Max-Planck-Institut
für
Astrophysik

Annual Report 2012

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 Simon White in post for the period 2012-2014.

In 2007 Martin Asplund arrived as a new director but, for personal reasons, returned to The Australian National University in 2011. He remains 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 arrived from the University of Texas, as a new director strengthen the institute's research into the beginnings and the evolution of the universe. Also in 2012, Wolfgang Hillebrandt retired and a search is currently under way for new director to replace him.

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.

Since 2001 the MPA has been part of the International Max-Planck Research School in Astrophysics, a joint initiative between the Max Planck Society and the Ludwig-Maximilians University of Munich. About 70 PhD students participate in the school of any given time, most of them at the MPE or the MPA. This has sustantially increased and internationalised the graduate student body at MPA over the last decade. Currently about 25 students at MPA participate in the IMPRS.

Since 1995 the Wissenschaftliche Institutsrat (WIR) has met regularly about 6 times a year to discuss all academic, social and administrativ issues affecting the institute. This consists of all the permanent scientific staff and elected representativs of the postdocs, students and support staff. It acts as the main formal conduit for discussion and communication within the institute and advises the directors on all substantive policy issues. Subcommittees of the WIR organise the hiring of postdocs and students, the monitoring os students progress, and other institutional activity.

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.

1.2 Current MPA facilities

Computational facilities

Computer and network facilities are a crucial part of everyday's life, but are in particular essential for theoretical scientists. 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 supercomputer centers, both on the national and international level.

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 their activities and development plans through regular meetings, to ensure continuity in the working environment experienced by the users. In 2012, the 100th of these meetings was celebrated. Furthermore, MPA participates actively in discussions of potential major investments at the RZG. Common hardware acquisitions by the two institutions are not unusual. The most important resources provided by the RZG are parallel supercomputers, PByte mass storage facilities (also for backups), and the gateway to the German sience and educational high-speed network backbone. RZG also hosts a number of mid-range computers owned by MPA. Presently, two Linux-clusters with 756 and over 2500 processor cores respectively are located at RZG, and are used for moderately parallel codes. In addition, a dedicated system of 156 cores, about 650 GB memory and 180 TB disk space is used, among other purposes, for data analysis of the Millenium simulations. This system also offers public web services to access and use the Millenium Database.

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, in large part are younger than 5 years and which (in 2012) amount to more than 170 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, but to 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 possible, too. MPA is also a partner in the eduroam-consortium, thus allowing its members unrestricted access to WLAN at all participating institutions.

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 in-house 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 from construction work for the nearby extension building. They are now being hosted at RZG; due to the excellent network connection and a well-planned installation concept MPA users experience no impact on convenience or performance over this period. The machines will return to MPA's new building after its completion in early 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 predominantly 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 149 journals and 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 the 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 (print and online). Additional technical services such as several PCs and terminals in the library area, copy machines, a colour book-scanner, 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 2012), and Mrs. Blank (half time; administration of journals)

1.3 2012 at the MPA

1.3.1 Retirement of Wolfgang Hillebrandt

At the end of February 2012 Wolfgang Hillebrandt retired as director at the MPA. Wolfgang first came to the 1978 led it with great skill through its most difficult period, the time of uncertainty after Rudolf Kippenhahn's retirement in 1991, and he played a major role in defining, the character of the current institute, in particular its strong emphasis on high-end computer simulation of astrophysical problems. Over the years he has also ensured that the MPA has remained an major international center for the study of exploding stars, and recently he has involved the institute in many of the major observational initiatives which have arised from the need to understand supernovae more precisely was highlighted by their use in tracking the accelerated expansion of the Universe.

A major conference on supernovae was organised in Garching in September and this prvided a good opportunity to organise a "Festkolloquium" to celebrate Wolfgang's scientific career. Stan Woosley, Ewald Müller, Bruno Leibundgut and Matthias Steinmetz gave talks mixing personal reminiscences within scientific history and a survey of the field today. Then a party was held for Wolfgang by the whole institute which invited many old friends, and involved a wide variety of presents including a home still which almost set fire to the institute when the enthusiasts whom had bought it tried to demonstrate how it works.

While the retirement of Wolfgang Hillebrandt is undoubtedly a landmark in the scientific life of the institute little has so far changed, since he continued to participate in the MPA intellectual activities as vigorously as ever. The real changes will presumably begen to be apparent once his (and Martin Asplund's) successor is in post.

1.3.2 The new building

2012 saw the MPA's extension building change from a large hole in the ground to a complete building which even has its own telescope done on the roof (the only one in Garching, intended priority for TU students and outreach). Although this work naturally involved quite a lot of noise and dust on occasion overal it was carried out with remarkably little affect on MPA activity. Because of its location, it did saver the internal link between MPA and MPE so that scientists had to brave the elements to move between the two institutes. The new building will be finished at the end of March 2013 and will house the computer group, the MPA main computers, the MPA/MPE administration and a new 120 seat lecture room. This will not, however, be the end of major building work at MPA because at about the same time a complete renovation of the MPA guesthouse will be started. This has been closed for two years because of serious mildew problems.

