources are channeled into areas where new instrumental or computational capabilities are expected to lead to rapid developments. Active areas of current research include stellar evolution, stellar atmospheres, accretion phenomena, nuclear and particle astrophysics, supernova physics, astrophysical fluid dynamics, high-energy astrophysics, radiative processes, the structure, formation and evolution of galaxies, gravitational lensing, the large-scale structure of the Universe and physical cosmology. Several previous research areas (solar system physics, the quantum chemistry of astrophysical molecules, general relativity and gravitational wave astronomy) have been substantially reduced over the last two decades.

Various aspects of the MPA's structure have historical origins. Its administration (which at present is housed primarily in the main MPA building but will move to a new extension building in early 2013) is shared with the neighboring, but substantially larger MPI für extraterrestrische Physik (MPE). The library in the MPA building also serves the two institutes jointly. All major astronomical books and periodicals are available. The MPA played an important role in founding the Max-Planck Society's Garching Computer Centre (the RZG; the principal supercomputing centre of the Society as a whole). MPA scientists have free access to the RZG and are among the top users of the facilities there. Ten posts at the computing centre, including that of its director, are formally part of the MPA's roster. This arrangement has worked well and results in a close and productive working relationship between the MPA and the RZG.

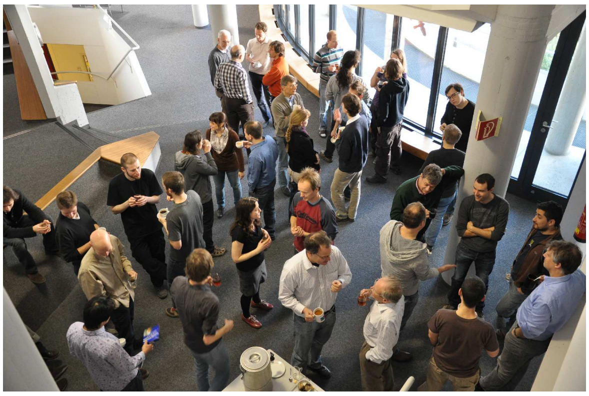

Figure 1.1: traditional morning "scientific coffee" at MPA

1.2 Current MPA facilities

The MPA building itself is a major asset for its research activities. It was specially designed by the same architect as ESO headquarters, and the two buildings are generally considered as important and highly original examples of the architecture of their period. Although the unconventional geometry of the MPA can easily confuse first-time visitors, its open and centrally focused plan is very effective at encouraging interaction between scientists (for example at the now traditional morning "scientific coffee") and makes for a pleasant and stimulating research environment (see Fig. 1.1).

During the past ten years the steady growth of MPA's personnel has caused severe problems. There is no longer enough office space available, and the lecture room is now much too small even for the "house seminars", let alone for special events such as the Biermann lectures. In its earlier stages, the expansion in numbers could be accommodated by conversion of laboratory space into offices and by removal of rarely used library holdings to a remote store. The institute's capacity for such adaptation is now exhausted, however, and in 2007 a request was submitted the MPG's President and Central Administration for a building extension to relieve the problem.

Finally in 2009 the request received a positive answer. MPA got the permit for new extension with a total of about 900 m^2 usable space. The detailed planning started in fall of 2009. The aim was to provide a significantly bigger lecture hall (130 seats), office space for MPA's computer support group and their computer hardware, as well as offices for the MPA/MPE administration, the idea being that the administration/support groups would be located within easy reach of both institutes and, at the same time, all offices in MPA's "old" building would be used by scientists. Construction work started in June 2011 and will be finished by spring 2013.

Library

The library is a shared facility of the MPA and the MPE and therefore has to serve the needs of two institutes with differing research emphases – predominantly theoretical astrophysics at MPA and observational/instrumental astrophysics at the MPE. At present the library holds a unique collection of about 45000 books and journals and about 7200 reports and observatory publications, as well as print subscriptions for about 200 journals. It also manages online subscriptions for about 400 periodicals. In addition the library maintains an archive of MPA and MPE publications, two slide collections (one for MPA and one for MPE), a collection of approximately 400 CDs and videos, and it stores copies of the Palomar Observatory Sky Survey (on photographic prints) and of the ESO/SERC Sky Survey (on film). The MPA/MPE library catalogue includes books, conference proceedings, periodicals, doctoral dissertations, and habilitation theses, reports (both, print and online) Additional technical services such as several PCs and terminals in the library area, copy machines, a colour bookscanner, two laser printers, and a fax machine are available to serve the users' and the librarians' needs. The library is run by three people who share the tasks as follows: Mrs. Chmielewski (full time; head of the library, administration of books and reports), Mrs. Hardt (full time; interlending and local loans of documents, "PubMan", and publications management for both institutes - about 1100 publications 2011), and Mrs. Blank (half time; administration of journals).

Computational facilities

Computer and network facilities are a crucial part of everyday scientific life. At MPA, computing needs are satisfied by providing both extensive in-house computer power and access to the supercomputers and the mass storage facilities at the Max Planck Society's Garching Computer Centre (the RZG) and the Leibniz Computer Centre of the state of Bavaria (the LRZ). Scientists at MPA are also very successful in acquiring additional supercomputing time at various additional computer centers, both on the national and international level.

Figure 1.2: Construction of the MPA extension building/March 2012

The design, usage and development of the MPA computer system is organized by the Computer Executive Committee. This group of scientists and system managers also evaluates user requests concerning resources or system structure, with scientific necessity being the main criterion for decisions. RZG and MPA coordinate activities and development plans through regular meetings, to ensure continuity in the working environment experienced by the users. MPA also participates actively in discussions of potential major investments at the RZG. Common hardware acquisitions by the two institutions are not unusual. Presently, MPA has three Linux-clusters, each with several hundred processors, located at RZG. The most important resources provided by the RZG are parallel supercomputers, PByte mass storage facilities (also for backups), and the gateway to GWIN/Internet.

MPA's computer system guarantees that every user has full access to all facilities needed, and that there is no need for users to perform maintenance or system tasks. All desks are equipped with modern PCs, running under one operating system (Linux) and a fully transparent file system, with full data security and integrity guaranteed through multiple backups, firewalls, and the choice of the operating system.

With this approach MPA is achieving virtually uninterrupted, continuous service. Since desktop PCs are not personalized, hardware failures are quickly repaired by a complete exchange of the computer.

In addition to the desktop systems, which, are almost all younger than 5 years and which (in 2011) amount to more than 160 fully equipped working places, users have access to central number crunchers (about 20 machines, all 64-bit architecture; with up to 32 processor cores and 96 GB memory). The total on-line data capacity is beyond 500 Terabyte, individual user disk space ranges from a mere GB to several TB, according to scientific need.

All MPA scientists and PhD students may also get a personal laptop for the duration of their presence at the institute. These and private laptops may be connected to the in-house network, through a subnet well separated from the crucial system components by a firewall. Apart from the standard wired network (GB capacity up to floor level, and 100 MB to the individual machine), access through a protected WLAN is also possible.

The basic operating system relies on OpenSource software and developments. One MPA system manager is actively participating in the OpenSource community. The Linux system is an inhouse developed special distribution, including the A(dvanced) F(ile) S(ystem), which allows completely transparent access to data and a high flexibility for system maintenance. For scientific work licensed software, e.g. for data reduction and visualization, is in use, too. Special needs requiring Microsoft or Macintosh PCs or software are satisfied by a number of public PCs and through servers and emulations.

The system manager group comprises two full-time and two part-time system administrators; users have no administrative privileges nor duties, which allows them to fully concentrate on their scientific work.

In addition to the central MPA computer services, both the Planck Surveyor project and the SDSS group operate their own computer clusters. The former installation is designed in a similar fashion as the general system, and is maintained by an MPA system manager. The SDSS system is MS Windows based, and administered both by an MPA- and an additional SDSS-manager.

During 2011 central computer services had to be removed from MPA because of possible destructive impact of the nearby construction work for the extension building. They are now being hosted at RZG; due to the excellent network connection and a well-planned installation concept users experience no impact on convenience or performance in using MPA's computer system. The machines will return to MPA's new building after its completion.

1.3 2011 at the MPA

Planck Surveyor

Planck Surveyor is a medium-sized ESA satellite mission to map the Cosmic Microwave Background. It was launched in May 2009 and has been operating nominally on station at L2 since late August 2009. 'First light' was in September 2009. Already in July 2010 the international consortium released the first all-sky image of the microwave sky, using data spanning the full frequency range of Planck from 30 to 857 GHz. In early 2011, the Planck Early Release Compact Source Cataloge containing 15000 objects was published together with a series of twenty-six Planck Early Release Papers. These papers cover a broad spectrum of astrophysical topics, ranging from galactic science, over galaxy cluster measurements, to the detection of far-infrared anisotropies due to star burst galaxies during earlier cosmic epochs. A second round of Planck Intermediate Papers are in preparation for publication in 2012. The ultimate goal of the mission, precision cosmology, will be covered by publication appearing in 2013 and later. Science exploitation of the Planck Collaboration will continue until the end of 2014.

The nominal satellite mission ended 2011, however, thanks to the good performance of the cooling system, measurements with the both of Planck's instruments continued until early 2012. Then, as expected from the He-3 coolant consumption, the High Frequency Instrument had to be switched off. The Low Frequency Instrument will continue to deliver science data until the end of 2012.

The MPA is the only German participant in this effort with co-Investigators on each of the two instruments. Our role within the project was the development of a distributed processing system to be used as the backbone both for simulation of the mission and later for the data analysis itself. The mission simulation package was mainly developed at MPA and is still maintained here. MPA directly supports the operation of the Trieste data centre for the Low Frequency Instrument. Funding for this work, which had occupied 12 programmers and scientists at peak, comes from the DLR and from internal MPA resources. For the period 2012 until end 2014 further funding for four software specialist is ensured by the DLR. MPA scientists are playing a leading role within the Planck consortia in science associated with galaxy clusters as well as within the Planck editorial board, which supervises the science paper writing with a Planck-internal refereeing process.

LOFAR's first all-sky image

LOFAR is an innovative low-frequency radio interferometer project based primarily in the Netherlands. It is the first large facility instrument in the world for which beam construction is carried out entirely in software. This instrument strategy implies a very large computational requirement and in addition several of LOFAR's prime science drivers, particularly the search for redshifted 21 cm radiation from the epoch of reionization and studies of the structure of extended radio sources, are also focal points of research at MPA. Thus when the German Long Wavelength consortium (GLOW) was formed to negotiate German participation in the project, it was natural for MPA to join. The main body of the telescope is currently under construction in he Netherlands and consists of a scatter of antenna fields, each containing 48/96 “high-frequency" and 48/96 “low-frequency" antennae. German (and also UK, French and Swedish) participation consists in the construction of additional antenna fields which extend the baseline of the interferometer, together with broadband data links to transfer all data to Holland for processing. 4 out of 6 German antenna fields have already been built at Effelsberg, Tautenburg, Potsdam and Unterweilenbach. The latter (MPA's) was completed on a site 40 km north of Munich in June 2010 and it is regularly used for observations (its first low-band all-sky image is shown in Fig. 1.3). First usable data from a large fraction of the array (including the German stations) became available in early 2011.

Figure 1.3: aerial photo of the LOFAR antenna field, in Unterweilenbach, north of Garching

The MPA scientist in charge is Benedetta Ciardi, who also chairs the Science Working Group of the German LOng Wavelength (GLOW) Consortium. In addition, she is a core member of the LOFAR Epoch of Reionization Working Group.

Gruber Cosmology Prize ceremony at Garching

Several MPA scientists received prestigious awards in 2011. This year's Kyoto prize in science went to Rashid Sunyaev and the Franklin Institute announced in December that the 2012 Franklin Medal in Physics also goes to him. Hendrik Spruit won Hale Prize for solar physics in recognition of his “insightful and pioneering work on the structure of magnetic flux tubes and sunspots and on their interaction with the flow of energy in the solar convection zone” and Gerhard Börner was honoured by the Chinese government with the “International Science and Technology Cooperation Award”.

Figure 1.4: Gruber Prize ceremony: (from left) Marc Davis, George Efstathiou, Carlos Frenk, Simon White

A special event was the Gruber Cosmology Prize ceremony which took place on October 27, honouring Marc Davis (University of California at Berkeley), George Efstathiou (Cambridge University), Carlos Frenk (Durham University), ans Simon White for “their pioneering use of numerical simulations to model and interpret the large-scale distribution of matter in the Universe” (See Figure 1.4). All four awardees delivered a lecture and, since by chance it happened to be Carlos Frenk’s 60th birthday, there were good reasons for yet another party at MPA.

Adventurous Biermann lectures 2011

The Biermann lecture series, which started in 1997, aims to stimulate scientific activities across the Munich astronomical community and has been very successful in previous years. World-class scientists working on topics in theoretical and computational astrophysics are invited to spend one month in Garching, to give a series of prize lectures and to interact with colleagues at MPA and in the various surrounding institutes.

In this year’s Biermann lectures, Professor Eliot Quataert (Fig. 1.5) from the University of California, Berkeley, spoke to his audience about “Adventures in Theoretical Astrophysics”. The series of talks touched on some of the astrophysical processes and objects he studies, ranging from plasmas in galaxy clusters, through star and galaxy formation to gravitational wave sources.

As always the lectures were very well attended and, also as always, the lecture series offered another opportunity for a “beer and pretzel” party (Fig. 1.6) in MPA’s backyard, which this year served also as a farewell party for Martin Asplund (See Fig. 1.7, and 1.8).

The year 2011 saw the 25th anniversary of Ludwig Biermann’s death (Fig. 1.10). The founding father of the MPA, after whom the Biermann lectures are named continued to work on the physics of comets, their origins and appearance in the inner solar system even after he officially retired in 1975. The German Astronomical Society has named a prize after him, awarding the *Ludwig Biermann Research Prize* annually to an exceptional young scientist.

Rudolf-Kippenhahn-Prize for Rainer Moll

At the end of May, the Rudolf-Kippenhahn-Prize for the best scientific paper written by a student at the MPA was awarded to Rainer Moll, a former MPA student, now at the Max Planck Institute for Solar System Research, for his publication ’Large jets from small-scale magnetic fields’. The prize is awarded jointly by the institute and its former director, after whom it is named, to recognize originality, impact on science and quality of writing for a publication to which the selected students made the dominant contributions (See Fig. 1.9).

In his paper, Rainer Moll presents a numerical study of magnetic cores rotating inside a non-magnetic stellar envelope, investigating under what conditions a magnetically powered jet is formed that can break through the envelope. As the processes involved are very complex and vary over a wide range of scales, he had to invent a new method for his 3-dimensional, magnetohydrodynamic simulations: In a numerical grid, with which the flow can be followed over a factor of 1000 in distance, it is possible to cover the full development of the unsteady flow, including the strong magnetically driven instabilities evolving inside it. The laudatio particularly recognized Moll’s inventiveness in problem definition, and in developing methods for visualization and physical interpretation of the complex 3-dimensional results.

Public Outreach

MPA scientists are actively engaging with the public to communicate recent scientific findings and to rouse interest in astronomy of young people in particular. As in previous years, the scientists presented public talks as well as lectures to school classes. They served as guides both for groups visiting the institute and at the temporary cosmology exhibition on the “Evolution of the Universe” at

Figure 1.5: Eliot Quataert (Biermann lecturer 2011)

Figure 1.6: Eliot Quataert (opening the beer barrel after the Biermann lectures)

Figure 1.7: Martin Asplund and Wolfgang Hillebrandt (farewell party)

Figure 1.8: farewell cake for Martin Asplund

Figure 1.9: Rudolf Kippenhahn Prize ceremony: Former MPA-director Rudolf Kippenhahn presented Rainer Moll with the prize certificate.

Figure 1.10: Ludwig Biermann (1907-1986)-first director of MPA

the Deutsches Museum, which was jointly developed and financed by the MPA, and other Munich astronomy institutions as part of the International Year of Astronomy 2009. This exhibition has now been confirmed as a permanent installation as part of the Astronomy Exhibition at the Deutsches Museum.

In 2011, a number of events were organised for the public and for school classes. In mid-April, some 40 girls came to the astronomical Max Planck Institutes in Garching to learn more about work as a female astronomer. Just as in the previous years, all available places for the joint programme of MPA and MPE were taken in just a few days.In the course of the varied morning programme, the girls listened to a scientific talk about stars and took part in a panel discussion with students and postdocs. Further topics for discussion were then raised in the "astro quiz", in which the girls had to answer questions about our solar system, stars, galaxies and the universe with the help of experts from MPA and MPE. In one special task for the astro quiz, the girls even had to make a model of our solar system true to scale on unfurled toilet paper. The Girls' Day is an initiative throughout Germany to encourage girls to learn more about occupational areas that are still male-dominated and that girls consider only seldom when it comes to choosing a career path.

In October, the MPA took part in the Campus Open Day with almost 3000 people visiting the institute. The programme included hourly talks, poster presentations and Q&A-sessions with scientists, as well as the well-established *kids lab*, which was again very popular. A new highlight was the digital planetarium, which was assembled in the upstairs lecture hall. The digital planetarium show *Changing Skies*, which was scripted and programmed by a team of MPA's junior scientists, started with well-known constellations and visualised changes due to the motion of the Earth. It then moved on to intrinsic changes of the celestial objects, showing various stages in stellar evolution, and expanding the view to observations of other galaxies, some of which are very distant like the ones in the Hubble Deep Field. Due to the finite speed of light, this allows the scientists to study galaxies in different evolutionary stages and even enables them to look back to the very beginning of the Universe itself. As this show could only present a general overview, different aspects could then be discussed with the scientists available throughout the MPA.

Commemorating the 100th anniversary of the Max Planck Society, Max Planck Institutes throughout Germany including the MPA welcomed students on 11 November to a special programme.

Figure 1.11: In the inflatable dome of the digital planetarium, students are taken on a journey through the universe.

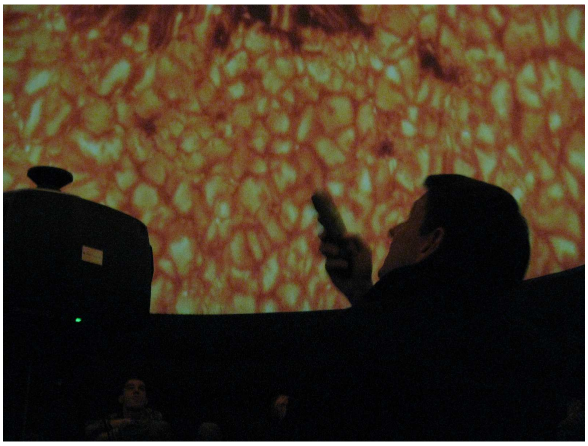

Figure 1.12: The show with the digital planetarium starts with a detailed look on the solar surface, which is constantly fluctuating.