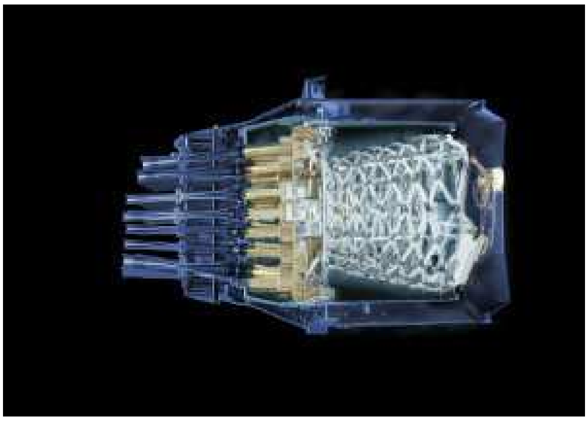

Figure 1.1: Planck's instruments *Credits: ESA (images by AOES Medialab)*

Planck Surveyor

The High Frequency Instrument on ESA's Planck mission has completed its survey of the remnant light from the Big Bang. The sensor ran out of coolant on Saturday, 14. January, as expected, ending its ability to detect this faint energy. The Planck Surveyor is an ESA mission to map the Cosmic Microwave Background using two instruments, the High Frequency Instrument (HFI) and the Low Frequency Instrument (LFI). The satellite was launched in May 2009 and has been operating at L2 since August 2009. By the time HFI had to be switched off, Planck had worked perfectly for 30 months, about twice the span originally required and completed five full-sky surveys with both instruments. Able to work at slightly higher temperatures than HFI, the LFI continued surveying the sky, providing calibration data to improve the quality of the final results. Planck sees not only the primordial microwaves from the Big Bang but also the emission from cold dust throughout the Universe.

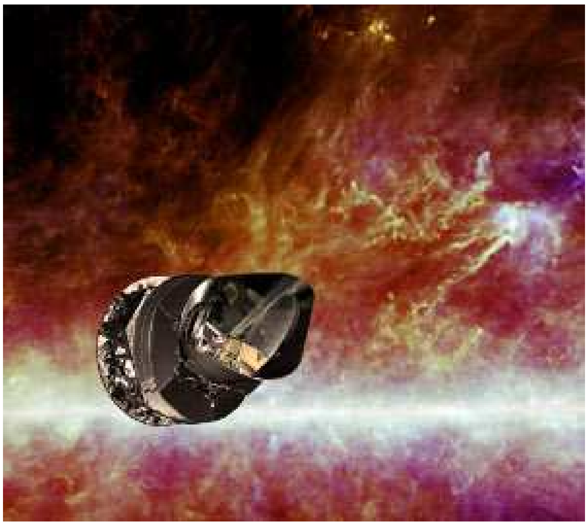

Figure 1.2: Artist's impression of the Planck spacecraft *Credits: ESA - C. Carreau*

Initial results from Planck were announced in 27 papers on early science results in 2011. During 2012 eleven further intermediate papers were published, covering topics from Sunyaev-Zeldovich measurements of galaxy filaments and galaxy super-clusters to the Planck view on gamma ray emission regions of the Milky Way. The first results on the Big Bang and very early Universe can only be released after an extremely careful and painstaking analysis of the data to remove all of the contaminating foreground emission and tease out the faintest, most subtle signals in the remnant emission. The Big Bang data will be released in two stages, the first 15.5 months' worth in early 2013, and the full data release from the entire mission a year after that.

New MPA director

In 2012, Eiichiro Komatsu relocated from the University of Texas to become director at the Max Planck Institute for Astrophysics. With his research interest in the cosmic microwave background and theories of the early universe, he will further strengthen the institute's investigations of the beginnings and the evolution of the universe (see Fig. 1.3. Eiichiro Komatsu maintains strong ties to the University of Texas, where he was director of the "Texas Cosmology Center", an interdisciplinary centre to study the nature of dark matter and dark energy, the origin of matter in the universe and how structures formed and evolved. This centre brings together astronomers and physicists, theory and observations. Both at the TCC and at the MPA, there is increasing involvement in observational programmes to apply theoretical models and simulations to the real world, so that they can be further refined. Komatsu became fascinated by astronomy while at school and went on to study astronomy at the Tohoku University in Japan, graduating with his PhD thesis on *"The Pursuit of Non-Gaussian Fluctuations in the Cosmic Microwave Background"* in 2001. While working on his doctoral thesis, he joined the WMAP science team at Princeton, and then became an assistant professor of astronomy at the University of Texas. From 2010 on, he was director of the Texas Cosmology Center. In 2004, he received the Young Astronomers Award from the Astronomical Society of Japan for his work on constraining inflationary models of the early universe and in 2010 the Nishinomiya-Yukawa Memorial Prize for physics for his studies of the early universe, as well as several other awards and fellowships. In 2012, he and the WMAP team led by Charles Bennett also received the Gruber Cosmology Prize. As a member of the WMAP team since 2001 and lead author of the papers presenting the cosmological interpretation of their five- and seven-year WMAP datasets, Eiichiro Komatsu played a major role in the success of the WMAP enterprise. He becomes the third MPA scientist to win the $500,000 Gruber Cosmology Prize after Rashid Sunyaev (2003) and Simon White (2011).