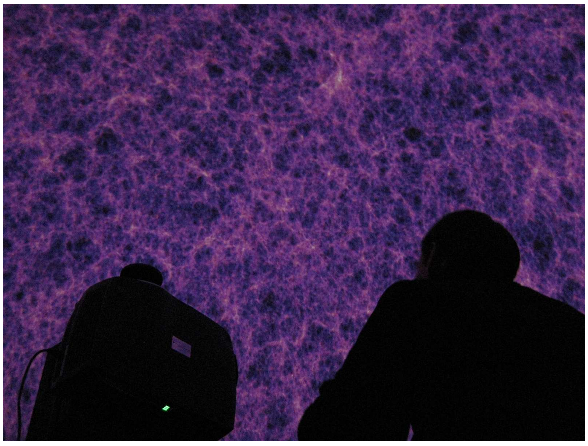

Figure 1.13: The Millenium Simulation shows the large scale structure in the universe, which is in good agreement with actual observations.

The Kaiser Wilhelm Society was founded in 1911, and was renamed the Max Planck Society in 1948. At the MPA, 10th to 12th grade high-school students were invited to learn more about the astronomical research at our institute in the new digital planetarium show and in scientific talks. Due to the overwhelming interest from schools, similar activities with talks and the planetarium show are planned for future events (See Figures 1.11, 1.12 and 1.13).

The MPA scientists also supervised undergraduates and high school students on small research projects during internships, wrote articles for popular science media, and acted as interview partners for newspaper, radio and television journalists for both international and German national media. In addition to regular science highlights on the MPA webpages, the public outreach office issued a number of press releases about important scientific findings and milestones for the Planck project, which were taken up by numerous (mainly online) media. This information was complemented by event announcements and news about prizes and awards for MPA scientists.

2 Scientific Highlights

2.1 Data analysis and steam engines

Thermodynamics describes the molecular chaos that you find for instance inside a steam engine. It is impossible to calculate the positions and velocities of each of the countless molecules in a boiler. However, if an engineer is interested in the typical velocities of these molecules, to determine the pressure in the boiler for example, he can use thermodynamics. This theory provides us with reliable calculations of such global properties by simplifying the very complicated dynamics of the individual molecules through statistical arguments (see Fig. 2.1).

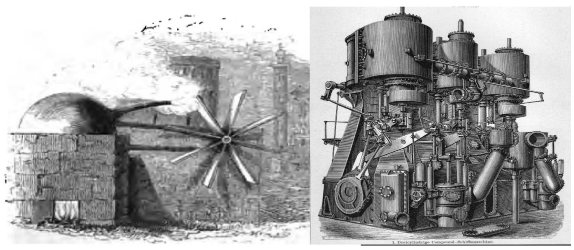

Figure 2.1: The development of powerful steam engines during the industrial revolution benefited from the theory of thermodynamics. Copyright: Lardner, Dionysius and F.A. Brockhaus, Berlin und Wien [both Public domain], via Wikimedia Commons

Modern astronomers collect light from outer space to produce astronomical images at different wavelengths. At a first glance there is not much common ground with the typical applications of thermodynamics. When dealing with observations, however, there are also uncertainties that can only be dealt with in a statistical sense. The sky brightness has to be determined theoretically for an infinite number of pixels; but the data are coarse-grained, washed-out, noisy, most often incomplete, and always finite. Intelligent methods are needed to convert the telescope data into the most accurate image of the sky.

Unfortunately there are often an infinite number of possible images of the sky to match the observational data. These possibilities are just as confusing as the molecular chaos in a boiler but can be dealt with using the same statistical methods. In a steam engine, the behaviour of the water molecules is governed by two parameters: the internal energy U of the water and its entropy S. The former is the mean energy of the molecules due to their motion and the intermolecular attractive forces. The latter describes the amount of molecular chaos: the larger the entropy the more violent the motion. Thermodynamics postulates that the water will reach an equilibrium, so that the combination of internal energy, entropy and temperature T is minimised. This combination is called Gibbs energy: G = U - TS, and helps to understand water at different temperatures. At low temperatures the water molecules want to minimise their internal energy and therefore form drops or crystals. At high temperatures, they will form a gas, which even though energetically costly is very chaotic (and therefore has large entropy).

Torsten Enßlin and Cornelius Weig from the Max Planck Institute for Astrophysics have now shown that the same terms, internal energy, entropy, and Gibbs energy, can be applied to the problem of reconstructing digital images. The entropy describes the uncertainty of assigning a particular brightness to the individual sky pixels. The internal energy describes the probability of the various sky images, which have to be taken into account within the boundaries given by the uncertainty. The best possible sky image can then be calculated from the interplay between internal energy and entropy. Moreover, in contrast to traditional techniques, the new method also gives an error map, showing the uncertainty in all pixels.

The researchers were able to show that many long established imaging algorithms are based on this approach, which originated in the century-old thermodynamics. However, completely new algorithms can be developed as well. One such example, and its application to astronomical data, is described in highlight 2.12. The entropy concept was already known in image reconstruction theory, but the internal energy, which is needed to determine the Gibbs energy, had not been introduced as such. The same thermodynamical laws contributing to the industrial revolution could again play an important role in today's development of information technologies. (Torsten Enßlin and Cornelius Weig)

References: T. A. Enßlin and C. Weig: "Inference with minimal Gibbs free energy in information field theory", Phys. Rev. E 82, 051112 (2010).

2.2 The First Stars in the Universe

Structure formation in the Universe started with the contraction of the smallest dark matter halos. These so-called 'minihalos' with about one million solar masses confined the intergalactic gas within their gravitational potential wells, where it became gradually denser and hotter (see Fig. 2.2). At the centre of these minihalos, at one point the gas was dense enough to form molecular hydrogen – the simplest molecule in the Universe – which allowed the gas to cool by activating internal degrees of freedom. This cooling then resulted in the runaway gravitational collapse of the gas to densities comparable to that of the Sun. Finally, a protostar formed, which had only a thousandth of a solar mass initially, but which rapidly accreted gas from the surrounding envelope. The newborn star continued to grow until it entered the main sequence of hydrogen burning after about one hundred thousand years.

Numerical simulations performed over the past decade found little evidence for fragmentation during the initial collapse phase, indicating that the first stars formed in isolation. Assuming that all the gas in a minihalo accretes onto the only protostar, simple one-dimensional calculations show that Population III stars will grow to about one hundred times the mass of the Sun. As they are extremely massive, they emit many more ionizing photons than normal, present-day stars and could leave a distinct imprint on the 21-cm background radiation. They influence the reionization of the Universe and, furthermore, give rise to extremely energetic supernova explosions - perhaps even the so-called pair-instability supernova, which disrupts the entire progenitor star and leaves no compact remnant behind.

In recent work, Thomas Greif and his colleagues used a new simulation technique to investigate the evolution of gas up to one thousand years after the formation of the first protostar. In the large spatial and dynamical range covered by their simulation, they found that the gas fragmented quite vigorously into about ten individual protostars instead of forming a single object (see Fig. 2.3). Since all individual stars accreted from the same, common gas reservoir, the typical mass of their Population III stars is reduced to about ten solar masses. In the further stellar evolution, this would severely limit the stars' ability to explode as pair-instability supernovae. Instead, these stars could end their lives as more conventional core-collapse supernovae and gamma-ray bursts, which have a very distinct observational signature.

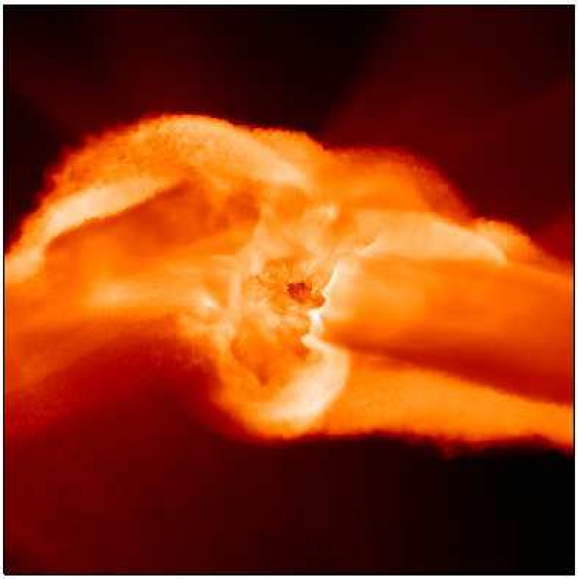

Figure 2.2: The collapse of gas in a dark matter 'minihalo', shown in a box with 30,000 lightyears on a side. The gas heats due to the release of gravitational potential energy. Only at the centre the gas cools due to molecular hydrogen. The temperature is color-coded from black (coolest) to white (hottest).

A second intriguing result of the same simulation is the ejection of protostars from the central gas cloud by gravitational slingshot effects, well before they have accreted even one solar mass. Such low-mass stars are extremely long-lived and could survive over cosmic time to the present day. They might even be observable in our own Galaxy. Discovering these stars would provide a tell-tale signature of the revised formation scenario proposed by Thomas Greif and his collaborators. (Thomas Greif, Volker Springel, Simon White et al.)

References:
Thomas H. Greif, Volker Springel, Simon D. M. White, et al. : "Simulations on a Moving Mesh: The Clustered Formation of Population III Protostars", Astrophys. J. **737**, id. 75

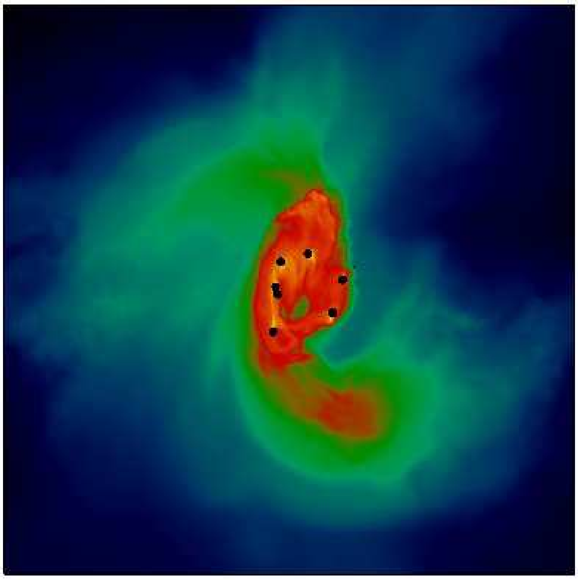

Figure 2.3: The gas at the centre of the minihalo forms a disk that fragments into a small cluster of protostars. The size of the box is only 200 astronomical units on a side. The density is color-coded from black (most underdense) to yellow (densest).

2.3 The Odd Spatial Distribution of Radio Galaxies on Cosmic Scales

Radio-loud AGNs are galaxies that host a supermassive black hole in their centre that is accreting material from its surroundings. These AGNs have been found to very large distances, corresponding to times when our universe was less than half its current age. Other observations indicate that around this time, the universe becomes dominated by a new component different from matter and radiation, called *Dark Energy*, which counteracts the attractive forces of gravity and hence accelerates the expansion rate of the Universe.

This Dark Energy is subject of intensive research. Major on-going and upcoming optical surveys attempt to characterize its nature by investigating how it modifies the lensing pattern of galaxies or their clustering, or by directly measuring the expansion rate at different cosmological epochs. One clear-cut prediction for Dark Energy is that it should modify the growth of gravitational potential wells on the largest scales, if it indeed accelerates the expansion rate of the universe. In a Universe with a flat geometry such as ours, in the absence of Dark Energy gravitational potential wells should

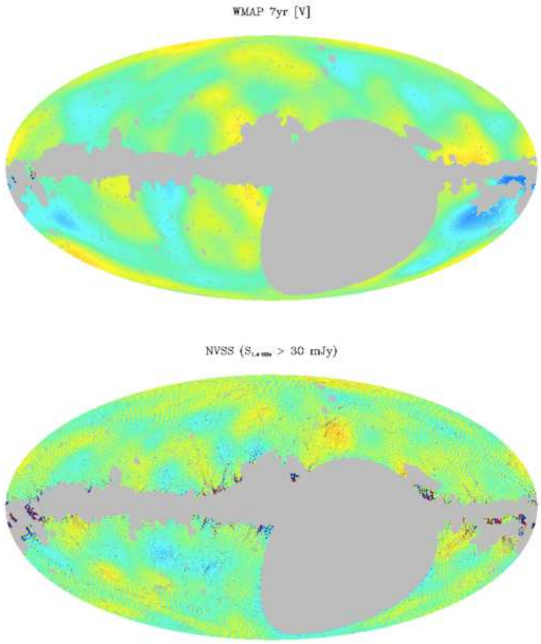

Figure 2.4: Simulated CMB map (top) and simulated projected density map mimicking the spatial distribution for the NVSS AGN catalogue (bottom). As expected from theory, both maps are similar particularly on large scales. In these mock maps only fluctuations on angular scales larger than ∼12 degrees are shown, which makes these similarities visible even to the naked eye. Grey areas are discarded in the analysis of real data (see Fig. 2.5).

remain constant: their growth due to gravitational enhancement of overdensities is perfectly cancelled by the expansion rate of space. However, if Dark Energy becomes dominant and accelerates the universal expansion rate, then these gravitational potential wells should become shallower, at least on the largest scales.

This shrinking of the potential wells should have an observable effect on the intensity anisotropies of the Cosmic Microwave Background (CMB). This radiation was emitted at very early epochs of our universe, roughly 380,000 years after the Big Bang, and has crossed the whole visible universe when it reaches us. In particular, the CMB photons must have crossed the evolving gravitational potential wells. If these have become shallower during the time required for CMB photons to cross those wells, then these photons should have gained some energy, since they leave a potential well that is shallower at exit than it was at entrance. This gravitational *blue-shift* of the CMB is known as the Integrated Sachs-Wolfe effect (hereafter ISW).

The number of gravitational potential wells varies along different directions on the sky, which means that the ISW effect will introduce angular anisotropies on the intensity pattern of the CMB. Now, if galaxies and AGNs preferentially form in those same potential wells, then there should be some correlation between the angular pattern of the CMB and the AGN angular distribution. Figure 1 shows this similarity in two simulated maps of the CMB radiation and the angular density fluctuations of radio galaxies after filtering out small scale anisotropies. On large angular scales (corresponding to large gravitational potential wells) both maps show some resemblance, which can be measured with high significance by applying a statistical analysis.

Applying the same statistics to real observational data, however, shows no significant similarity between these two maps. Figure 2.5 shows real CMB data (as measured by the WMAP satellite) and the angular distribution of objects in the NRAO VLA Sky Survey (NVSS) catalogue, which contains some 1.6 million extragalactic radio sources, of which more than 99% should be AGNs.

What does this mismatch mean? The CMB, on the one hand, has been compared to theoretical expectations and has proved to be in good agreement overall. On the other hand, the fluctuations of NVSS sources on large scales show a clear excess when compared to predictions. The fact that this excess is present for different flux thresholds (i.e. also brightest, clearly detected sources, show

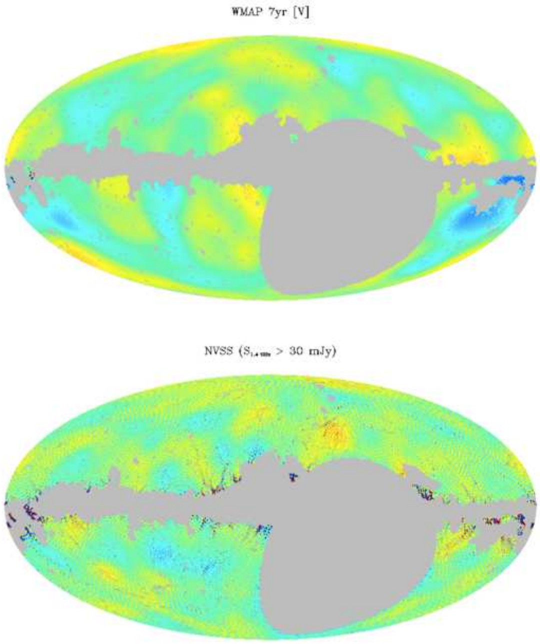

Figure 2.5: Maps of real WMAP 7th year (V-band) CMB data (top) and the projected density of real AGNs in the NVSS catalogue (bottom). Grey areas are discarded in the analysis due to either a lack of data or high contamination by other astrophysical sources. There does not seem to be any similarity (contrary to what is shown in Fig.2.4), which is confirmed by a statistical analysis.

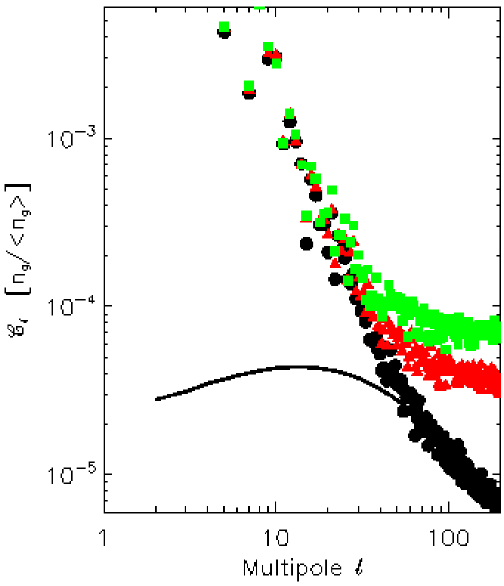

Figure 2.6: Amount of angular fluctuations in the NVSS AGN distribution for different angular multipoles (l). At low multipoles (corresponding to large angular scales) there seems to be a clear excess when comparing to theoretical predictions (black solid line). Black, red and green symbols correspond to AGN at different flux thresholds: 2.5, 30 and 60 mJy, respectively. At high multipoles (corresponding to small angular scales), the excess of red and green symbols (corresponding to 30 and 60 mJy) is well understood: This effect arises because of the relatively small number of AGNs above those flux cuts.

this abnormal behaviour) makes any observational systematic unlikely - but not impossible.

Is this excess of large scale anisotropy of radio AGN comparable to that recently claimed in the Sloan catalogue of Luminous Red Galaxies? Is this excess a signature of intrinsic non-Gaussianity in the matter fluctuation field in our universe? Do the AGNs in NVSS really sample the large scale gravitational wells? Can we derive conclusions on the mysterious Dark Energy from this result? These are all exciting, open questions, which are the subject of current investigations. (Carlos Hernandez-Monteagudo).

References: Carlos Hernandez-Monteagudo: "Revisiting the WMAP-NVSS angular cross correlation. A skeptic's view", Astron. and Astrophys. **520**, 101 (2010).

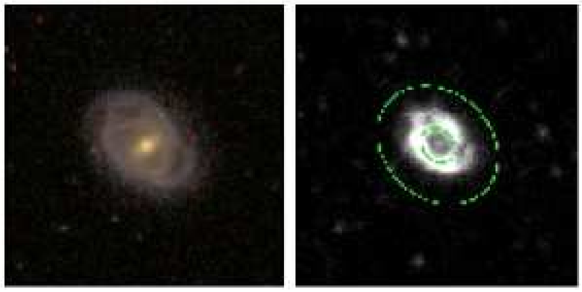

Figure 2.7: SDSS and GALEX images of one galaxy in the HI sample with a strong colour gradient. Left: SDSS g,r,i colour composite image; right: NUV map. In the UV light a bright ring is visible, which is not evident in the optical image.

2.4 New Evidence for inside-out formation of galaxy disks

The fraction of available baryons locked up in stars in galaxies such as our own Milky Way is only around 20 percent. Simple physical considerations predict that most of these baryons should cool, accrete and form stars. Up to the present day, the galaxies accrete additional material in the form of gas from the external environment as some observational evidence shows. In particular, neutral hydrogen (HI) cloud complexes, HI-rich dwarfs in the vicinity of spiral galaxies, extended and warped outer layers of HI in spiral galaxies, and lopsided galaxy disks have all been cited as evidence for ongoing gas accretion in nearby spiral galaxies. However, the total amount of gas accreting in this way is much too low to sustain star formation at the observed rates of 2-3 solar masses per year in these spirals. Astronomers have attempted to look for gas accretion in other forms, e.g. in an extended, hot gaseous corona surrounding the galaxy, in the form of ionized gas at intermediate temperatures, or in tiny clouds of neutral gas (where a *tiny* cloud for astronomers has a mere one thousand to one hundred thousand solar masses). But in spite of these on-going searches, conclusive evidence for gas accretion remains elusive.

If we cannot observe gas accretion directly, can we at least hope to observe its effects? Semi-analytical models for the formation of disk galaxies, their chemical evolution and star formation are commonly based on the "inside-out" picture in the context of Cold Dark Matter cosmologies. In this scheme, gas in the dark matter halo surrounding the galaxy cools, falls onto the galaxy, and fuels star formation in the disk. As the gas conserves its angular momentum and gas accreted at late times

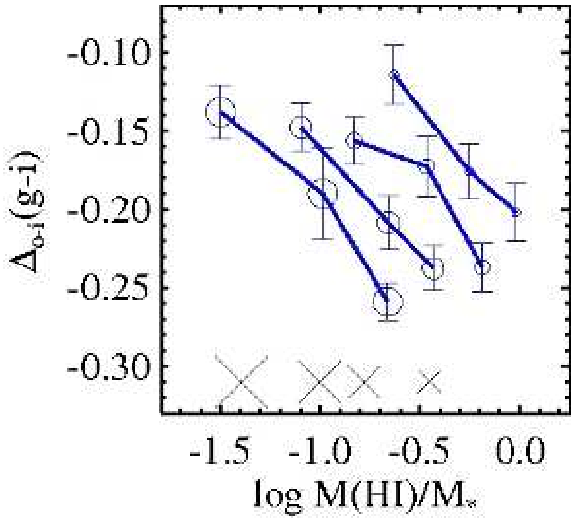

Figure 2.8: Relation between the colour gradient and HI mass fraction. In each stellar mass bin (circles with the same size), galaxies with higher HI mass fraction have stronger colour gradients, meaning that the galaxies become bluer towards the edge.

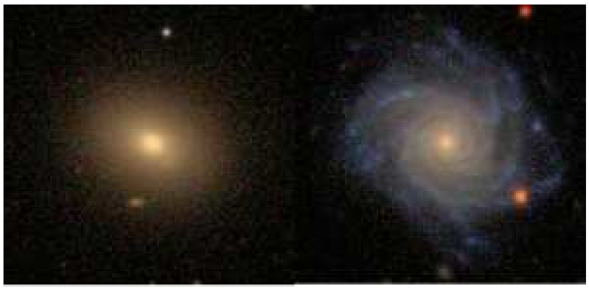

Figure 2.9: SDSS images of two galaxies in the sample. The left image shows a typical galaxy with low asymmetry and the right image a typical galaxy with high asymmetry. The study showed that that the asymmetry of the galaxies is connected more closely to the total star formation than the HI mass fraction.

has a higher specific angular momentum, it settles in the outer regions of the galaxy. In this picture, galaxies with recently acquired gas from their halo therefore should have not only unusually high gas mass fractions but also young, star-forming outer disks.

To test this picture, the MPA scientists performed a statistical study of the colours, star formation rate and neutral hydrogen (HI) gas fractions in galaxies. The sample of HI-rich, nearby galaxies (see Fig. 2.7) was selected based on a combination of data from the Arecibo Legacy Fast ALFA survey (ALFALFA) and the GALEX Arecibo SDSS Survey (GASS).

Galaxies with more gas are in general bluer and show more active star formation. The new study now showed that an increasing HI content also leads to a colour gradient across the galaxy disk: Galaxies with larger HI fractions have bluer, more actively star-forming outer disks compared to their inner parts (see Fig. 2.8). This means that the outer regions of HI-rich galaxies are younger. HI-rich galaxies also appear larger in blue light than in red light.

These results are indeed consistent with the *inside-out* picture of disk galaxy formation. They furthermore provide indirect evidence for the idea that disk galaxies continue to grow through gas accretion in the local Universe. The study also showed that there is no intrinsic correlation between the HI fraction and the measured asymmetry of the optical light of the galaxy. This suggests that the gas was most likely accreted smoothly and not in discrete units (see Fig. 2.9). (Jing Wang, Guinevere Kauffmann, Roderik Overzier and Barbara Catinella)

References:

Wang, J., Kauffmann, G., Overzier, R., Catinella, B. et al., “The GALEX Arecibo SDSS survey: III Evidence for the Inside-out Formation of Galactic Disks”, Mon. Not. R. Astron. Soc. **412** 1081–1097 (2011).

2.5 Present-day cosmic elemental abundances from massive stars in the solar neighbourhood

The formation and evolution of all objects in the universe, galaxies, stars, interstellar gas and dust, planetary systems, and even life, are tightly related to the origin and evolution of the chemical elements and therefore to the cosmic cycle of matter. Theories related to these phenomena hence need to be anchored to certain reference values for chemical abundances, traditionally chosen to be those of the Sun. However, whenever the current state of the chemical evolution of cosmic matter is of interest, B-type stars are better indicators. They allow an accurate spatial and temporal mapping of element abundances, providing a snapshot of the chemical composition of nearby stellar nurseries at the present day. B-stars are also preferable over some other present-day abundance indicators accompanying massive star formation, the H II regions.

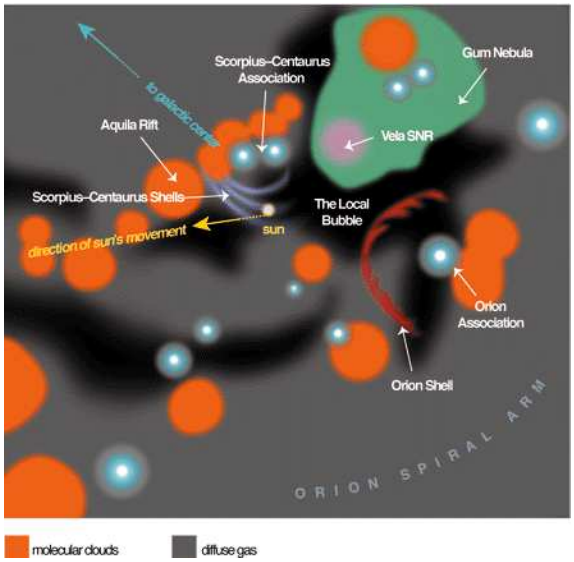

Figure 2.10: A schematic sketch of the Galactic neighbourhood around the Sun, out to about 1500 light years. The 29 sample stars are distributed in the Orion, Scorpius-Centaurus and other associations shown in blue/white as well as in the field within this area. Credit/copyright: Linda Huff and Priscilla C. Frisch

This is because the heavy elements in these luminous gaseous nebulae are partially depleted onto dust grains, which is difficult to quantify.

F. Nieva (MPA) and N. Przybilla (Uni Erlangen) have performed a comprehensive study of a carefully selected sample of early B-type stars in the solar neighbourhood, shown schematically in Fig. 2.10. Various telescopes in the Northern and Southern hemisphere were used to obtain high-quality spectra of the sample stars. With these new data, sophisticated non-local thermodynamic equilibrium models, and a novel self-consistent analysis method, the stellar parameters and chemical abundances of these 29 massive stars could be derived with unprecedented accuracy and precision.

One of the most surprising results is that the stars analysed in this study show a high level of chemical homogeneity (varying only by about 10%, see Fig. 2.11). This is independent of their location, does not depend on whether they are members in an OB association or field stars, and is also regardless of their temperature (15000 to 35000 K), mass (6 to 20 solar masses) and age (about 5 to 50 million years). This high degree of chemical homogeneity agrees with studies of absorption lines in the interstellar medium, but challenges all previous work on B-type stars in our Galactic vicinity,

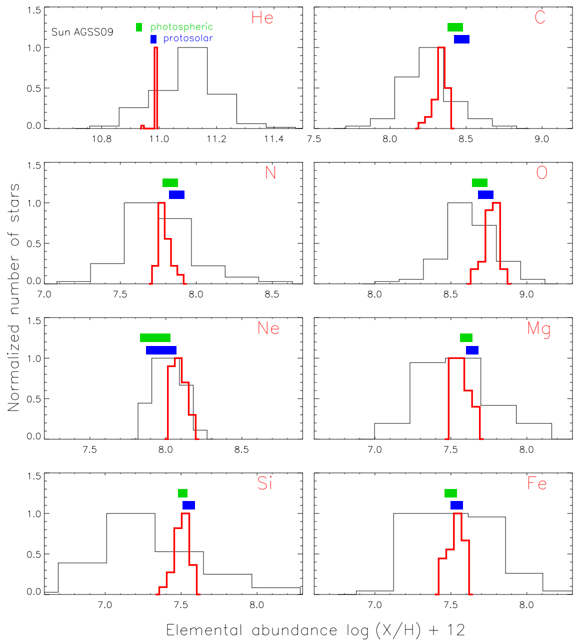

Figure 2.11: Abundance distribution of various chemical elements in the B-type star sample (red histograms) in comparison with data from the literature (black histograms). The much narrower distribution indicates a much higher uniformity in the present-day chemical composition of the cosmic matter in our Galactic neighbourhood than suggested by all previous work. Photospheric and protosolar abundances are taken from the most recent study by M. Asplund and colleagues. They are indicated by coloured bars, representing the uncertainty range. The new solar abundances (for example of carbon and nitrogen) are more similar to this work than older solar values.

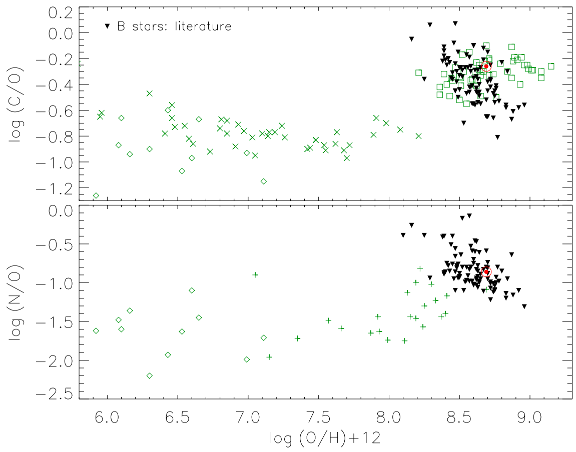

Figure 2.12: Evolution of the carbon/oxygen and nitrogen/oxygen ratios over cosmic times, represented by the incremental increase of the oxygen abundance. Green symbols represent long-lived solar-type stars, black symbols B-type stars from the literature. Solar photospheric abundances of Asplund and colleagues are indicated by the red circle.

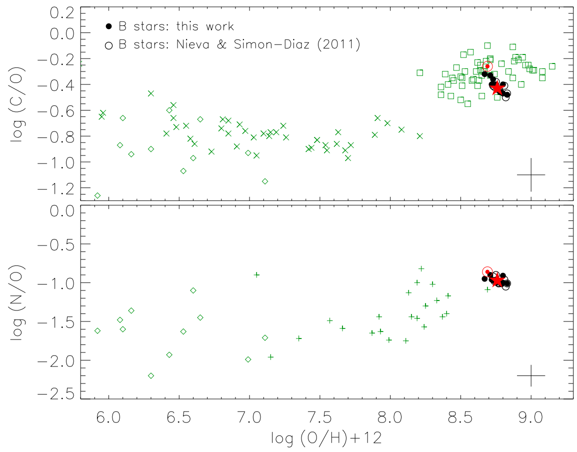

Figure 2.13: Same as Fig. 2.12, but with the black symbols representing the B-stars of the present work. The smaller spread of abundance values clearly shows that the spectral modelling of the B-type stars has been improved.

which claim a scatter of elemental abundances by a factor of 2 to 3.

The high degree of homogeneity lead Nieva and Przybilla to propose a present-day cosmic abundance standard (CAS) based on B-stars in the solar neighbourhood. Comparing these to the equally accurate solar abundances, one can identify similarities and differences in the abundances for individual elements that are of relevance for various aspects of astrophysical research. (Maria Fernanda Nieva and Norbert Przybilla)

References:

Nieva, M. F. and Przybilla, N., “Present-Day Cosmic Abundances. A comprehensive study of nearby early B-type stars and implications for stellar and Galactic evolution”, Astron. and Astrophys.

Nieva, M. F. and Simon-Diaz, S.: The chemical composition of the Orion star-forming region. III. C, N, Ne, Mg and Fe abundances in B-type stars revisited”, Astron. and Astrophys. **532**, A2, 1–14 (2011).

2.6 Faraday caustics: Light patterns from cosmic magnetism

Imagine a sunny day at the pool. Looking down at the bottom of the pool reveals a network of ridges of bright light, like those depicted in Fig. 2.14 that is constantly in motion. These structures, known as optical caustics, are an effect of the sunlight being focused to a single point as it is refracted by the wavy surface of the water. The rippling surface causes light to "pile up" in certain regions at the bottom of the pool instead of filling all the space equally.

What does this have to do with astrophysics? Recently, Michael Bell, Henrik Junklewitz and Torsten Enßlin have shown that similar features, which they are calling “Faraday caustics”, can be seen in images of polarized radio emission produced using next generation radio telescopes. Just as the caustics at the bottom of the pool trace conditions at the surface of the water, Faraday caustics trace specific properties of magnetic fields in the universe. In the same way that one might study the properties of the pool’s surface by observing the network of light patterns at the bottom, the authors propose that Faraday caustics may be very useful for learning about the distribution of magnetic fields in the universe and to help shed light on their yet unknown origins.

Magnetic fields can be found everywhere in the cosmos. They are generated by planets, like the Earth, stars or other celestial objects, and permeate the vast space of the largest structures in the universe, such as galaxy clusters. Nevertheless, although we know of their existence, it is often difficult to measure their exact properties. For those observing radio waves, an effect known as Faraday rotation can be a good tracer of some of the

Figure 2.14: Optical caustics at the bottom of a swimming pool. Ripples on the surface of the pool refract the sunlight to produce a bright network of features on the floor. Similarly with Faraday caustics, particular magnetic field configurations produce bright features in polarized radio emission.

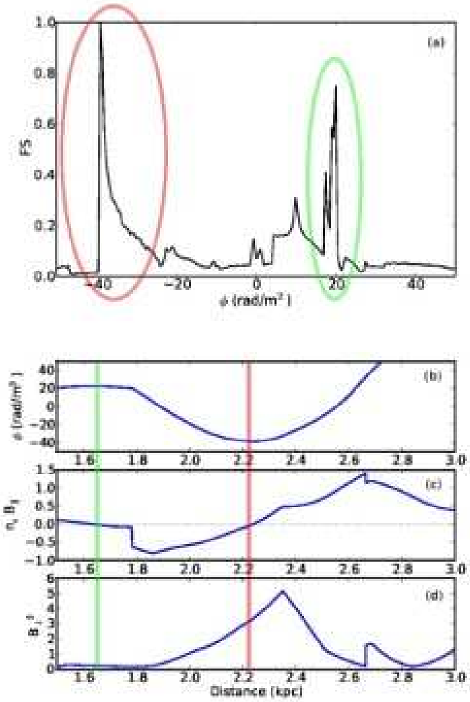

Figure 2.15: a) A simulated Faraday spectrum, i.e. the polarized intensity separated by the amount of Faraday rotation suffered. The spectrum shows examples of Farday caustics, circled in red and green. b) The Faraday rotation as a function of distance along the line of sight (LOS). c) The LOS component of the magnetic field as a function of LOS distance. This effects the Faraday rotation. Faraday caustics appear when this is zero. d) The magnetic field in the plane of the sky as a function of line of sight distance. The caustics, circled in red or green in the Faraday spectrum, are associated with features in the magnetic field distribution marked by the like colored lines.

magnetic fields' properties. The effect of Faraday rotation is that the plane of polarization of a radio wave is rotated as it passes through a magnetized plasma. The amount of rotation depends, among other things, on the properties of the magnetic field and the observed frequency. Since this rotation can be calculated from polarization sensitive observations at different frequencies, Faraday rotation has been a very useful tool for studying cosmic magnetism.

Astronomers face the problem that the radiation from a single direction might have been emitted by two or more different radio sources. The radiation from each source would have traveled through different magnetic fields and been rotated by different amounts. How can astronomers distinguish between these sources? To overcome this problem a new measurement technique was devised in recent years called "Rotation Measure Synthesis". This technique uses the same mathematical approach used to analyze the different frequency components that produce a complicated acoustic signal, like a song. After measuring polarized radio emission at many different frequencies, one can reconstruct the 'Faraday spectrum', i.e. separate the polarized emission into components that are rotated by different amounts due to Faraday rotation. In this spectrum, Faraday caustics are predicted to leave a tell-tale trace (Fig. 2.15).

The scientists of the Max Planck Institute have shown that Faraday caustics are caused by reversals of the magnetic field orientation along a line of sight. Such reversals are quite common in turbulent astrophysical environments, therefore Faraday caustics are predicted to appear in many observations. The behavior and statistics of the Faraday caustics will reveal structural and statistical properties of cosmic magnetic fields.