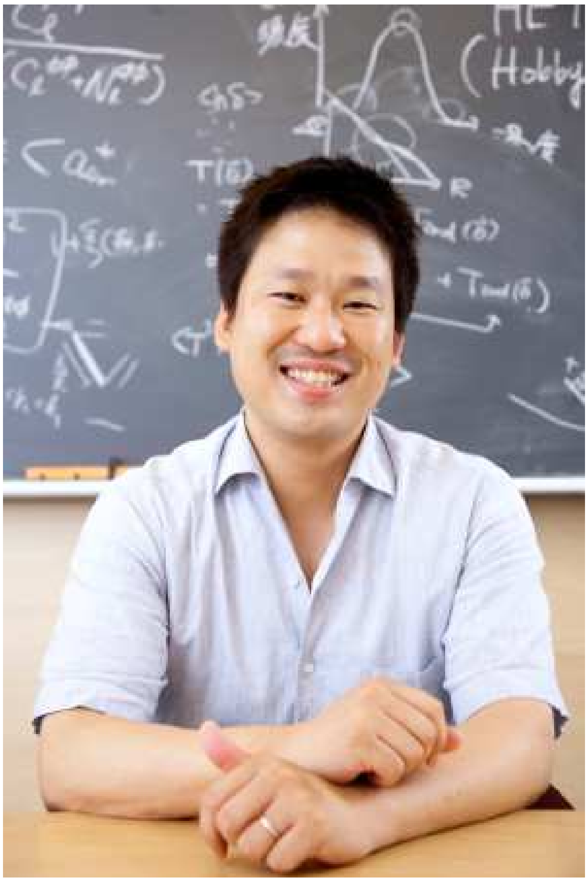

Figure 1.3: Eiichiro Komatsu (new director at MPA)

At MPA Komatsu will continue his studies of the Cosmic Microwave Background radiation. Further research interests include the large-scale structure of the Universe, the Sunyaev-Zeldovich effect, dark matter and dark energy, as well as the infancy of the Universe: inflationary scenarios, the dark ages and reionisation.

LOFAR's first all-sky image

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

Figure 1.4: Artist's impression of a field of individual SKA antennae with a diameter of 15m SKA Organisation/Swinburne Astronomy Productions

Figure 1.5: Christopher Reynolds (Biermann lecturer)

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 the 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. 5 out of 6 German antenna fields have already been built at Effelsberg, Julich, 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. First usable data from a large fraction of the array (including the German stations) became available in early 2011. The commissioning phase for some of the telescope observational modes has been successfully completed and observations are under way. 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.

Biermann lectures 2012

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.

Biermann lecturer explores the Ins and Outs of Black Holes Following a well-established tradition, in 2012 the Max-Planck-Institute for Astrophysics invited Prof. Christopher Reynolds from the University of Maryland as Biermann lecturer to the Munich area. Chris Reynolds research interests revolve mainly around black holes, from the astrophysics of the black holes (both stellar and supermassive) themselves to the physics of the material around them as well as the associated relativistic jets and he presented various aspects of black hole physics in his lectures, which were very well attended. As the name implies, black holes cannot be seen but nevertheless the latest generation of X-ray observatories has produced a wealth of data about their immediate surroundings, which can be extremely hot. Reynolds and his group use these observations to study Active Galactic Nuclei and galactic black hole candidates, in particular the inner relativistic accretion disks. One of the most interesting questions is whether the black hole rotates, but measuring the rotation is difficult. Not only is the effect of a rotating black hole on its surroundings very subtle, moreover, several different physical models can fit the same spectroscopic data. On the theoretical front, Reynolds therefore studies the physics of accretion discs and how many of these degeneracies can be lifted.

Rudolf-Kippenhahn-Prize for Ralph Schönrich

The annual Rudolph Kippenhahn Prize was awarded in 2012 to Ralph Schönrich for his paper on "Galactic Rotation and Solar Motion from Stellar Kinematics", which appeared in the journal Monthly Notices of the Royal Astronomical Society. Now working as a Hubble Fellow at the Ohio State University, Ralph Schönrich received the cer-

Figure 1.6: Rudolf Kippenhahn Prize ceremony: Ralph Schönrich received the certificate from managing director Simon White

tificate from managing director Simon White end of September (See Fig. 1.6). The selected paper, which Ralph Schoenrich published as single author, demonstrates three methods to determine the distance to the galactic centre and the solar motion in a model-independent way. These parameters are among the central questions to determine the structure of the Milky Way; however, many classical strategies rely either on local kinematic data or make assumptions on the gravitational field of our galaxy. Ralph Schönrich used a new estimator of absolute galactic rotation, which does not depend on solar velocity. Unfortunately Rudoph Kippenhahn, former director of MPA and donor of the prize, could not be at the institute in person for the ceremony. He was represented by MPA director Simon White, who presented Schönrich with the prize, and by Ewald Müller, who was part of the selection committee. Schönrich's paper was selected in an unanimous decision out of nine applications. In the laudation, Müller mentioned in particular that as an IMPRS student, Schönrich switched topics for his PhD, but still finished his thesis on time and passed his exams with summa cum laude.

Guinevere Kauffmann elected to the NAS

At the beginning of May, the U.S. National Academy of Sciences announced that MPA scientist Guinevere Kauffmann is among the 84 newly elected members chosen in 2012 in recognition of their distinguished and continuing achievements in original research. Kauffmann will be inducted into the Academy in April 2013 during its 150th annual meeting in Washington, D.C. Election to the NAS is considered the highest distinction which the US scientific community confers on its members. Renowned past members include Albert Einstein, Robert Oppenheimer, Thomas Edison, Orville Wright and Alexander Graham Bell. Nearly 200 living academy members have won Nobel Prizes. It is quite unusual for Americans working abroad to be elected. In 2012, only two of the 84 new members work outside the US. Kauffmann is also one of only two astronomers elected this year, the other being Marcia J. Rieke from the University of Arizona. In her research, Kauffmann studies the formation and evolution of galaxies both theoretically, using computer based semi-analytic models, and observationally, through the analysis of large multiwavelength surveys. The National Academy of Sciences is a private, non-profit honorific society of distinguished scholars engaged in scientific and engineering research. It is dedicated to the furthering of science and technology and to their use for the general welfare. It regularly advises the US government on scientific questions related to public policy. Established in 1863, the National Academy of Sciences is charged to "investigate, examine, experiment, and report upon any subject of science or art."

Public Outreach

The institute employs various strategies to reach a wide audience. Several groups and school classes visited the MPA to learn more about astronomy in general and our work in particular. For these groups, in addition to talks, junior scientists presented a show in the digital planetarium in the form of a journey from the skies over Garching to the beginnings of the universe, touching on various aspects of MPA research. To highlight just a couple of events: In April the MPA again took part in the annual Girls Day and the 50 places available were booked rapidly. In a questionnaire after the programme, the girls replied that this was 'cool' and a 'super event' and that it was interesting to learn about a career 'that would not immediately come to mind'. In October, the annual meeting of the press officers of the various Max Planck Institutes took place at the neighbouring Max Planck Institute for Extraterrestrial Physics and some 15 colleagues took the opportunity to learn about this very exciting possibility for public outreach. Also in October, a special planetarium event was organised internally at the MPA to give all colleagues and especially newcomers a chance to see the current status and contribute new ideas and input to the show. As a result, the task force now has several new members replacing those that have left the MPA in the meantime.

MPA scientists were also involved in educational programmes for school teachers and gave public talks outside the institute, e.g. in the framework of Café & Kosmos, an event series organised together with the Excellence Cluster Universe, ESO, MPE and MPP. They supervised undergraduates and high school students on small research projects during internships, served as guides for tour groups through the Cosmology exhibition at the Deutsches Museum, which was curated partly by MPA, wrote articles for popular science media and acted as interview partners for press and TV journalists. The public outreach office issued a number of press releases about important scientific results as well as news about awards and prizes for MPA scientists. These were published on the MPA website as well, complementing the popular monthly scientific highlight series.

In 2012, the new travelling exhibition of the Max Planck Society, the Science Tunnel 3.0, premiered in Paderborn. It takes the visitor on a journey through the major issues of basic research, starting with a module on the Universe - from quarks to the cosmos. Members of the MPA advised on the overall concept of this part of the exhibition and contributed material. Among the relevant topics for MPA were the early universe, structure formation, galaxy evolution and the simulation of processes in stars at the end of their lifetime. Already one year earlier, the Max Planck Science Gallery was inaugurated in Berlin as a walk-in digital installation, designed as a response to social networks and the mobile Internet. It aims to arouse curiosity about what is ahead of us and what lies behind innovation, providing insights into new scientific issues and prospects, and to make an active contribution to public debate in Germany and Europe. A special exhibition dedicated to astrophysics is planned for 2013, but updated information about the MPA and its research groups has already been included and can be found through multi-touch technologies as well as contactless interfaces.