The authors show that the new European radio telescope LOFAR, in whose construction the Max Planck Institute for Astrophysics is participating, will be ideally suited to observing Faraday caustics. Using LOFAR and other telescopes, future observations specifically designed to look at Faraday caustics will greatly improve our understanding of the magnetic fields in our own and other galaxies, and help to unravel their yet unknown origins. This is the aim of the German research unit

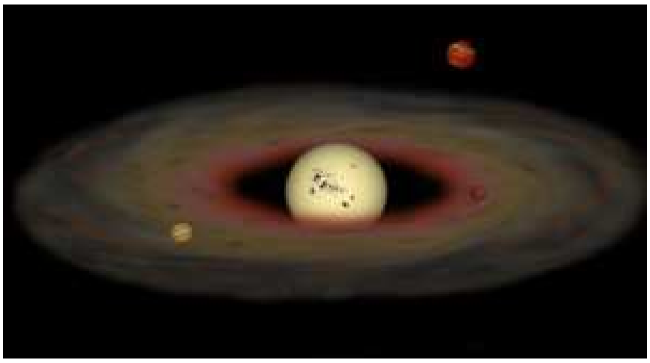

Figure 2.16: Artist's impression of a system of hot Jupiters, with its Sun-like host star, and the gaseous disk from wich the planets formed after the merger of the binary star system. Copyright: MPA

Magnetisierung des interstellaren und intergalaktischen Mediums (Magnetization of the interstellar and intergalactic medium) funded by the German Society of Research (DFG). (Michael Bell, Henrik Junklewitz and Torsten Ensslin)

Reference:

Bell, M., H. Junklewitz, T. A. Enßlin: "Faraday caustics: Singularities in the Faraday spectrum and their utility as probes of magnetic field properties", Astron. and Astrophys. **535**, A85, 1–14 (2011).

2.7 Curious, these inflated hot Jupiters

The number of exoplanets dicovered is rapidly increasing thanks to space-based telescopes like Kepler and COROT that can detect the tiny decrease in light when a planet transits in front of its host star. A remarkable group among these are the so-called "hot Jupiters": planets with masses like Jupiter's, but orbiting very close to their star, with periods of 2-5 days. They are often (but not always) much larger than expected for their mass: by factors up to 3.

Our Jupiter probably also started its life with such a large size, but by radiating heat from its surface rapidly shrunk to its present size. Left on their own, planets of this size and mass contract on a time scale of $10^7 - 10^8$ years. This causes a problem: the hosts stars of the hot Jupiters do not look that young at all, they look just like normal stars of $2 - 8 \times 10^9$ years. How can these planets stay 'inflated' for such a long time? This puzzle has become one of the central themes in the study of exoplanets.

A currently popular idea is that the unusual size of the planet has to do with irradiation by the nearby host star. So close to the star, the surface of the planet is much much hotter than that of Jupiter. If a way can be found to transport this heat into the interior of the planet, it could be sufficient to keep the planet inflated for as long as it orbits around the star. The effect of such irradiation can be calculated rather reliably (with the theory of stellar structure and evolution), and the answer is not good. Irradiation expands the planet by only a small amount, up to some 10%. Instead, most of the irradiating flux is effectively radiated back from the surface, and the expansion mostly a small surface effect. Much effort has gone into alternative scenarios for somehow getting the irradiating heat flux into the interior of the planet, or for tapping the planet's energy of rotation through tidal heating (such as happens for example in Jupiter's moon Io). These proposals have not been very successful thus far.

Large planets orbiting close to their star are much easier to find than small ones at larger distances. Correcting for this selection effect, it is estimated that hot Jupiters occur only in about 1% of the planet systems. It is therefore possible that they are exceptions that formed by a different channel than for example our own planet system. The proposal made here is that hot Jupiters are actually as young as they look, and that their host stars are not as normal and old as they look, but formed only recently from a binary star.

Close binary stars consisting of two stars with masses around that of the Sun are abundant. Such stars are "magnetically active": they have a magnetic field that drives an outflow of gas from the star. Like in the case of the Sun, this wind causes the stars to loose angular momentum, and by the close tidal spin-orbit coupling of the stars, this causes the binary orbit to shrink. It can take several 10^9 years before the stars finally touch, but the following squence of events happens very fast (Fig. 2.17). The two stars merge into a single rapidly rotating star. Numerical simulations have shown that the final stages of this process take only 10-100 binary orbital periods.

The binary orbit contained more angular momentum than a single star can take, and the excess spreads into a gasous disk surrounding the star, in which planets can form. The mass in this disk, of the order 0.1 solar masses, is plenty to form several Jupiter-sized planets. Since the disk forms close to the star, these planets would also orbit close to the star. Being close together, they disturb each other's orbits by their gravitational force. Such closely packed systems are dynamically unstable. Most planets are kicked out of the system or crash into the star, the remaining one(s) will typically orbit on excentric, inclined (or even retrograde) orbits. These are just the properties observed in hot Jupiter systems. (Henk Spruit, Eduardo Martin)

Reference: Martin, E.L., H.C. Spruit, R. Tata: Astron. Astrophys. **535**, A50.

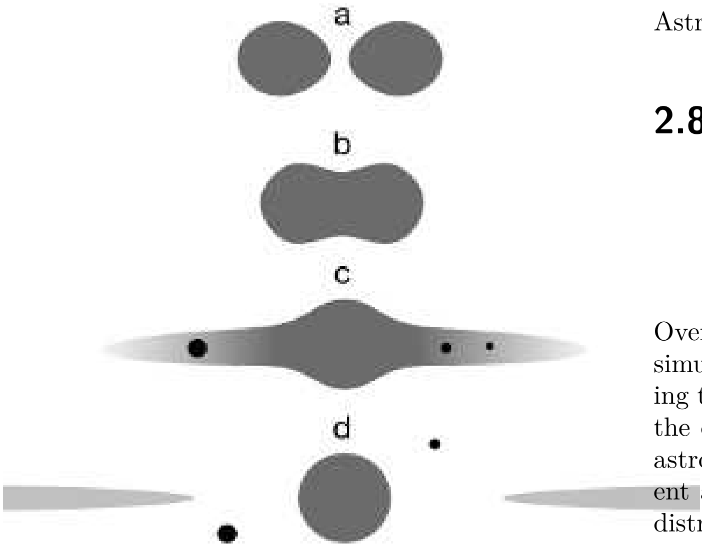

Figure 2.17: Schematic of how planets are formed in the merging of two stars. A close binary system of two small stars (a) is slowly getting smaller by the loss of energy due to magnetic winds from the stars until they touch (b). The stars merge, the excess of angular momentum in their orbits causes a dense 'excretion' disk to spread outwards, in which planets form (c). As the disk dissipates further outward the planets disturb each other's orbits by their gravitational pull, resulting in eccentric, inclined orbits out of the disk plane. In this sketch the smallest planet is kicked out; in many cases only one (large) planet remains orbiting close to the star. Copyright: MPA

2.8 The Millennium-XXL Project: Simulating the Galaxy Population in Dark Energy Universes

Over the last two decades, cosmological numerical simulations have played a decisive role in establishing the ΛCDM paradigm as a viable description of the observable Universe. For instance, they allow astronomers to explore the impact of the different aspects of this standard model on the spatial distribution of galaxies, which can then be directly compared with observation to validate or rule out a particular model. Similarly, such simulations have proven to be an indispensable tool in understanding the low- and high-redshift Universe, since they provide the only way to accurately predict the outcome of non-linear cosmic structure formation.

Scientists at the Max-Planck-Institute for Astrophysics, together with collaborators in the Virgo consortium, have recently completed the largest cosmological N-body simulation ever performed. This calculation solved for the gravitational interactions between more than 300 billion particles over the equivalent of more than 13 billion years, thus simultaneously making predictions for the mass distribution in the Universe on very large and very small scales. Carrying out this computation proved to be a formidable challenge even on today's most powerful supercomputers. The simulation required the equivalent of 300 years of CPU time and used more than twelve thousand computer cores and 30 TB of RAM on the Juropa Machine at the Jülich Supercomputer Centre in Germany, one of the top 15 most powerful computers in the world at the time of execution. The simulation generated more than 100 TB of data products.

This new simulation, dubbed the Millennium-XXL, follows all 6720^3 particles in a cosmologi-

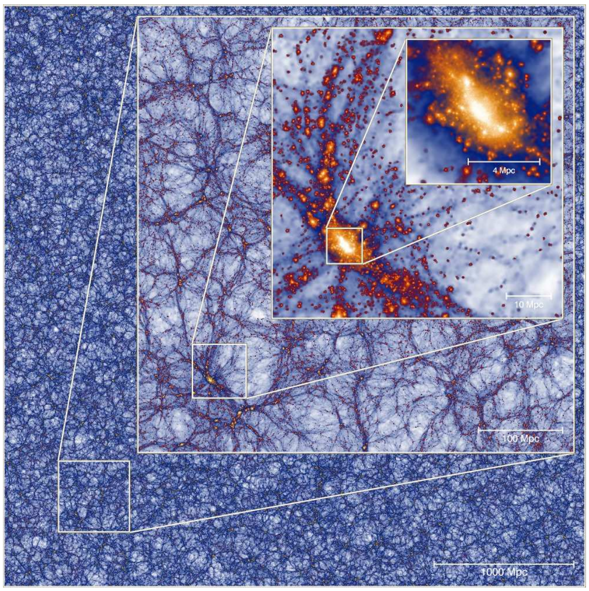

Figure 2.18: The mass density field in the Millennium-XXL focusing on the most massive halo present in the simulation at z=0. Each inset zooms by a factor of 8 from the previous one; the side-length varies from 4.1 Gpc down to 8.1 Mpc. All these images are projections of a thin slice through the simulation of thickness 8 Mpc.

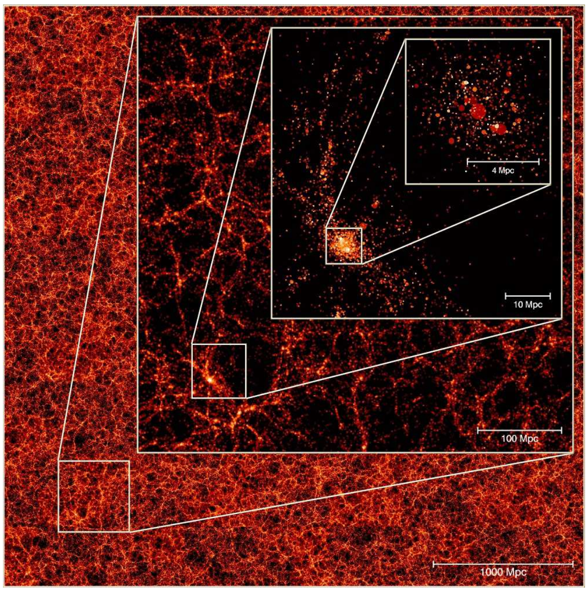

Figure 2.19: The predicted galaxy distribution in the Millennium XXL simulation. Each galaxy is represented by a sphere, whose intensity and size are related to the expected total mass in stars and the size of its cold gas disk, respectively.

cal box of side 4.1 Gpc, resolving large-scale structure with an unprecedented combination of volume and detail. The enormous statistical power of the simulation is hinted at in Fig. 2.18, which shows the projected density field on very large scales and for the largest cluster found at z=0. The simulation has been used to model galaxy formation and evolution, providing a sample of around 700 million galaxies at low redshift, whose distribution is displayed in Fig. 2.19. This allows detailed clustering studies for rare objects such as quasars or massive galaxy clusters, and also new ways to physically model observations. In particular, the scale-dependent relation between galaxies and the underlying dark matter distribution, and the impact of non-linear evolution on the so called baryonic acoustic oscillations (BAOs) measured in the power spectrum of galaxy clustering can be addressed in a fully physical way for the first time.

This work is expected to be crucial in understanding new observational data, whose aim is to shed light on the nature of the dark energy via measurements of the redshift evolution of its equation of state. In particular, the arrival of the largest galaxy surveys ever made is imminent, offering enormous scientific potential for new discoveries. Experiments like SDSSIII/BOSS or PanSTARRS have started to scan the sky with unprecedented detail, considerably improving the accuracy of existing cosmological probes. These experiments, combined with theoretical effors like the newly performed simulation, will likely lead to challenges to the standard ΛCDM paradigm for cosmic structure formation, and perhaps even to the discovery of new physics. (Raul Angulo and Simon White)

2.9 Cold gas and star formation in galaxies

Galaxies in the nearby Universe come in a wide variety of shapes, colours and sizes, yet this diverse population is found to obey many complex relations between their different properties. A global picture emerges, where galaxies mostly fall in one of two categories: either they are gas-rich, blue, spiral-like and actively star-forming, or else they are red, gas-poor and featureless. If we want to understand how galaxies form and evolve such as to produce this picture, it is essential to pinpoint when, where and how stars are formed in any galaxy. While detailed observations of the stellar light of galaxies can already teach us a great deal, a major hurdle in our understanding is our comparatively poor knowledge of the gas contents of

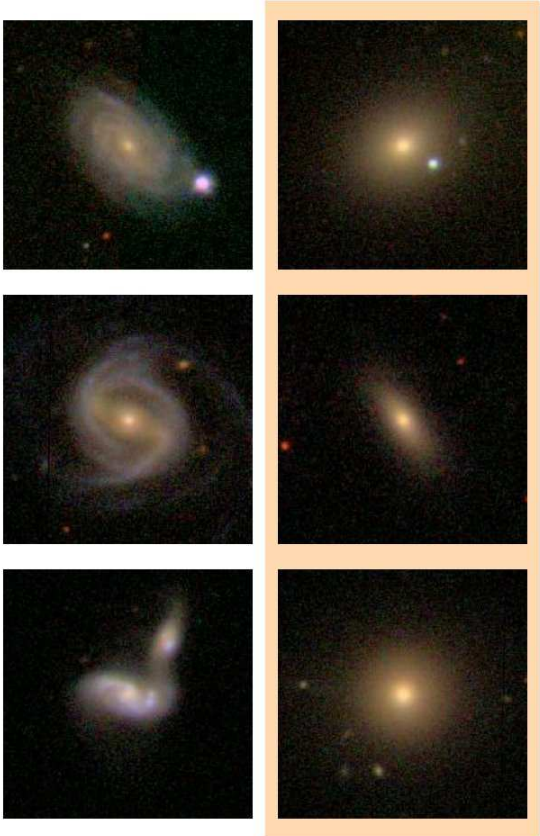

Figure 2.20: SDSS images of 6 galaxies observed as part of the COLD GASS survey. In the left-hand side column are examples of star-forming galaxies, where atomic and molecular gas are found in normal abundance. The right-hand side column shows three red and passive galaxies: these kinds of galaxies have very little molecular gas, yet can contain surprising amount of atomic gas. The survey aims at understanding why molecule formation is so inefficient in these galaxies.

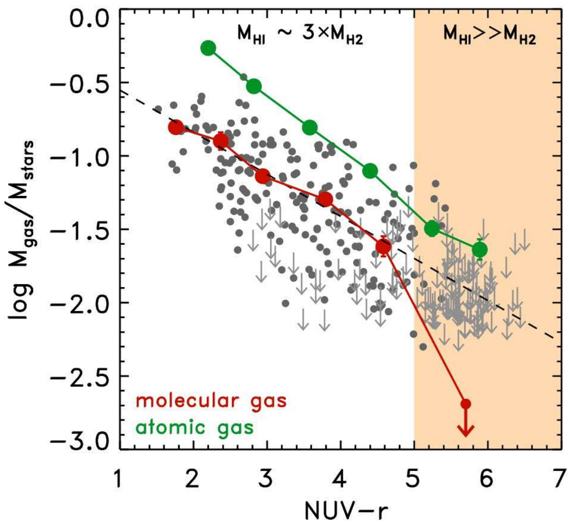

Figure 2.21: Relation between the amount of gas in a galaxy and its color. While the atomic gas fraction is a continuous function of color, there is a sharp break in the molecular gas abundance in the reddest galaxies (data from Catinella et al. 2010, Fabello et al. 2011 and Saintonge et al. 2011).

these galaxies. Since cold gas is the fuel for star formation, we need a better picture of how galaxies are supplied in gas, how they process this gas into stars, and how some of the gas is then returned to the outside environment. Only then can we hope to really understand how galaxies evolve.

To answer these questions, scientists at the Max Planck Institute for Astrophysics are part of an international team currently using some of the world's largest radio telescopes to map the gas contents of massive galaxies in the nearby Universe. Complementary information comes from the extensive multi-wavelength data set that is being assembled by the team, including data from the Sloan Digital Sky Survey (SDSS), the UV satellite GALEX, and the Arecibo radio-telescope.

The IRAM 30-metre telescope, atop Pico Veleta in southern Spain, is providing key information about how gas is transformed into stars. The telescope, which is funded and operated by the French CNRS, the German Max Planck Society and the Spanish IGN, can observe at millimetre wavelengths and trace the presence of molecular gas in galaxies - allowing the scientists a glimpse at the last step along the cycle of gas: Once gas is accreted onto galaxies, it cools in regions where it is compressed, leading to the formation of molecules and then stars. The COLD GASS survey team, led by Amelie Saintonge from MPE and Guinevere Kauffmann from MPA, has used the IRAM 30-m telescope to perform a census of this molecular gas in a sample of 350 galaxies representative of the population of massive galaxies in the nearby Universe.

The survey so far has been used to trace the abundance of molecular gas in galaxies as a function of their mass, colour and morphology. This showed impressively the existence of sharp divides in the galaxy population based on their gas contents. With the IRAM observations, the scientists could identify a population of galaxies with no more than trace amounts of molecular gas. These

Figure 2.22: The IRAM 30m telescope

galaxies are the most passive at the present epoch, with very little to no on-going star formation.

A surprising result emerges when the IRAM data are combined with the extensive multi-wavelength data set: While the IRAM observations find this population of "red and dead" galaxies, with no significant trace of either molecular gas or star formation, the Arecibo radio telescope shows that these galaxies can contain a significant amount of atomic gas, which under normal circumstances would cool and ultimately form stars.

Why can these galaxies be rich in atomic gas and yet not be able to form stars? This observation alone tells us about the existence of a bottleneck in the star formation process in massive galaxies: it is not enough for a galaxy to have a large reservoir of atomic gas; the conditions have to be just right for this gas to reach the low temperatures and high densities required for star formation. The results of large numerical simulations, also conducted by the MPA team and their collaborators, are now being tested against these observations. The combination of these detailed simulations and the large body of data provided by the COLD GASS survey will likely mark a step forward in our understanding of how galaxies evolve through the cycling of gas and the formation of stars. (Amelie Saintonge)

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2.10 Music of stars reveals their properties

Our galaxy is comprised of stars of different sizes, ages, and chemical compositions. Current observational techniques can put some constraints on stellar properties, such as effective temperature, surface gravity and composition. However, in order to estimate masses and radii, these measurements need to be complemented with theoretical calculations of stellar evolution, where large uncertainties remain due to our limited understanding of the physical processes taking place in stellar interiors. This has implications in many fields of astrophysics, from characterizing simple stellar populations in galactic globular clusters to reconstructing the formation history of distant galaxies.

Fortunately, stars like the Sun are not static and provide us with additional information by means of their oscillations. Just like air flowing through a musical instrument, vigorous convective motions in the outer layers of stars excite acoustic waves that propagate through the stellar interior. Depending on the characteristics of its resonant cavity, the star will vibrate in different frequencies and overtones, periodically swelling and contracting as the pressure waves travel through its interior. Asteroseismology is the field of astrophysics occupied with the study of these (and other) types of stellar pulsation.

In principle, every star with a convective outer layer should present acoustic oscillations, often termed solar-like oscillations as they were first ob-

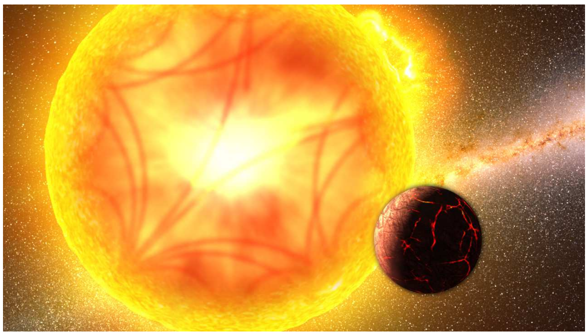

Figure 2.23: Artist's impression showing sound waves trapped in the interior of one star, with an orbiting planet in the foreground. Kepler has observed oscillations in more than 500 solar-type stars. Credits: G. Perez Diaz, IAC (MultiMedia Service).

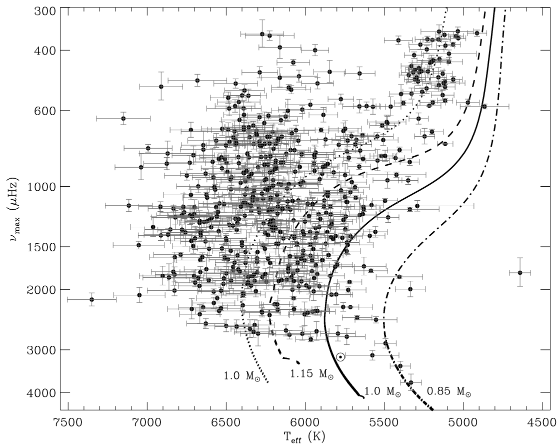

Figure 2.24: Frequency of maximum oscillation power (ν_{max}) vs. effective temperature (T_{eff}) for the complete sample of stars, for which oscillations were detected. Evolutionary tracks for some stellar parameters are also plotted: at solar metallicity for 0.85 solar masses (dash-dotted line), 1.0 solar mass (solid line), and 1.15 solar masses (dashed line); and at sub-solar metallicity for 1.0 solar mass (dotted line). The Sun is marked with a dotted circle close to the bottom of the 1.0 solar mass track

served in the Sun. However, the brightness variations they produce are fairly small, and can be on the order of only a micro-magnitude. This level of precision is very challenging to obtain from ground observations, which led astronomers to look for possibilities of observing from space, where higher accuracy can be achieved.

The Kepler mission has been the most successful example of asteroseismic observations. As the illustration in Figure 2.23 shows, one of the main aims of this satellite is to detect extrasolar planets by the "transit method". As the planet on its orbit moves between the parent star and the observer it will lead to a small dimming of the star. The detected spectra of oscillations need to be carefully analysed to distinguish between an external cause such as a planet and intrinsic oscillations of the star itself. Staring at the same field in the sky for the entire mission, Kepler continuously and simultaneously monitors the brightness of more than 100,000 stars in our galaxy.

One of the many important achievements of the Kepler mission is the detection of oscillations in more than 500 stars in the so called main-sequence phase. In this longest evolutionary phase in a star's lifetime, stellar energy is produced by fusion of hydrogen - their main constituent - into helium.

Using a measure of the stellar surface temperature (known as effective temperature), we can compare in Figure 2.24 the seismic observations – measured with an unprecedented level of precision - with theoretical predictions. Interestingly enough, it turns out that a large fraction of the seismic observations lie in the region where evolutionary tracks for stars with masses close to one solar mass are located. Is it possible to pinpoint the masses and radii of these stars?

Asteroseismology provides the answer by what is known as the *direct method* for mass and radius determination. The two global asteroseismic quantities, the large frequency separation and the frequency of maximum oscillation power, are tightly correlated over a wide range of values. Moreover, they are correlated with the accurately known solar parameters, such as the surface temperature, through scaling relations. As the oscillations depend on the characteristics of the resonant cavity (i.e. the size of the star), we can directly determine the mass and radius of a star using the global seismic parameters coupled with the effective temperature.

Figure 2.25 shows more than 70 targets with a mass determined to be close to solar among the large ensemble of stars with oscillations detected. For a few of these stars, accurate metallicities (i.e. the abundance of elements heavier than hydrogen and helium) have been measured from spectroscopy, and the agreement with evolutionary calculations is exquisite. The data therefore suggests that we have successfully identified, for the first time, an evolutionary sequence of field stars with masses very close to one solar mass.

These findings have several interesting implica-

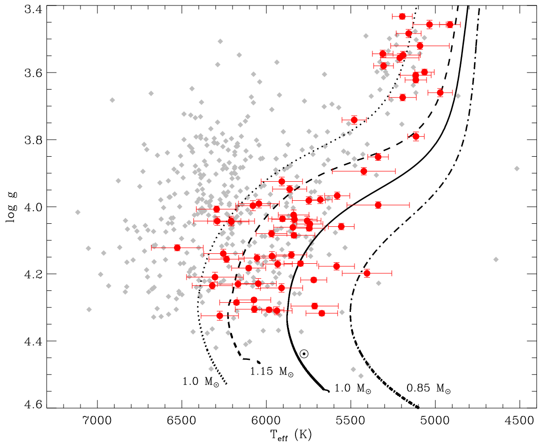

Figure 2.25: This plot shows the effective temperature and a measure of the surface gravity (log g) for all targets, where log g was obtained from scaling relations. Stars with masses determined to be 1 solar mass ± 15% are plotted as red circles, while the rest of the stars with detected oscillations are plotted as grey diamonds (without error bars to reduce clutter). The spread is most likely due to differences in the chemical compositions of the stars. Stellar tracks and position of the Sun are the same as in Figure 2.24

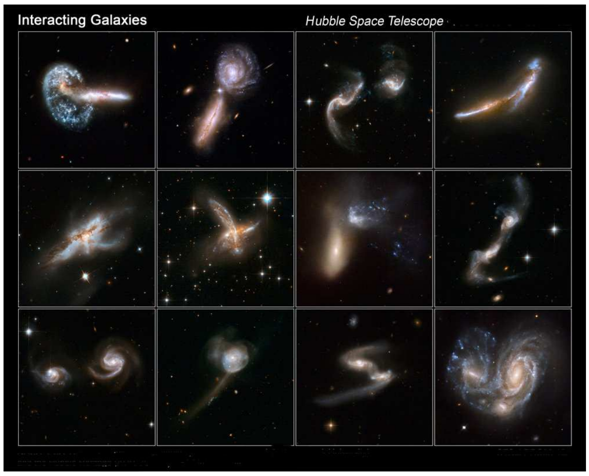

Figure 2.26: Collection of HST images of interacting galaxies. Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

tions for astrophysics. We can now perform differential analysis on stars with similar masses but in different evolutionary stages, following their development throughout the main-sequence phase. It also demonstrates the capability of asteroseismology to characterize stellar populations in a certain region of the sky.

Seismic observations coupled with effective temperature estimates allow the determination of masses and radii to a very high level of precision for stars in different evolutionary phases. This opens the exciting possibility of deriving stellar ages to a precision exceeding that possible by other techniques adopted in stellar population studies, such as isochrones or chromospheric activity dating. Combining these results with parameters obtained from stellar colours, such as metallicities, and angular diameter (and thus distances when comparing this with radii) could offer a complete picture of the stellar population in the Kepler field.

The possibilities are many, and the potential of asteroseismology to constrain theoretical models, unveil underlying physical processes, and discover the dynamical history of our galaxy is finally being exploited. (Victor Silva Aguirre, Luca Casagrande, Ralph Schönrich, Achim Weiss).

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2.11 Black hole pairs: shrinking, stretching and flipping

In the standard cosmological scenario of structure formation, galaxies assemble through successive mergers of larger and larger systems (see Fig. 2.26 for images of interacting galaxies). Apart from larger galaxies, this also leads to the formation of pairs of massive black holes, called black hole binaries (see Fig. 2.27 for an illustration), in their centres. Stars that undergo a close encounter with a black hole binary tend to extract energy and angular momentum from the binary, and are ejected to larger distances, while the orbital separation of the binary shrinks. If enough energy is transferred to the stellar population, the black holes come so close that eventually they merge in a burst of gravitational waves. Calculations of the evolution of black hole binaries generally assume spherically symmetric galaxy models. During mergers, however, strong perturbations are produced, which lead to significant deviations from spherical symmetry and to rotation.

So how do black hole binaries evolve in realistic merger remnants? To answer this question, scientists at the Max Planck Institute for Astrophysics

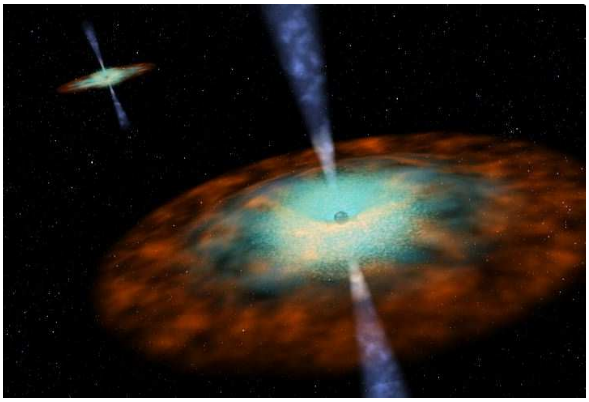

Figure 2.27: Artist's illustration of a binary black hole system. Credit: NASA, Jet Propulsion Laboratory.

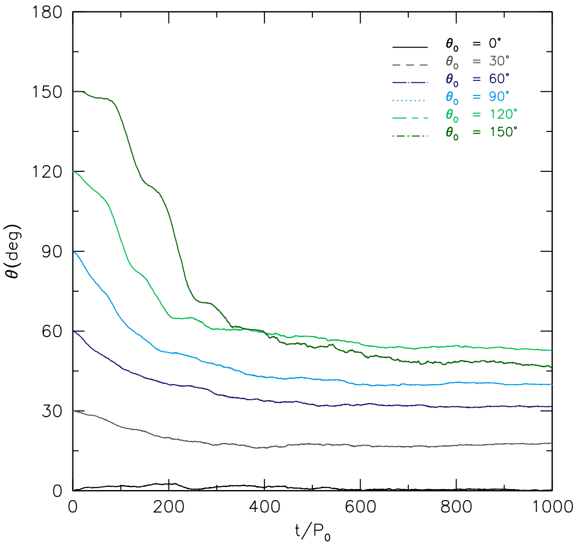

Figure 2.28: Evolution of the angle between the angular momentum vector of the black hole binary and that of the stellar cusp. Time is expressed in units of the initial binary orbital period. Different lines are for models with different initial values of the separation angle, from 0 deg to 150 deg. (Adapted from Gualandris, Dotti, Sesana, 2012)

and international collaborators performed a series of numerical simulations of galaxy mergers as well as black hole binaries immersed in rotating merger remnants. In these calculations, the gravitational forces between all pairs of particles in the galaxies are computed and very accurate trajectories are derived.

Simulating the merger of two galaxies using highly accurate numerical methods is an extremely challenging computational task, and required more than one year of uninterrupted computations on the GPU machines at the Max Planck Institute for Astrophysics and on the special purpose GRAPE cluster at the Rochester Institute of Technology (Rochester, USA). The results of these calculations, however, are very interesting.

The evolution of black hole binaries in spherically symmetric galaxies is characterized by a first phase, where the binary separation shrinks, followed by a stalling phase of very slow orbital decay. In contrast, the evolution in realistic merger remnants proceeds to very small separations - separations that are small enough that the emission of gravitational waves becomes dominant and the black holes coalesce to form a single black hole.

Simulations of black hole binaries in rotating systems also show that the eccentricity of the binary evolves, where the nature of this evolution (to a more or less eccentric orbit) depends on the degree of co-rotation in the stellar cusp. As the separation of the two black holes shrinks due to close encounters with stars, the orbit will circularize in time, if a large fraction of stars co-rotate with the binary. However, if most stars move on counter-rotating orbits, the binary becomes more eccentric. The latter effect, which could arise as a result of mergers between galaxies of different mass, has important implications for the possible detection of gravitational waves emitted by coalescing black hole binaries.

In addition, if the angular momentum of the binary is initially misaligned with respect to that of the stellar system, a reorientation of the binary orbital plane occurs. In spherically symmetric models, the orientation of the binary plane suffers only small changes on long timescales due to a kind of random walk process as interacting stars exchange angular momentum with the binary. If, on the other hand, the binary is immersed in a stellar system with net rotation where the angular momentum is misaligned, it tends to realign its orbital plane with the angular momentum of the stars. This reorientation takes place on the same timescale over which the separation shrinks and can be quite significant, with changes as large as 100 degrees.

The realignment of the binary plane seen in the simulations may have significant implications for astrophysical observations. The direction of the spin axis of the single black hole that results from the ultimate merger of the binary is affected by the orientation of the binary plane before coalescence.

The spin axis, in turn, determines the orientation of the accretion disk around the remnant black hole and, in radio-loud systems, the direction of the radio jet. (Alessia Gualandris).

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2.12 New all-sky map shows the magnetic fields of the Milky Way with the highest precision

All galaxies are permeated by magnetic fields, including our own Milky Way galaxy. Despite intensive research, the origin of galactic magnetic fields is still unknown. One assumes, however, that they are built up by dynamo processes in which mechanical energy is converted into magnetic energy. Similar processes occur in the interior of the earth, the sun, and - in the broadest sense - in the gadgets that power bicycle lights through pedaling. By revealing the magnetic field structure throughout the Milky Way, the new map provides important insights into the machinery of galactic dynamos.

One way to measure cosmic magnetic fields, which has been known for over 150 years, makes use of an effect known as Faraday rotation. When polarized light passes through a magnetized medium, the plane of polarization rotates. The amount of rotation depends, among other things, on the strength and direction of the magnetic field. Therefore, observing such rotation allows one to investigate the properties of the intervening magnetic fields.

To measure the magnetic field of our own galaxy, radio astronomers observe the polarized light from distant radio sources, which passes through the Milky Way on its way to the Earth. The amount of rotation due to the Faraday effect can be deduced by measuring the polarization of the source at several frequencies.

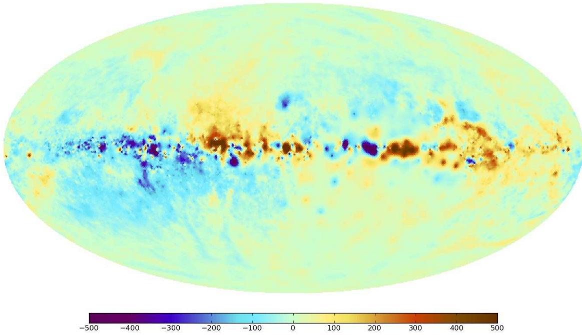

Figure 2.29: The sky map of the Faraday effect caused by the magnetic fields of the Milky Way. Red and blue colors indicate regions of the sky where the magnetic field points toward and away from the observer, respectively. The band of the Milky Way (the plane of the galactic disk) extends horizontally in this panoramic view. The center of the Milky Way lies in the middle of the image. The North celestial pole is at the top left and the South Pole is at the bottom right.

Each such measurement can only provide information about a single path through the Galaxy. To get a complete picture of the magnetic fields in the Milky Way from Faraday rotation measurements, one must observe many sources distributed across the entire sky. A large international collaboration of radio astronomers have provided data from 26 different projects to give a total of 41,330 individual measurements. On average, the complete catalog contains approximately one radio source per square degree of sky.

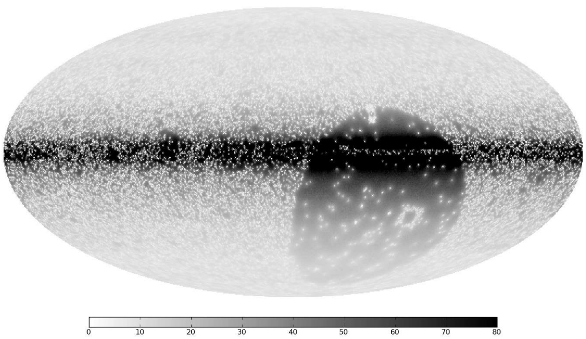

Figure 2.30: The uncertainty in the Faraday map. Note that the range of values is significantly smaller than in the Faraday map (Fig. 2.29). In the area of the celestial south pole, the measurement uncertainties are particularly high because of the low density of data points.

Even with so much data, coverage of the sky is still rather sparse. There remain large regions, especially in the southern sky, where so far only relatively few measurements have been made. Therefore, to obtain a realistic map of the entire sky, one must interpolate between the existing data points. Here, two difficulties arise. First, the respective measurement accuracies vary greatly, and more precise measurements should have a greater influence. Also, the extent to which a single measurement point can provide reliable information about its surrounding environment is not known. This information must therefore be directly inferred from the data itself.

In addition, there is another problem. The measurement uncertainties are themselves uncertain owing to the highly complex measurement process. It so happens that the actual measurement error for a small but significant portion of the data can be more than ten times as large as those indicated by the astronomers. The perceived accuracy of these outliers can strongly distort the resulting map if one does not correct for this effect.

To account for such problems, scientists at MPA have developed a new algorithm for image reconstruction called the "extended critical filter". To derive this algorithm, the team makes use of the tools provided by the new discipline known as information field theory. Information field theory incorporates logical and statistical methods applied to fields, and is a very powerful tool for dealing with inaccurate information. In particular, the method of *thermodynamical inference* (see Section highlight 2.1) was used to develop the novel approach. The approach is quite general and can be of benefit in a variety of image and signal-processing applications, not only in astronomy, but also in other fields such as medicine or geography.

In addition to the detailed Faraday depth map (Fig. 2.29), the algorithm provides a map of the uncertainties (Fig. 2.30). Especially in the galactic disk and in the less well-observed region around the south celestial pole (bottom right quadrant), the uncertainties are significantly larger.