Figure 1.7: The Max Planck Science Gallery in Berlin presents its exhibitions entirely digitally, with a high degree of interaction and visitor participation

2 Scientific Highlights

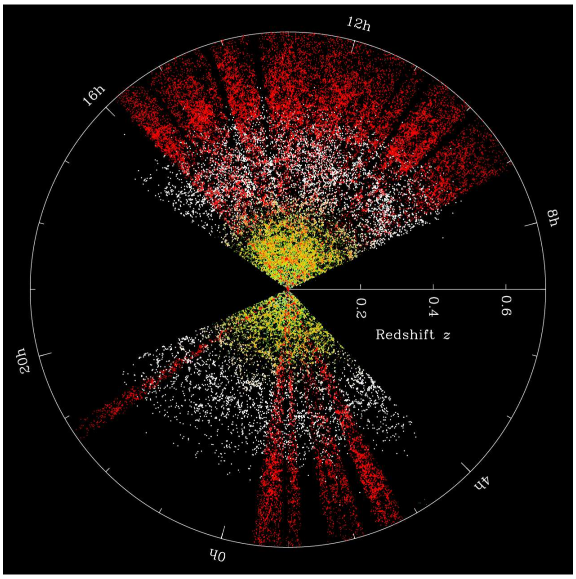

Figure 2.1: This pie-diagram shows the sky distribution of the BOSS massive galaxies. In red, we show the new BOSS Galaxies that probe to a high redshift (greater distance) than the previous SDSS luminous red galaxy (LRG) sample (shown in white) and the normal (MAIN) SDSS galaxies in yellow. (*copyright: Michael Blanton and the SDSS-III Collaboration*)

2.1 SDSS-III finds a large population of massive galaxies still alive eight billion years after the Big Bang

Building on the legacy of the Sloan Digital Sky Survey (SDSS), the SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS) is currently mapping the spatial distribution of the most massive galaxies in the Universe (Fig. 2.1). MPA scientists have been involved in the SDSS for more than a decade. They have been using the galaxy spectra obtained by these experiments to infer important physical information about the stars and the gas in these systems, which illuminate how galaxies formed and evolved over the history of the Universe.

Scientists from an international collaboration consisting of the MPA , Nanjing University, the University of Wisconsin and Johns Hopkins University, as well as other members of the BOSS team, studied the masses and ages of around 300,000 massive galaxies at redshifts ranging from 0.45 to 0.7, corresponding to a time when the Universe was 60 percent of its present age. These galaxies all have stellar masses larger than 100 billion suns (10^{11} Msun), making this the largest sample of massive galaxies with spectra to have been analyzed thus far.

Massive galaxies are very interesting to cosmologists, because they are thought to represent the end point of galaxy evolution. The now standard Lambda-Cold Dark Matter paradigm provides detailed predictions for how structure in the dark matter component of the Universe assembles over time. In short, structure formation is a "bottom-up" process, with the smallest dark matter halos collapsing first, and then merging to form larger and larger systems such as groups and giant clusters of galaxies.

For a long period, these cosmological predictions came under attack by many observers, because the most massive galaxies that were known appeared to consist only of extremely old stars. How could this be consistent with a scenario in which the most massive structures formed last? As telescopes grew more powerful, observers were able to survey faint galaxies in the very distant Universe, where light travel times become comparable to the age of the Universe itself. The observers found that the total stellar mass in massive galaxies present at early cosmic epochs was indeed far less than today, confirming that massive galaxies assembled rather recently. However, they also found that the most massive galaxies in the early Universe were apparently still composed of relatively evolved stars – in other words, no matter how far back in time observers looked, they found little evidence for recent star formation once a galaxy reached a certain threshold in stellar mass.

These results caused much consternation among theoreticians, who calculated that large quantities of gas should be cooling and forming stars in the dark matter halos surrounding massive galaxies. As a result, there has been much debate and speculation about exotic mechanisms that heat the gas

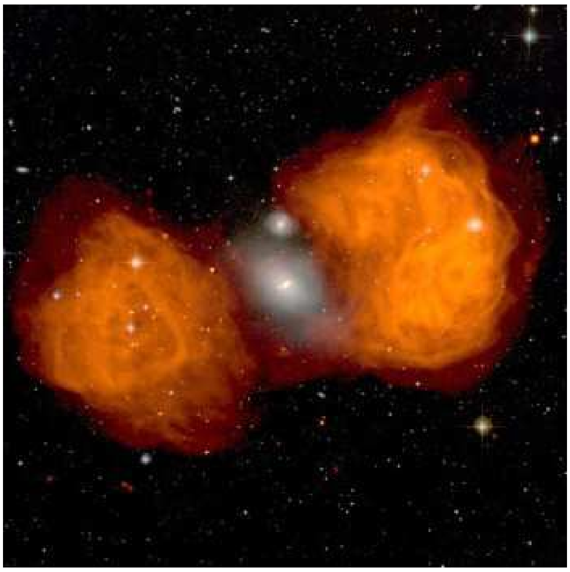

Figure 2.2: A massive elliptical galaxy is shown together with its radio-emitting lobes of high energy particles.