To better emphasize the structures in the galactic magnetic field, in Figure 2.31 the effect of the galactic disk has been removed so that weaker features above and below the galactic disk are more visible. This reveals not only the conspicuous horizontal band of the gas disk of our Milky Way in the middle of the picture, but also that the magnetic field directions seem to be opposite above and below the disk. An analogous change of direction also takes place between the left and right sides of the image, from one side of the center of the Milky Way to the other.

A particular scenario in galactic dynamo theory predicts such symmetrical structures, which is supported by the newly created map. In this scenario, the magnetic fields are predominantly aligned parallel to the plane of the galactic disk in a circular or spiral configuration. The direction of the spiral is opposite above and below the galactic disk (Fig. 2.31). The observed symmetries in the Faraday map stem from our position within the galactic disk.

In addition to these large-scale structures, several smaller structures are apparent as well. These are associated with turbulent eddies and lumps in the highly dynamic gas of the Milky Way. The new map making algorithm provides, as a by-product, a characterization of the size distribution of these turbulent structures, the so-called power spectrum. Larger structures are more pronounced than smaller, as is typical for turbulent systems. This spectrum can be directly compared with computer simulations of the turbulent gas and magnetic field dynamics in our galaxy, thus allowing for detailed tests of galactic dynamo models.

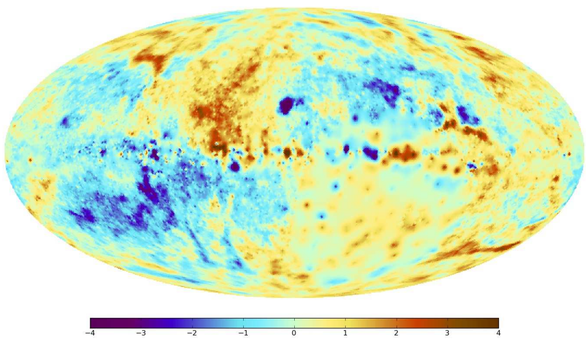

Figure 2.31: In this map of the sky, a correction for the effect of the galactic disk has been made in order to emphasize weaker magnetic +field structures. The magnetic field directions above and below the disk seem to be diametrically opposed, as indicated by the positive +(red) and negative (blue) values. An analogous change of direction takes place accross the vertical center line, which runs through the +center of the Milky Way.

The new map is not only interesting for the study of our galaxy. Future studies of extragalactic magnetic fields will draw on this map to account for contamination from the Galactic contribution. The next generation of radio telescopes, such as LOFAR, eVLA, ASKAP, Meerkat and the SKA, are expected in the coming years and decades, and with them will come a wealth of new measurements of the Faraday effect. New data will prompt updates to the image of the Faraday sky. Perhaps this map will show the way to the hidden origin of galactic magnetic fields. (Niels Oppermann, Henrik Junklewitz)

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3 Publications and Invited Talks

3.1 Publications in Journals

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Przybilla, N. and M. F. Nieva: Mixing of CNO-cycled matter in pulsationally and magnetically active massive stars. 272th Symposium of the International Astronomical Union. Proc. of Active OB stars: structure, evolution, mass loss, and critical limits. Eds. Neiner, C., G. Wade et al. Cambridge, UK : Cambridge University Press, Vol. **272**, 26–31.

Przybilla, N., M. F. Nieva and K. Butler: Testing common classical LTE and NLTE model atmosphere and line-formation codes for quantitative spectroscopy of early-type stars. GREAT-ESF Workshop: Stellar Atmospheres in the Gaia Era, Brussels, Belgium, Journal of Physics: Conference Series Vol. **328**, 1–12.

Przybilla, N., M. Firnstein, M. F. Nieva et al.: Mixing of CNO-cycled matter in massive stars. In: The Multi-Wavelength View of Hot, Massive Stars - 39th Liege, Belgien International Astrophysical Colloquium. Proc. Bulletin de la Societe des Sciences de Liege. Vol. **80**, 279–284

Ramsay, S., T. Lebzelter et al. (incl. M. F. Nieva): CRIRES-POP: a library of high resolution spectra in the near-infrared. In: The Multi-Wavelength View of Hot, Massive Stars - 39th Liege, Belgien International Astrophysical Colloquium. Proc. Bulletin de la Societe des Sciences de Liege. Vol. **80**, 509–513.

Rembiasz, T., M. Obergaulinger, et al. (incl. E. Müller): High-order methods for the simulation of hydromagnetic instabilities in core-collapse supernovae. In: 274th Symposium of the International Astronomical Union, Eds. Bonanno, A., E. de Gouveia and A. Kosovichev, Advances in Plasma Astrophysics, Cambridge, UK: Cambridge University Press Vol. **274**, 479–481.

Röpke, F., I. Seitenzahl, S. Benitez et al.: Modeling type Ia supernova explosions. In: International Workshop on Nuclear Physics, 32nd Course., Erice, Sicily, Italy. Progress in Particle and Nuclear Physics Vol. **66**, 309–318.

Sazonov, S., E. Churazov, R. Krivonos et al.: Statistical properties of local AGN based on the INTEGRAL/IBIS 7-year all-sky hard X-ray survey. In: 8th INTEGRAL Workshop "The Restless Gamma-ray Universe" Trieste : SISSA, Proceedings of Science **006**, 1–7.

Schnerr, R.S. and H.C. Spruit: The total solar irradiance and small scale magnetic fields. In: Solar Polarization Workshop 6, Proc. Eds. Kuhn, J.R, D. Harrington, H. Lin et al. ASP Conference Series Vol. **437**, 167–172.

Schönrich, R.: What Velocities and Eccentricities tell us about Radial Migration. In: Proc. 'Assembling the Puzzle of the Milky Way', Le Grand Bornand, Eds. C. Reyle, A. Robin, M. Schultheis, Vol. **19**, 1–7.

Seitenzahl, I.: Internal conversion electrons and supernova light curves. In: International Workshop on Nuclear Physics, 32nd Course., Erice, Sicily, Italy. Progress in Particle and Nuclear Physics Vol. **66**, 329– 334.

Spruit, H.C.: Magnetically powered jets. In: 25th Texas Symposium on Relativistic Astrophysics (TEXAS 2010), AIP Conference Proceedings, Melville, NY, USA : American Institute of Physics, Eds. Aharonian, F., W. Hofmann and F. Rieger, Vol. **1381**, 227–246.

Zhuravleva I.: Gas turbulent motions in galaxy clusters: In. Memorie della Societá Astronomica Italiana Supplementi, Vol. **82**, 481–483.

3.2.2 Publications available as electronic file only

Ritter, H. and U. Kolb: Catalogue of cataclysmic binaries, low-mass X-ray binaries and related objects (Editions 7.15 and 7.16).
http://www.mpa-garching.mpg.de/RKcat/ *http://physics.open.ac.uk/RKcat/* *http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=B/cb* *http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=B/cb*

3.3 Invited review talks at international meetings

M. Asplund: 7th International School of Planetary Sciences (Kobe, Japan, 10.1-15.1)
– Origin of the elements (Trento, Italy, 16.5-20.5)
– Galactic archaeology (Shuzenji, Japan, 1.11-5.11)
– Origin of matter and evolution of Galaxies (Tokyo, Japan, 14.11-17.11)
– OMEG5 (Tokyo, Japan, 18.11)

G. Börner: Die Entwicklung des Kosmos. Jahresversammlung der Nationalen Akademie der Wissenschaften Leopoldina (Halle, 23.9.-25.9.)

B. Ciardi: The first galaxies workshop (Ringberg, Germany 27.06.–01.07)
– Gas in Galaxies: from Cosmic Web to Molecular Clouds (Seeon, Germany 14.06.–18.06)
– GRBs as probes: from the progenitors' environment to the high redshift universe (Como, Italy, 16.05.–20.05.)
– Ringberg Workshop on Galaxy Evolution (Ringberg, Germany, 18.04.–21.04.)

E. Churazov: Astrophysics and Cosmology with Galaxy Clusters, (Santa Barbara, 14.3.-18.3.)
– Fornax, Virgo, Coma et al., (Garching, 27.6.-1.7.)
– JENAM 2011, (St.Petersburg, Russia, 4.7.-8.7.)
– 2011 Chandra Science Workshop, (Boston, USA, 12.7.-14.7.)

M. Dijkstra The Cosmic Odyssey of Baryons conference (Marseille, France, 20.6-24.6)
– Hydrogen Cosmology Workshop (Cambridge, MA, USA, 16.5 – 20.5)

T.A. Enßlin: Primordial Magnetism Workshop (Arizona State University, 30.3.–2.4.)
– 2011 Ringberg Workshop on Galaxy Evolution (Ringberg Castle, 17.4.-22.4.)
– A fresh view of the radio sky: science with LOFAR, SKA and its pathfinders (Annual meeting of the Astronomische Gesellschaft, Heidelberg, 19.9.-23.9.)

M. Gilfanov: Multifrequency behavior of High Energy Cosmic Sources Frascati Workshop 2011 (Vulcano, Italy, 23.5-28.5)
– European Week of Astronomy and Space Science JENAM-2011 (St.Petersburg, Russia, 4.7-8.7)
– Binary Paths to Type Ia Supernovae Explosions IAU Symposium 281 (Padova, Italy, 3.7-8.7)
– X-ray Atsrophysics up to 511 keV (Ferrara, Italy, 14.9-16.9)
– LOFT Science meeting (Amsterdam, The Netherlands, 26.10-28.10)
– High Energy Astrophysics - 2011 (Moscow, Russia, 13.12-16.12)

T. Greif: Virgo Meeting (17.4.-21.4.)
– First Galaxies Workshop, (26.6.-1.7.)

W. Hillebrandt: Advanced Topics in Astrophysics (Llafranc, Costa Brava, 4.5 -6.5.)

H.-Th. Janka: Physics of neutron stars (St. Petersburg, Russia, 11.7.–15.7.)
– Explosive Ideas about Massive Stars – from Observations to Modeling (Stockholm, Sweden, 10.8.–13.8.)

G.Kauffmann: Celebrating the career of A. Wolfe, (Ringberg, Germany, 1.7-4.7)
– Galaxy Formation, (Durham, UK, 18.7.-22.7.)

B. Müller: "Multi-dimensional core-collapse supernova simulations with VERTEX , Hamburg Neutrinos from Supernova Explosion (Hamburg, Germany, 19.7.-23.7.)

E. Müller: "Fusion and Astrophysical Plasmas , 478th Heraeus Seminar, (Bad Honnef, Germany, 18.4.-20.4.)
– Advanced Topics in Astrophysics , Conference, (Llafranc, Spain, 4.5.-6.5.)
– Explosive Ideas about Massive Stars - from Observations to Modeling , Conference, (Stockholm, Sweden, 10.8.-13.8.)

Th. Naab: ESO workshop: Fornax, Virgo, Coma et al.: Stellar systems in high-density environments (27.6. - 1.7.)

H. Ritter: The Golden Age of Cataclysmic Variables and Related Objects, (Palermo, Italy, 12.9.-17.9.)

H. Spruit: 218th meeting of the American Astronomical Society, (Boston MA, USA, 21.5.–26.5.)
– Annual Meeting, Solar Physics Division of the AAS, (Las Cruces NM, USA, 13.6.–17.6.)
– Nonequilibrium Dynamics in Astrophysics and Material Science (Kyoto, Japan, 31.10.–3.11.)
– Transients in Astrophysics (Hsinchu, Taiwan, 12.12.–16.12.)

R. Sunyaev: Physics of Neutron Stars - (St. Petersbourg, Russia, 11.7.–15.7.)
– A new era for sz science, (Santander, Spain, 27.6.-30.6.)
– Cosmology with X-ray and Sunyaev-Zeldovich Effect Observations of Galaxy Clusters (Huntsville, USA, 19.9.–22.9.)
– High Energy Astrophysics Today and Tomorrow (Moscow, Russia, 13.12.–16.12.)

A. Weiss: 20-th Stellar Pulsation Conference, (Granada, Spain, 5.9.–9.9.)

S. White: Fine-scale structure in the dark matter distribution, (Toronto, Canada, 28.3.–30.3.))
– 8th Sino-German Workshop, (Shanghai, China, 26.4.–29.4.)
– Symposium on Dark Matter, (Baltimore, USA, 2.5.–5.5.)
– Conference on Galaxy Formation, (Durham, U.K. 18.7.–22.7.)
– International Conference on Particle Physics and Cosmology, (Porto, Portugal, 22.8.–26.8.)
– First eRosita International Conference on Mapping the Structure of the Energetic Universe, (Garmisch-Partenkirchen, Germany 17.10.–20.10.)

3.4 Public talks

R. Angulo: Osorno, Chile (28.12.)

M. Asplund: Fundacion BBVA, Madrid (3.10)

G. Börner: MPA Open House, Garching (15.10.)

E. Churazov: Nürnberg Planetarium (4.12.)

T.A. Enßlin: Volkssternwarte Rosenheim (16.6)

H.-Th. Janka: DESY Hamburg (20.7.)
– MPA Open House, Garching (15.10.)
– Café & Kosmos, München (8.11.)

D. Kruijssen: Dutch Radio 2, NCRV Cappuccino (13.8.)
– Dutch Radio 2, NCRV Cappuccino (27.8.)
– Dutch Radio 1, BNN Today (29.8.

K. Lind (contributed talk): Subaru 3rd international conference, Shuzenji, Japan (02.11.)

Z. Magic: MPA Open House, Garching (15.10.)

E. Müller: Lehrerfortbildung Dachau (7.7.)
– Open House, MPA Garching (15.10.)
– MPG day, MPA Garching (11.11.)

B. Müller: Volkssternwarte Winzer (9.4.)

G. Robbers: MPA Open House, Garching (15.10.)

R. Schönrich: MPA Open House, Garching (15.10.)

R. Sunyaev: John Bahcall Lecturership, USA National Air and Space Museum (21.10.)
– Space Telescope Science Institute (26.10.)
– Goddard Space Flight Center (27.10.)

S. White: MPA Open House, Garching (15.10.)

3.5 Lectures

W. Hillebrandt: WS 2010/2011 and WS 2011/2012 TU München

T.A. Enßlin: SS 2011 and WS 2011/2012 (seminar), LMU München

H.-Thomas Janka: SS 2011, TU München

E. Müller: WS 2010/2011 and SS 2011, TU München

H. Ritter: WS 2010/2011, LMU München

A. Weiss: SS 2011, LMU München

Short lectures

M. Asplund: "The chemical composition of the Sun and solar-type stars" (Center of Planetary Science, Kobe, Japan, 10.1-15.1)

M. Dijkstra: "Probing the Epoch of Reionization with Lyman Alpha Emitting Galaxies + X-Ray heating during the Epoch of Reionization" (ETH Zurich, 7.4 –8.4)

A. Weiss: "Stellar Structure and Evolution" (IMPRS on Astrophysics, Garching, 24.10.–28.10.)

R. Sunyaev: Kyoto Prize Commemorative lecture, (Kyoto Kongress Hall, 11.11.)
– Hendrik de Waard Jubilee Lecture, (Groningen, 24.5.)

4 Personnel

4.1 Scientific staff members

Directors

M. Asplund (until 31.8.), W. Hillebrandt (managing director until 31.12.2011), R. Sunyaev, S.D.M. White (managing director since 1.1.2012)

Research Group Leader

E. Churazov, B. Ciardi, M. Gilfanov, H.-Th. Janka, G. Kauffmann, T. Naab, E. Müller.

External Scientific Members

R. Giacconi, R.-P. Kudritzki, W. Tscharnuter.

Emeriti

H. Billing, R. Kippenhahn, F. Meyer, H.U. Schmidt, E. Trefftz.

Staff

R. Angulo, A. Bauswein, M. Bell, M. Bergemann, A. Bogdan (until 31.1.), P.M. Bottino (1.2.-31.5.), L. Casagrande (until 31.12.), B. Catinella, P. Cerda-Duran (until 31.10.), E. Churazov, B. Ciardi, R. Collet (until 14.10.), A. Cooper, "I. Cordero-Carrión, M. Dijkstra, J. Donnert (1.7.-30.9.), M. Dotti (until 28.2.), T. Enßlin, M. Fink (until 31.5.), J. Fu, M. Gabler (since 1.12.), M. Gilfanov, T. Greif, M. Grossi (until 31.7.), A. Gualandris, S. Hachinger (1.7.-30.9.), B. Henriques, C. Hernandez-Monteagudo (until 14.4.), G. Hütsi (since 1.10.), H.–T. Janka, P. Jofre-Pfeil (until 30.4.), J. Johansson (since 27.9.) G. Kauffmann, R. Khatri, S. Khedekar (since 21.9.) K. Kovac (until 31.12.), R. Krivonos, M. Kromer, D. Kruijssen (since 20.7.), K. Lind, G. Lemson, M. Maciejewski, A. Marino, I. Maurer (until 31.5.), P. Mazzali, B. Metcalf (until 28.2.), S. Mineo (1.9.-31.10.), P. Montero, B. Moster, B. Müller, E. Müller, T. Naab, M.F. Nieva (until 30.6.), R. Overzier (until 31.8.), Biswajit Pandey (since 1.2.), M. Reinecke, G. Ruchti, A. Ruiter, A. Saintonge, L. Sales, L. Sbordone (until 14.6.), C. Scoccola (until 21.6.), I. Seitenzahl (until 31.5.), F. Shankar (until 31.5.), H.C. Spruit, A. Sternberg (since 15.12.), T. Tanaka (since 1.9.), S. Taubenberger, S. Tsygankov (until 30.6.), S. Walch (since 1.11.), A. Weiss, R. Wiersma (until 30.9.), A. Wongwathanarat (since 1.3.). I. Zhuravleva (since 1.11.)

Associated Scientists:

U. Anzer, H. Arp, G. Börner, G. Diercksen, W. Kraemer, E. Meyer–Hofmeister, H. Ritter, J. Schäfer, H.-C. Thomas, R. Wegmann.

Ph.D. Students

[1] R. Andrassy* (since 1.9.), M. Aumer, P. Baumann, S. Benitez, V. Biffi*, A. Chung* (sinc 1.9.), B. Ciambur* (since 1.9.), F. Ciaraldi-Schoolmann, F. De Gasperin, J. Donnert (until 31.6.), P. Edelmann, S. Fabello*, M. Gabler (until 25.11.), L. Graziani*, S. Hachinger (until 30.6.), F. Hanke, N. Hariharan* (since 1.9.), M. Herzog, M. Hilz, L. Hüdepohl, M.L. Huang, F. Ianuzzi*, A. Jendreieck* (since 1.8.), A.