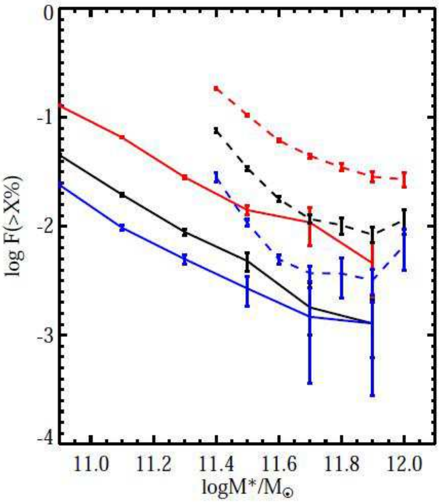

Figure 2.3: The solid red,black and blue lines show the fraction of galaxies that have formed more than 5,10 and 15% of their stars in the last billion years as a function of stellar mass. These results are for galaxies with median redshift z=0.1 in the SDSS low redshift main sample. The dashed red, black and blue lines show the same thing for galaxies with median redshift z=0.5 in the BOSS sample.

and prevent it from forming stars. Examples range from giant explosions powered by material accreting onto central black holes of a billion or more solar masses, to Megaparsec-scale jets of charged particles traveling at relativistic speeds, which penetrate and heat the gas surrounding the galaxies.

The results from SDSS-III indicate that these exotic mechanisms may have a much harder time stopping star formation in massive galaxies at higher redshifts. The MPA/Wisconsin/JHU team employed a technique that could estimate the age of the stars in a galaxy using detailed stellar absorption line features in their spectra. In massive galaxies, the youngest stars are often shrouded in cocoons of dusty gas that absorb much of the blue light emitted by young hot stars, so inferences based on galaxy colour can lead to wrong answers. The new technique and the unprecedentedly large galaxy sample, allowed the team to conclude that the fraction of the most massive galaxies with young stars has decreased by a factor of 10 over the last 4 billion years (see Fig. 2.2). At redshift 0.5, more than 10% of all galaxies with stellar masses of around 200 billion solar masses have experienced a significant recent episode of star formation. These results are at odds with claims from some observers that the stars in the very most massive galaxies all formed 2-3 billion years after the Big Bang.

In a recent update, the same team were able to demonstrate that radio-loud AGN (Fig. 2.3) do play a key role in regulating star formation in these systems. Massive galaxies with detectable emission at 20 cm in the Faint Images of the Radio Sky at Twenty centimetres survey had more quiescent recent star formation histories than radio-quiet galaxies of the same mass. These new results suggest that massive galaxies experience cyclical episodes of gas accretion, star formation and black hole growth, followed by the production of a radio jet that shuts down further activity. The results are exciting, because next generation X-ray satellites will be able to detect the gas as it cools and forms stars in these massive galaxies, and next generation radio surveys will track in detail how energetic particles propelled by black holes deposit their energy into this gas. Constraints on jet-driven feedback processes will then be considerably more quantitative. (Guinevere Kauffmann)

References:

Yan-Mei Chen, Guinevere Kauffmann, Christy Tremonti, Simon White, Timothy Heckman et al.,“ Evolution of the most massive galaxies to z $\sim$ 0.6 - I. A new method for physical parameter estimation ”, MNRAS, **421**, 314 (2012)

Yan-Mei Chen, Guinevere Kauffmann, Timothy Heckman, Christy Tremonti, Simon White et al., “ Evolution of the most massive galaxies to z $\sim$ 0.6 - II. The link between radio AGN activity and star formation”, MNRAS, in press (2013)

2.2 Trojan horses within molecular clouds: How do a few massive stars determine the fate of a whole galaxy?

Less than 1% of all new-born stars have a mass of more than 8 solar masses by the time nuclear burning in their centres is initiated and they start to shine. Both the life and death of a massive star are intriguingly different and much more exciting than those of a low mass star, such as our Sun. During its lifetime, a massive star heavily affects its parental gas cloud – mostly consisting of cold (10 Kelvin), molecular gas – by strong UV radiation and a fast stellar wind. Due to the emitted UV radiation, the surrounding molecular cloud is quickly ionised and heated to ∼10,000 Kelvin, and a so-called HII region is formed. The hot, ionised bubble expands into the cold, turbulent environment, thereby sweeping up more and more gas and possibly triggering new star formation. The massive star exhausts its fuel fairly rapidly, burning for only a few million years. In death, it explodes as a supernova type II and releases an enormous amount of energy, which further accelerates and heats the surrounding gas to up to 100 million Kelvin. Even though massive stars are rare, they are most important for galaxy formation and evolution. They represent the main source of stellar feedback energy and are able to destroy molecular clouds from within, thus regulating the star formation efficiency in the galaxy. Moreover, their feedback, and in particular their death in the form of a supernova explosion, may even drive large-scale galactic winds and outflows. Gas which is driven out of the galaxy by this process might ultimately be unavailable for new star formation.

Scientists at MPA study the dispersal of molecular clouds by UV radiation (see Fig. 2.4) and Supernova explosions of massive stars (see Fig. 2.5) in highly resolved, three-dimensional computer simulations. They show that relatively small molecular clouds with a mass of 10,000 solar masses may easily be disrupted by ionising radiation alone, long before the star explodes as a supernova. However, the disruption of more massive molecular clouds requires more drastic measures. While the initial ionising feedback due to radiation is still an essential ingredient when modelling the disruption of high-mass clouds, only supernovae are actually able to disrupt clouds with 100,000 to 1 million solar masses. Modelling the stellar feedback involves complex, non-linear cooling processes in the interstellar medium. This means that the Supernova explosion is much more efficient when taking place in a pre-ionised, low-density HII regions. By performing simulations of Supernova explosions in clouds with and without previous ionisation, the scientists are able to quantify how much the efficiency improves. In fact, for simulations with previous ionisation and cooling the results are remarkably close to the ideal and well-studied Sedov explosion case, in which the cloud is not allowed to cool radiatively. This result is very important for correctly estimating the impact of feedback in the interstellar medium.

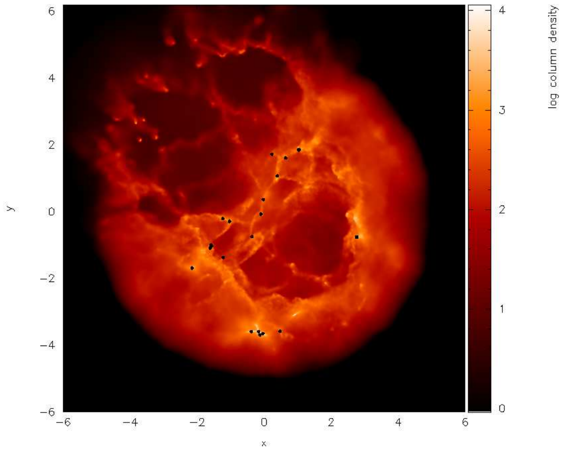

Figure 2.4: 3D simulation of an HII region expanding into a molecular cloud with $10,000\ M_\odot$. The colouring indicates the column density along the projected direction. Black dots are new stars, which form in these self-gravitating simulations.

Understanding how this feedback propagates over more than six orders of magnitude in spatial scale, from milli-parsec scales, at the sites of massive star formation, to kilo-parsec scales, is a computationally challenging quest. The team is now ready to set the next milestone by performing highly resolved **Si**mulations of the whole **L**ife**C**ycle of a molecular **C**loud (SILCC-project). They have been awarded more than 40 million CPU hours on SuperMUC, the new 3 petaflop supercomputer, which has just been launched at the Leibniz-Rechenzentrum Garching. Currently, SuperMUC is Europe's fastest supercomputer and number four in the known universe. The SILCC project will shed light on the intricate impact of massive stars, from molecular cloud assembly, over to star formation and feedback, to gas ejection from the galactic disk (see Fig. **??**). These complex three-dimensional simulations will involve a

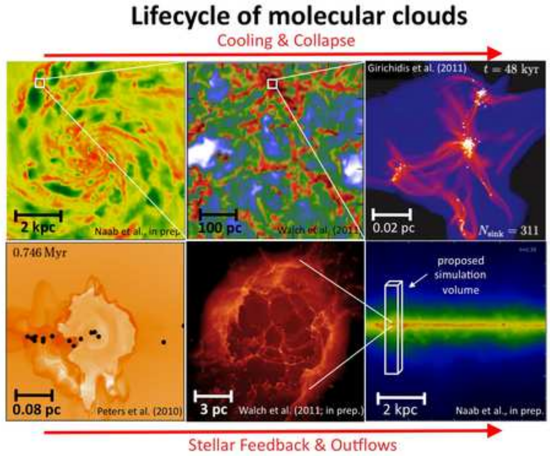

Figure 2.6: The SILCC project aims to capture the full life cycle of a molecular cloud in one simulation. The panels show the individual steps from cloud assembly to star formation, feedback and driving of large-scale galactic outflows. Each step has been studied in an individual simulation by members of the SILCC team.

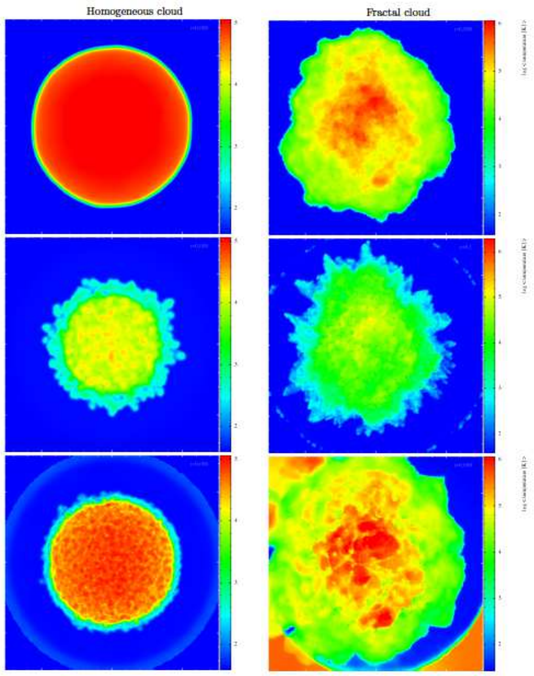

Figure 2.5: Temperature profiles, showing the impact of a supernova explosion in a 10x more massive molecular cloud. The three panels show: a) the adiabatic case (without radiative cooling); b) the case with radiative cooling; c) the full model, in which the cloud has been affected by ionising radiation before the supernova explodes.

multitude of physical effects that, to date, have not yet been included in a single computation. Investigating all of these processes in a systematic way time will give detailed insight about how feedback from massive stars can regulate star formation efficiencies in galaxies. (Stefanie K. Walch, Thorsten Naab)

References:

Stefanie K. Walch, Anthony P. Whitworth, Thomas Bisbas, Richard Wünsch, David Hubber, "Dispersal of molecular clouds by ionising radiation", MNRAS **427**, 625 ff (2012)

Stefanie K. Walch, Thorsten Naab, "The impact of supernova explosions on ionised molecular clouds", to be submitted to MNRAS.