[1] *IMPRS Ph.D. Students

Jeeson-Daniel*, H. Junklewitz, O. Just, S. Karl (until 31.10.), F. Koliopanos* (since 1.9.), A. Kolodzig* (since 1.4.), N. Krachmalnikoff* (termination of MPA PhD studies on 31.12.), C. Laporte*, M. Li, Z.W. Liu, N. Lyskova*, T. Mädler (until 28.2.), Z. Magic*, F. Miczek, S. Mineo* (until 31.8.), U. Nöbauer, N. Oppermann, L. Oser, M. Petkova* (until 31.8.), E. Pllumbi* (since 1.10.), L. Porter*, S. Rau, T. Rembiasz*, M. Sasdelli* (since 10.10.), R. Schönrich (until 30.11.), M. Selig (since 1.11.), V. Silva*, F. Stasyszyn (until 28.2.)*, I. Thaler*, M. Ugliano*, M. van Daalen*, J. von Groote, M. Wadepuhl, J. Wang, A. Wongwathanarat* (until 28.2.), T. Woods* (since 12.9.), R. Yates, Z. Zhang*, I. Zhuraleva* (until 31.10.).

Diploma students

T. Ertl (since 14.11.), M. Gänsler (since 14.3.), E. Gall (until 15.11.), N. Heners (since 15.5.), S. Lutter (until 15.11.), U. Nöbauer (until 1.2.), M. Selig (until 20.9.), M. Uhlig (until 1.11.), H. Weingartner (until 1.11.), L. Winderling (since 1.10.)

Technical staff

Computational Support: H.-A. Arnolds, B. Christandl, N. Grüner, H.-W. Paulsen (head of the computational support)
PLANCK group: M. Bell, U. Dörl, T. Enßlin (group leader), W. Hovest, J. Knoche, J. Rachen, M. Reinecke, T. Riller, G. Robbers
MPDL: J.W. Kim
Galformod: M. Egger
Secretaries: M. Depner, S. Gründl, G. Kratschmann, K. O'Shea, C. Rickl (secretary of the management).
Library: E. Blank, E. Chmielewski (head of the library), C. Hardt.

4.1.1 Staff news

B. Ciardi: received the Italian Order of Merit (Cavaliere della Repubblica Italiana)

Hans-Thomas Janka: received the *Hanno und Ruth Roelin-Preis* für Wissenschaftspublizistik 2011.

Markus Kromer: *Otto-Hahn-Medaille* der Max-Planck-Gesellschaft.

Rainer Moll: received the *Kippenhahn Prize* (for the best scientific paper written by a student at the MPA 2011)

Rashid Sunyaev: received the *2012 Franklin Medal in Physics* and the *2011 Kyoto Prize* in Science.

Hendrik Spruit: received *George Ellery Hale Prize* for achievement in solar physics.

Simon White: (together with three other astronomers) received the *Gruber Cosmology Prize.*

4.2 PhD Thesis 2011/Diploma thesis 2011

4.2.1 Ph.D. theses 2011

Julius Donnert: On the diffuse non-thermal emission from galaxy clusters. Ludwig-Maximilians Universität München.

Michael Gabler: Coupled core-crust-magnetosphere oscillations of magnetars. Technische Universität München.

Stephan Hachinger: Analysis of spectra of Type I Supernovae with radiative transfer models. Technische Universität München.

Steffen Hess: Particle hydrodynamics with tessellation techniques. Ludwig-Maximilians Universität München.

Simon Karl: The Antennae Galaxies - a key to galactic evolution. Ludwig-Maximilians-Universität München.

Thomas Mädler: Axially symmetric space-times and the characteristic formulation of general relativity. Technische Universität München.

Stefano Mineo: X-ray emission from star-forming galaxies. Ludwig-Maximilians Universität München.

Margarita Petkova: Numerical radiative transfer and the hydrogen reionization of the universe. Ludwig-Maximilians Universität München.

Till Sawala: Simulations of Dwarf Galaxy Formation. Ludwig-Maximilians Universität München.

Ralph Schönrich: Structure, kinematics and chemistry of the Milky Way Galaxy. Ludwig-Maximilians Universität München.

Victor Silva: Mixing processes in stellar interiors: new insights from asteroseismology. Ludwig-Maximilians Universität München.

Federico Stasyszyn: Smoothed particle magneto-hydro-dynamics for cosmological applications. Ludwig-Maximilians-Universität München.

Jing Wang: The relation between morphology, star formation rate and gas fraction in galaxies. Univ. of Science and Technology of China.

Annop Wongwathanarat: Multidimensional simulations of core collapse supernovae using a two-patch overset grid in spherical coordinates. Technische Universität München.

Irina Zhuravleva: Radiative transfer in hot gas of galaxy clusters: constraints on ICM turbulence. Ludwig-Maximilians Universität München.

4.2.2 Diploma theses 2011

Elisabeth Gall: Interpreting the Near-Infrared Spectra of Type I Supernovae using the “Golden Standard” of SN2005cf as an Example. Technische Universität München.

Stefan Lutter: Evolution and Stability of Disk Galaxies. Ludwig-Maximilians Universität, München.

Ulrich Nöbauer: Monte Carlo radiation hydrodynamics. Technische Universität München.

Marco Selig: Information field theory for high energy astronomy Technische Universität München.

Maximilian Uhlig: Cosmic ray driven Winds in Galaxies. Technische Universität München.

Maximilian Ullher: Eine Faradaykarte der Milchstraße unter Annahme approximativer Symmetrien. Ludwig-Maximilians Universität, München.

Helin Weingartner: Statistische Modellierung und Rekonstruktion von diffuser Röntgenstrahlung von Galaxienhaufen. Technische Universität München.

4.2.3 PhD Thesis (work being undertaken)

Monique Alves-Cruz: S-process in extremely metal-poor stars. LMU.
Abstract: In the last two decades a large number of stars from the Galactic halo has been observed in high-resolution. These observations, motivated by the search for metal-poor stars in surveys such as HK and Hamburg/ESO, brought to light intriguing nucleosynthesis signatures. One of them is the overabundance of s-process elements observed in several extremely metal-poor stars (EMPS - [Fe/H]<-3.0). The goal of this project is to verify the role of s-process nucleosynthesis in primordial AGB stars as a source of the s-enrichment in EMPS.

Robert Andrassy: Convective overshooting in stars by 3-D simulations. University of Amsterdam.
Abstract: The overshooting phenomenon, which can be driven by several physical mechanisms, accompanies convection in fluids under very general conditions. The project aims to explore long-term effects caused by overshooting with the main application to deep interior convection in stars. By employing a combination of simplified semi-analytical models and 3D hydrodynamical simulations, the project could provide valuable outputs improving current stellar evolution models.

Michael Aumer: Simulations of Disk Galaxy Evolution. LMU.
Abstract: The aim of this thesis is to study the evolution of Milky-Way like disk galaxies in a fully cosmological framework predicted by the LambdaCDM scenario. Two aspects of this topic we would like to address, are: A) The stability of thin, galactic disks against dynamical heating imposed by substructure predicted for LambdaCDM halos. B) The mixing of metals ejected from disk galaxies in supernova-driven winds and its effect on the metal enrichment of the IGM. For these purposes we use and update the multiphase SPH galaxy formation code by Scannapieco et al 2005/2006.

Patrick Baumann: Chemical composition of solar-type stars and its impact on planet-hosting. LMU.
Abstract: Work on elemental abundances in solar-like stars. We want to fins out, if there is any connection between the chemical composition of a star and whether it's hosting a planet or not. Preliminary results indicate that the Sun has different abundances of refractory elements compared to solar-type field stars, which might be due to terrestrial planet formation.

Sandra Benitez: Model-Independent Reconstruction of the Expansion History of the Universe. TUM.
Abstract: Type Ia supernovae are the best (relative) distance indicators out to z 1 and it was by means of their luminosity distances that the notion of an accelerated expansion of the Universe was established a decade ago . Based on the largest sample of these objects available today, we have reconstructed the expansion history of the Universe in an model-independent way. Our method is purely geometric and does not make any assumptions on the matter/energy content of the Universe. This approach allow us to obtain H(z) in a straightforward way directly from the data. Also we are able to yield constrains on very different Dark Energy models and non-standard cosmologies based in very different physical assumptions.

Veronica Biffi: Studying the physics of galaxy clusters by simulations and X-ray observations. LMU.
Abstract: Clusters of galaxies are optimal targets to study the large–scale structure of the Universe as well as the complex physical processes on the smaller scales. It is therefore vital to unveil cluster intrinsic structure, precisely estimate their total gravitating mass, and accurately calibrate scaling relations between observable quantities. A promising approach to achieve a more detailed picture of such complicated objects is found in the comparison between hydrodynamical numerical simulations of galaxy clusters and X–ray observations

Andrew Chung: High-redshift Lyman-α945; Emitters. LMU
Abstract: My thesis is focused on Lyman-α945; Emitters and associated objects such as Lyman-α945; Absorbers and Lyman-α945; Blobs. Currently the source of the extremely high luminosities of Lyman-α945; Blobs remains ambiguous. One proposed explanation is scattering of a central source by an outflowing extended circumgalactic medium. In my thesis I examine the effect of galactic outflows on the radiative transfer of Lyman-α945; photons produced in star-forming regions of the embedded galaxy, and investigate whether this can be used to put constraints on galactic outflow models.

Bogdan Ciambur: Extensions of semi-analytic modelling to the study of the galaxy population evolution with redshift. LMU.
Abstract: In the Lambda-CDM cosmological model, galaxies form from gas condensing at the centres of hierarchically merging dark matter haloes. A powerful way to explore their evolution is through the use of semi-analytical models. During my PhD I will attempt to understand the processes which stop the growth of massive galaxies, turning off their star formation, and to further implement this knowledge in the MPA semi-analytic model. Thus far, the treatment has been to incorporate radio-mode feedback from AGN, in the form of a recipe. This proved successful in e.g. improving the fit to the bright-end luminosity function that the model produced. Further constraints from various channels and a subsequent refinement of the AGN feedback recipe are the broad aims of my thesis. One such channel is a joint galaxy clustering and weak lensing study, which involves a comparison of observational signatures with those from simulations.

Franco Ciaraldi-Schoolmann: Stochastic modeling of Type Ia supernovae explosions in Large Eddy Simulations. TUM.
Abstract: The focus of my work is on explosions of Chandrasekharmass white dwarfs in the delayed detonation scenario. Here, an open question is how to implement the transition of the thermonuclear burning front from a subsonic deflagration toa supersonic detonation (DDT). For this a subgrid scale model for DDTs is developed which models the relevant parameters for a DDT on unsresolved scales in Large Eddy Simulations. The goal is to find out to what extend these simulations can explain the observed variances in brightness in Type Ia supernovae.

Francesco De Gasperin: Cosmological Evolution of Supermassive Black Holes With LOFAR. LMU.
Abstract: Work on the framework of LOFAR commissioning. LOFAR is the new radio telescope that has been built in the Netherlands and throughout Europe. With its revolutionary capabilities and by means of more well-known devices, I study the interaction between AGN (Active Galactic Nuclei) and ICM (Intra-Cluster Medium), putting constraints on galaxy evolution paradigms.

Philipp Edelmann: Hydrodynamical simulations coupled to nuclear reaction networks in stellar astrophysics. TUM.
Abstract: The aim of this thesis is to investigate problems in stellar astrophysics which require simultaneous treatment of hydrodynamics and nuclear burning. To this end an existing low Mach number hydrodynamics code is extended with a nuclear reaction network and different methods of coupling these source terms are tested. Verifying prescriptions used in one-dimensional stellar evolution simulations with multi-dimensional simulations is the main application. This may provide new insights into critical stages of stellar evolution.

Silvia Fabello: HI properties of nearby galaxies from ALFALFA data stacking. LMU.
Abstract: The neutral gas (HI) in galaxies is crucial to understand their evolution, as it fuels future star formation. Currently on-going blind HI surveys, such as ALFALFA (Arecibo Legacy Fast ALFA) survey, will produce HI data over a cosmologically significant volume, but will not detect a large fraction (80%) of the high mass, gas-poor galaxies. This high mass range is the regime where galaxies seem to make a transition between blue and star-forming and red and passively-evolving. I have developed a software tool to co-add ALFALFA HI data that allows one to recover the average neutral gas content of a population of galaxies, even if individual sources are not detected. Using this technique I can characterize the HI content of nearby high mass galaxies, eg. by studying HI scaling relations or analyzing the dependence on nuclear and environmental properties. This will give us a better insight into current models of galaxy formation.

Luca Graziani: Cosmological Radiative Transfer through metals in CRASH. LMU.
Abstract: Radiative transfer (RT) in cosmology is a useful technique to investigate the IGM status at the epoch of galaxy formation and to constraint the efficiency of the primordial radiative processes. The inclusion of metal ionization states in the CRASH radiative transfer simulations is obtained coupling the code with the sophisticated photo-ionization engine Cloudy and applied to constraint QSO spectra observations with theoretical models, to study the physical status of the IGM and finally to constraint the cosmic UV background fluctuations at $z \sim 2$-3.

Florian Hanke: Three-dimensional simulations of core-collapse supernovae using a detailed neutrino transport description. TUM.
Abstract: 3D simulation of core-collapse supernovae using a detailed neutrino transport description are crucial for understanding the explosion mechanism of massive stars in detail. They will allow us to study convection and hydrodynamical instabilities in a satisfactory manner. In particular this effects should facilitate the explosion of massive stars. Due to extremely high demands of computer time of such 3D calculations our simulation tool must make use of massively parallel machines and a new efficient neutrino transport description will be coupled to the three-dimensional hydrodynamics code to determine the true systematics of core-collapse supernovae.

Nitya Hariharan: Numerical Developments of the Radiative Transfer code CRASH. TUM.
Abstract: CRASH is a 3D Radiative Transfer Code based on the Monte Carlo method. The code calculates self-consistently the evolution of H, HI, He, HeI and HeII. A parallel version to this approach exists and a serial version that follows the evolution of metals has been developed. We plan to harmonize the serial and parallel version to provide the full functionality within the parallel version. As of now, CRASH makes use of fixed cartesian grids. We plan to make use of an Adaptive Mesh Refinement library instead. In addition, we will study the feasibility of coupling CRASH with a hydrodynamics code. This will allow radiative transfer to be done self-consistently with the hydrodynamics calculations rather than via post-processing.

Matthias Herzog: Dynamical Simulations of Phase Transitions in Compact Stars. TUM.
Abstract: We perform multi-dimensional hydrodynamical simulations of the conversion of a hadronic neutron star to a strange quark star. Following the example of thermonuclear burning in white dwarfs, we model the conversion process as a combustion. First results show that the combustion becomes turbulent and the resulting star is a hybrid star containing a atrange quark matter core and a hadronic outer layer.

Michael Hilz: Evolution of Elliptical Galaxies. LMU.
Abstract: We use a set of N-body simulations of one- and two-component galaxy models to show how consecutive galaxy mergers affect the scaling relations of elliptical galaxies. Analyzing the dynamical processes during equal-mass and minor mergers we find that especially the latter scenario is very efficient by growing a galaxy's size and decreasing its velocity, which might solve the 'compactness problem' of early-type galaxies at a redshift of ~ 2.

Lorenz Hüdepohl: Neutrino cooling evolution of newly formed proto neutron stars. TUM.
Abstract: I study the formation and first few seconds in the live of a proto neutron star, the remnant of the gravitational collapse of a massive star. During this period, the compact object emits a vast amount of neutrino radiation, which I simulate with a sophisticated radiative transfer code. This radiation might carry information about the unknown high density equation of state for hot neutron star matter and plays a crucial role for driving the so-called neutrino driven wind, where material from the proto neutron star's surface is accelerated away by the interaction with neutrinos - an interesting site not only for nuclesynthesis but also a playground for neutrino physics.

Mei-Ling Huang: Radially resolved star formation histories of disk galaxies. LMU.
Abstract: Using the long-slit spectroscopy from Moran et al. (2012) we will constrain the radial dependence of the recent star formation histories of disk galaxies. We will compare age-sensitive indices such as the 4000 Angstrom break strength and Balmer absorption line equivalent widths, as well as present-day SFR measured from the Balmer emission lines, to a library of models generated from the Bruzual & Charlot (2003) population synthesis models, to constrain the timescale over which stars have been formed at different radii in the disk. We will examine the dependence of these SFH profiles on the atomic and molecular gas content of the galaxy, and compare these to the radially-resolved disk formation models of Jian Fu et al. Together with the radial dependence of the metallicity and element abundance ratios this analysis will place strong constraints on models for the assembly and evolution of disk galaxies in the local Universe, including the interplay between accretion, star formation and SN feedback in these systems.

Francesca Iannuzzi: Studying the survival of galaxies in hydrodynamical simulations of clusters. LMU.
Abstract: The project aims at investigating galaxy cluster formation and evolution by means of numerical simulations performed with a modified version of the TreeSPH code GADGET-3. This new version of the code employs adaptive softening to describe the gravitational interaction between the simulation particles; having this quantity variable in space and time, as opposed to having it fixed at the beginning of the simulation, allows to increase the spatial resolution in overdense regions whilst keeping particle-particle noise under control in less dense environments. Simulations involving gravitational as well as gas dynamics are likely to considerably benefit from the adoption of this scheme: the adaptive behaviour of the resolution scale should allow to follow the collapse of dark matter and particularly gas down to scales which are currently unachievable in standard simulations at comparable mass resolution, thus providing a more reliable representation of the behaviour of galaxy-like substructures.

Akila Jeeson-Daniel: Lyman Alpha Emitters around the Epoch of Reionization. LMU.
Abstract: LAEs are one of the important tools to study the Epoch of Reionization. I simulate LAEs between z=6-10 to compare them to observations. LAEs are simulated using cosmological hydrodynamical simulations by a modified version of Gadget-II and the radiative transfer of ionizing and lyman alpha radiation is done using CRASH-alpha.

Andressa Jendreieck: Stellar Parameter Estimation for Kepler Stars. LMU
Abstract: Red Giants have been observed extensively by the space missions CoRoT and Kepler, showing radial and non-radial solar-like oscillations. The goal of my PhD is to work on asteroseismology diagnostics of the structure of such stars. This work will embrace observational data from the Kepler satellite, stellar model calculations using the GARSTEC stellar evolution code and oscillation frequencies computations using two different codes: ADIPLS and FILOU. There will be a particular focus on improving the outer boundary condition calculations with the implementation of 3D atmosphere models in the evolution code by Zazralt Magic.

Henrik Junklewitz: Magnetic Field Statistics and Information field theory. LMU.
Abstract: This study is mainly concerned with the development of new imaging algorithms for multifrequency aperture synthesis in radio astronomy. The special focus lies on an approach which consequently implements bayesian inference methods and information field theory to enhance the capabilities of future radio astronomical studies of diffuse flux and magnetic fields under the presence of strong point sources and especially in galaxy clusters and filaments.

Oliver Just: Numerical models of hyper-accreting post-merger accretion tori. TUM.
Abstract: Remnant accretion discs around black holes created after compact object mergers are favored candidates for the central engines of short gamma-ray bursts and potential sites for the production of r-process elements. Using numerical simulations including detailed microphysics coupled to a neutrino transport scheme we calculate the energy deposition due to annihilation and absorption of neutrinos and analyze the dynamic outflow of radiation and matter as a function of the global parameters of these systems.

Filippos Koliopanos: Radiation processes in compact X-ray sources. LMU.
Abstract: UCXBs are X-ray binary stars with orbital periods of less than an hour and can be as short as 10 minutes, this short period implies that the two companions are so close together that it makes it impossible for a normal hydrogen rich star to be the donor. In UCXBs both stars are compact objects, possibly a white dwarf accreting on a neutron star or black hole. Optical and X-ray spectroscopy of UCXB candidates show weak C/O or He/N emission lines suggesting a C/O white dwarf or a helium star donor while other candidates show indications of an O-Ne-Mg WD companion Further spectral studies of UCXBs will yield information on the chemical composition of the donor thus giving us an insight on the most probable formation scenario of these objects. Our object for at least the first year of my PhD is to compare X-ray spectra of (candidate) UCXBs with Monte Carlo simulations of disk reflection spectra, aiming to get some constraints on the chemical composition of the accreting material. For this purpose I have developed a Monte Carlo simulation for X-ray reflection spectra. Starting with an initial power law spectrum illuminating a

semi-infinite-slab, the code provides the user with X-ray reflection continuum as well K? and K? lines for all elements from Li to Zn. We are currently studying X-ray spectra of UCXB candidates and we will use our simulation to attain further insight on the composition of the accreting material.

Alexander Kolodzig: AGN in the eROSITA all-sky survey: Statistics and correlation properties. LMU
Abstract: We study the statistics and correlation properties of active galactic nuclei (AGN) to be detected in the 4 year all-sky survey by the eROSITA telescope aboard Spectrum-X Gamma observatory (Launch 2013). We analyze the luminosity and redshift distribution of the detectable AGN. We further investigate the capabilities for studying large scale structures with the eROSITA all-sky survey data. For the latter the developed methods are tested with available X-ray surveys from the observatories Chandra and XMM-Newton.

Chervin Laporte: Galaxies in clusters. LMU.
Abstract: This thesis is focuses on galactic interactions in cluster environments. Currently, it addresses how the most massive galaxies grew from the early universe (z 2) until today in the densest environments using a set of high-resolution dark matter simulations (Phoenix project). New tools based on distribution functions are developed to represent realistic stellar density profiles in agreement with the luminosity function and size distribution of galaxies at z 2. We will study the fate of massive quiescent galaxies in clusters and the formation of BCGs. One will eventually also couple this scheme with semi-analytic models to address metallicity gradients in BCGs.

Natalya Lyskova: Physics of hot gas in elliptical galaxies. LMU.
Abstract: While density and temperature of the hot gas in early type galaxies are routinely measured, other properties, such as magnetic fields or microturbulence are not know, We investigate various observational signatures of these properties, in particular their effect on the apparent mass measurements based on X-ray data.

Zazralt Magic: Theoretical models for cool stars including multidimensional atmospheres. LMU.
Abstract: Stellar evolution models fail to reproduce correctly the surface of stars due to crude approximations of the atmosphere and the superadiabatic regime. In the course of my PhD thesis I will compute a grid of realistic 3D atmosphere models, which will resolve the above mentioned issues by nature. Later on, I will implement these accurate atmosphere models into a 1D stellar evolution code, in order to produce more precise evolutionary models.

Fabian Miczek: Simulation of low Mach number astrophysical flows. TUM.
Abstract: Stellar interiors often contain fluid motions at very low Mach number, for example convective motions or meridional circulation in rotating stars. However, an efficient and accurate numerical simulation of these flows is very challenging because of the large disparity of the fluid speed compared to the speed of sound. Therefore, the objective of this thesis is to develop a new simulation code with implicit time stepping and an improved spatial discretization technique in order to study the impact of these flows on the evolution of stars.

Ulrich Nöbauer: A Monte Carlo Approach to Radiation Hydrodynamics in Astrophysical Environments. TUM.
Abstract: In many astrophysical environments, the radiation field contributes significantly to the total energy and momentum balance. Also, the radiation-matter interactions are often very efficient in transferring energy and momentum between the radiation field and the surrounding material. Both properties call for a self-consistent treatment of the radiation-matter state when attempting to theoretically model these systems. The goal of this thesis is to develop an approach to radiation hydrodynamics that is based on coupling Monte Carlo radiative transfer techniques with finite-volume hydrodynamical methods. We particularly aim at retaining the advantages of Monte Carlo techniques to realize complex interaction physics and to address problems with arbitrary geometries. These benefits will render the Monte Carlo radiation hydrodynamical approach ideal to investigate aspects of supernovae explosions, for example interactions with the circumstellar material or identifying signatures of progenitor systems in Type Ia supernovae.

Niels Oppermann: Non-Gaussianities in Cosmology. LMU.
Abstract: The reconstruction of non-Gaussian signal fields is an important and non-trivial step in answering many astrophysical and cosmological questions. Non-Gaussianities are present in the cosmic microwave background radiation in the form of signatures of foregrounds, secondary effects, and the primordial quantum fluctuations themselves. They also play a prominent role in the cosmic matter distribution and in the properties of the Milky Way itself. Sophisticated inference techniques are needed to deduce statements about those fields from uncertain measurement data. We develop such techniques in the framework of Information Field Theory and apply them in a variety of different contexts.

Ludwig Oser: Galaxy Formation and Evolution. LMU.
Abstract: We are using hydrodynamical cosmological 'zoom-in' simulations to study the formation and evolution of massive galaxies. The simulations are performed with the help of the TreeSPH Code Gadget-2 and include star formation, radiative cooling, SN feedback and a uniform UV background. We find that galaxy formation appears to show a 'two-phase' character, with a rapid early phase ($z > 2$) during which "in-situ" stars are formed within the galaxy from infalling cold gas followed by an extended phase since $z < 3$ during which "ex-situ" stars are primarily accreted. We find that the ratio of in-situ to accreted stars is dependent on the galaxy mass and explains several observed properties of massive galaxies.

Else Pllumbi: Nucleosynthesis studies for supernova and binary merger ejecta. TUM.
Abstract: This project is about the study of the nucleosynthesis in the matter explosively ejected during supernova explosions, accretion induced collapse events of white dwarfs to neutron stars, and possibly also neutron star mergers. The goal of the project is to better understand the role of these astrophysical events for their contribution to the chemical enrichment of the galactic gas.

Laura Porter: Modelling dust in cool stellar and substellar atmospheres. LMU.
Abstract: Dust is manifestly a 3D phenomenon, like convection, with the two processes inextricably linked in cool stars and substellar objects. At present 1D models simulate dust by prescribing convection via a characteristic mixing timescale, but intrinsically are unable to reproduce the inhomogeneous surface structures and the observed L-T transition at the cool end of the main sequence. By including 3D dust formation, growth and transport within an existing stellar surface convection code, I plan to investigate the interplay between dust and gas with particular emphasis on investigating the L-T transition.

Stefan Rau: Gravitational lensing studies of dark matter halos. LMU.
Abstract: Gravitational lensing provides a unique tool to study the full (dark and baryonic) mass distribution of galaxy clusters. The presence of substructure in an otherwise smooth mass distribution will affect the morphology of the lensed images. We investigate the influence of these substructures as well as limits on the reconstruction of observed images. We use very high resolution N-body simulations, the Phoenix simulations, to predict the influence of hierarchical structure formation on the images and to compare the theoretical predictions with upcoming observational lensing surveys.

Tomasz Rembiasz: Non-ideal MHD instabilities and turbulence in core collapse supernovae. TUM.
Abstract: The magnetorotational instability (MRI) is one of the most promising mechanisms for the amplification of the magnetic field and the subsequent transport of angular momentum and the extraction of rotational energy from the proto-neutron star in core collapse supernovae. Since simulations of the MRI and MRI-driven turbulence require extremely fine grids that cannot be afforded in global models, the goal of this project is to study them in local simulations. One has to extract quantities characterizing the turbulent transport coefficients such as average Maxwell and Reynolds stresses and correlate them with simulation parameters, eg. different rotation profiles, hydrodynamic stratifications, hydrodynamic and magnetic Reynolds numbers. The final step is to apply the most promising turbulence models in global simulations and investigate their influence on the evolution of supernovae.

Michele Sasdelli: Principal Components Analysis of type Ia supernova spectra. LMU.
Abstract:The main goal of the project is to construct a meaningful metric space for type Ia supernova spectra using databases of observed supernovae. This space needs to be low dimensional, distinguish clearly different kind of type Ia supernovae and group together similar ones. Principal Component Analysis (PCA) is a statistical tool that could be useful for the purpose. PCA is a method for analysis reduction and data compression useful for classifying high dimensional data. Moreover, we plan to explore other statistical methods. Once the metric space is developed it can be useful for many scopes. Compare explosion models synthetic spectra to connect the characteristics of the spectra with the physics of the explosion, reddening estimation, find non-standard reddening laws of the type Ia SNe, automatic spectral classification, improve the calibration in their use as standard candles.

Marco Selig: Information Theory Based High Energy Photon Imaging. LMU.
Abstract: The proper analysis of data is an inevitable necessity in all fields of physics. In high energy astronomy, where observations in the X- and gamma-ray domain are performed, the data consist of information about the detected photons, i.e. their detection time, incidence angle, and frequency or energy. The numerous sources emitting X- and gamma-ray photons can be classified into two phenomenological classes, diffuse and point sources. Separating these source components from spatially resolved photon counts is a nontrivial task due to their superposition and the shot noise in the data. The main goal of this thesis is the reconstruction of the photon flux and its separation into diffuse and point-like components.

Irina Thaler: Solar magnetohydrodynamics. University of Amsterdam.
Abstract: Study of the structure of magnetic fields at the solar surface, and their effect on long-term variations in the Sun's brightness. The methods will include analytic models, realistic 3-D radiative magnetohydrodynamic simulations of sunspots and small magnetic structures, acquisition and analysis of high-resolution polarimetric observations with the Swedish 1- Solar telescope.

Marcella Ugliano: Explosion and remnant systematics for neutrino-driven supernovae. TUM.
Abstract: The currently favored scenario for the collapse and explosion of massive stars and the formation of neutron stars predicts a delayed explosion triggered by neutrino heating. In this thesis, this scenario is investigated with numerical simulations in one dimension for a wide range of progenitor stars and in two dimensions for a smaller subset of the 1D sample, in order to link the masses of the compact remnants and the explosion properties (like explosion energy and ejected nickel mass) to variations of the progenitor models. The calculations are performed with PROMETHEUS-HOTB, an Eulerian code with approximate gray neutrino transport, and carried out until the shock emerges from the stellar surface.

Marcel van Daalen: Correlation functions from the Millennium XXL simulation. LMU.
Abstract: We will use the Millennium XXL simulation, together with the original Millennium simulation, to reliably determine the theoretical galaxy correlation function out to scales of hundreds of Mpc, with the largest statistical sample to date. Along the way, we will estimate the effects of, for example, randomizing the positions of satellite galaxies within their parent haloes and reshuffling galaxies with the same mass. To obtain the correlation function for a given cosmology within a reasonable amount of time, a method will have to be devised with which it can be determined within some fixed maximum uncertainty, using a carefully picked subset of the full sample available.

Janina von Groote: Hydrodynamic modelling of the accretion-induced collapse of white dwarfs with detailed neutrino transport. TUM.
Abstract: O/Ne/Mg White Dwarfs may undergo accretion induced collapse, if they exceed the Chandrasekhar-mass, by accreting matter from a binary companion. This will lead to an event similar to an electron capture supernova. The goal is to simulate the collapse and get information about the conditions for nucleosynthesis.

Markus Wadepuhl: Simulations of the formation of a Milky Way like galaxy. TUM.
Abstract: Hydrodynamical cosmological simulations have so far in general not been able to successfully form realistic disc galaxies. This work is intended to investigate some of the detailed processes

happening during galaxy formation and to analyze their influence on the main galaxy and the population of satellite galaxies. This is done by utilizing extremely high resolution simulations and different numerical schemes.

Tyrone Woods: The Progenitors of Type Ia Supernovae. LMU

Abstract:To date, the question of which progenitor channel can reproduce the observed rate of type Ia supernovae (Sn Ia) remains unresolved. The single degenerate scenario posits that a white dwarf accretes stably from a companion star until reaching the Chandrasekhar mass, and is for much of its accretion history a strong ionizing source. With this is mind, my work focuses on determining new limits on the possible contribution of this channel to the total Sn Ia rate from consideration of the single degenerate channel's effect on the trace warm ISM now observed in many elliptical galaxies.

Rob Yates: Metal enrichment in galaxy formation models. LMU.

Abstract: Metals play a major role in many of the key evolutionary processes of galaxies, such as gas cooling, star formation and stellar evolution. However, currently, the treatment of metal production and distribution in semi-analytic models is rather crude. The principle aim of my PhD work is therefore to implement more sophisticated and realistic treatments, whilst also maintaining the simplicity and efficiency that is one of the key advantages of such models.

Zhongli Zhang: Low-mass X-ray binaries in early-type galaxies. LMU.

Abstract: The aim of the thesis is to study properties of low-mass X-ray binaries in nearby early-type galaxies. This study is based primarily on the archival data of Chandra observations. The unprecedented sub-arcsec angular resolution of Chandra telescopes capable of resolving individual compact sources in nearby galaxies makes it possible to study populations of accreting black holes and neutron stars in external galaxies. The specific goal of this study is to compare formation and evolution of populations of low-mass X-ray binaries in different environments - in globular clusters, in galactic nuclei and in the fields of galaxies, and investigate their dependence on the star-formation history and the age of the stellar population.

4.3 Visiting scientists

Name	home institution	Duration of stay at MPA
Pavel Abolmasov	Moscow University	12.11.–11.12.
Marcelo Alvarez	CITA, Canada	6.3.–3.4.
Mashhorr Al Wardat	Talal, Jordan	25.5.–22.8.
Patricia Arevalo	Univ. Cat. Chile	1.7.–30.7.
Tony Banday	Toulouse, France	2.3–16.3.
Isabelle Baraffe	ENS, Lyon, France	3.7.–2.8.
Altan Baykal	Ankara, Turkey	22.7.–15.8.
Andrey Belyaev	St. Petersburg	since 15.11.
Sergey Blinnikov	ITEP, Moscow	1.8.-10.9.
Akos Bogdan	CfA, Cambridge, USA	5.6.–18.6.
Volker Bromm	Texas Univ., USA	8.4.–11.6.
Matt Browning	CITA, Canada	14.2.–28.2.
Brian Chaboyer	ENS, Lyon, France	3.7.–2.8.
Jens Chluba	CITA, Canada	6.10.–18.10.
Nikolay Chugai	Inst. of Astron. Moscow	28.2.–30.3.
Peter Cotrell	Christchurch, New Zealand	15.5.–15.8.
Ismail Ferrero	Cordoba, Argentina	(since 1.10.)
Charles Gammie	Univ. of Illinois, USA	1.4.–21.7.
Nicolas Grevesse	Liege, Belgium	3.7.–21.7.
Qi Guo	Beijing, China	27.11.–11.12.
Carlos Hernandez Monteagudo	Teruel, Spain	1.6.–20.6.
Gerd Hütsi	Tallin, Estland	15.2.–15.5.
Nail Inogamov	Landau Inst. Moscow	till 27.2. and 15.11.–14.12.
Emille Ishida	IPMU, Kashiwa, Japan	1.5.–9.7.
Anatoly Iyudin	Moscow, Russia	4.7.–16.7.
Francisco Kitaura	AIP, Potsdam	1.4.–30.6.
Sergey Komarov	IKI Moscow, Russia	1.7.–31.7.
Rolf-Peter Kudritzki	Hawaii	1.1.–31.12.
Cheng Li	Shanghai Obs., China	2.10.–30.11.
Ming Li	CAS, China	since 2.11.
Zhengwei Liu	CAS, China	since 18.1.
Tina Lund	Aarhus, Denmark	7.3.–6.6.
Claudia Maraston	Portsmouth, U.K.	8.4.–8.5.
Lyudmilla Mashonkina	RAS, Moscow	30.5.–10.6.
Akira Mizuta	Chiba Univ., Japan	2.8.-11.9.
Dmitrij Nadyozhin	ITEP Moscow	14.3.–14.5.
Biman Nath	Raman Res. Inst. Bangalore India	18.3.–17.6
Julio Navarro	Victoria, Canada	8.5.–21.5.
Sergey Nayakshin	Leicester, U.K.	4.7.–4.8.
Ken Nomoto	Univ. of Tokyo, Japan	28.8.–10.9.
Yeisson Osorio	Uppsala University	17.10. – 05.11.
Francisco Prada	IAA, Spain	7.4.–7.5. and 1.7.–30.7.
Eliot Quataert	Berkeley, USA	3.7.–22.7.

Name	home institution	Duration of stay at MPA
Maurizio Salaris	Liverpool, U.K.	6.7.–17.7.
Michelle Sasdelli	Trieste, Italia	17.4.–1.5.
		and 8.9.–24.9.
Sergey Sazonov	IKI Moscow	5.1.–13.2.
		and 15.7.–21.8.
Pat Scott	Montreal, Canada	4.7.–24.7.
Nikolay Shakura	Sternberg Astron. Moscow	12.11.–11.12.
Stuart Sim	Stromlo Obs, Australia	13.3.–27.3.
Daniel Thomas	Portsmouth, U.K.	8.4.–8.5.
Rajat Thomas	CITA, Toronto	7.3.–11.4.
Alexei Tolstov	ITEP, Moscow	1.8.–21.8.
Victor Utrobin	ITEP, Moscow	17.10.–16.12.
Freeke van de Voort	Leiden Univ.	7.2.–6.8.
Shinya Wanajo	(CLUSTER guest)	1.1.–31.12.
Wenting Wang	Shanghai Observ.	until 15.11.
Jing Wang	USTC China	until 14.11.
Tim White	Sydney, Australia	9.11.–21.1.
Stuart Wyithe	Melbourne, Australia	9.2.–8.3.
Phillip Zukin	Cambridge, USA	1.8.–31.8.