2.3 Gas in Galaxies at the End of their Lives - Food for New Stars

For technological reasons, studies of the cold neutral gas in galaxies have lagged far behind studies of the stars in galaxies. Stars emit radiation at optical wavelengths, but cold hydrogen gas in atomic form (HI) emits radiation at a wavelength of 21 cm and is only detectable at radio wavelengths.

The last decade has seen renewed efforts to carry out HI surveys over large areas of the sky using ex-

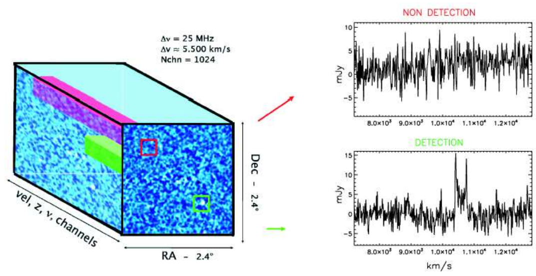

Figure 2.7: A schematic representation of an ALFALFA 3-dimensional data-cube. Each pixel represents a position on the sky (defined by RA and Dec) and a velocity, where each data cube is 2.4 by 2.4 degrees in size and about 5500 km/s in velocity range (25 MHz in frequency). For each pixel a value of the flux density is recorded. For each target, we extract a spectrum over the velocity range from the data-cube at a given position of the sky. Two examples of extracted spectra are shown on the right, illustrating an HI detection (bottom) and an HI non-detection (top). Image credit: Fabello, S. et al, 2011, MNRAS, 411, 993.

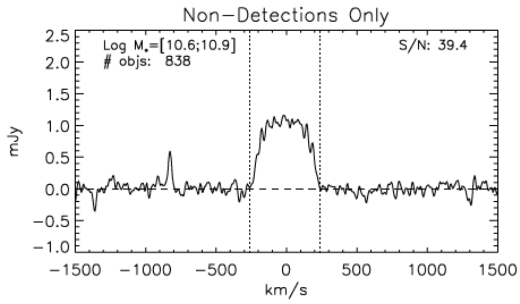

Figure 2.8: Example of stacked spectrum. Dotted lines show the boundaries of the signal, inside which we integrate the flux to compute the mass in atomic gas. *Image credit: Fabello, S. et al, 2011, MNRAS, 411, 993.*

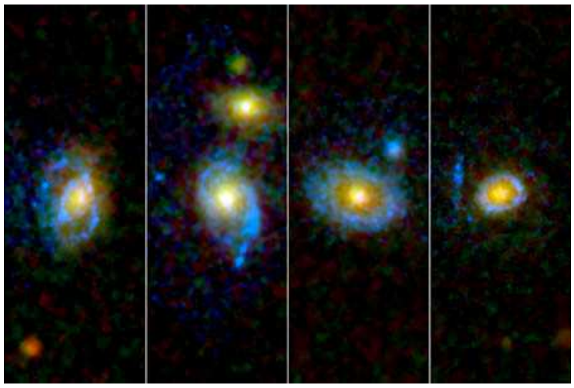

Figure 2.9: Examples of nearby elliptical galaxies that have been found to possess outer rings that are actively forming stars. In these images taken with the Hubble space telescope, ultraviolet light from young hot stars has been rendered in blue, while green and red light from the galaxies is shown in their natural colours. *Image credit: NASA/ESA /JPL-Caltech/STScI /UCLA.*

isting radio telescopes. The Arecibo Legacy Fast ALFA (ALFALFA) survey is the most advanced of these. When complete, ALFALFA will have detected more than 30,000 extragalactic HI line sources. However, ALFALFA is still shallow compared to state-of-the-art optical galaxy surveys, such as the Sloan Digital Sky Survey. As a result, most of the galaxies detected in such surveys are late-type spiral and irregular galaxies. Rather little is known about cold gas in early-type elliptical and lenticular galaxies.

In collaboration with researchers at Cornell University, MPA scientists developed a stacking tool that enabled them to measure the average atomic gas content of early-type galaxies. Spectra were extracted from the ALFALFA data "cubes" (see Fig. 2.7) at the positions of elliptical galaxies identified in the Sloan Digital Sky Survey. Although the HI line was usually not detected in individual spectra, it did appear when the spectra were carefully superposed (see Fig. 2.8). This allowed the MPA scientists to extract a measurement of the mean HI gas mass for the combined sample of galaxies.

Interestingly, the mean HI mass fraction does not drop below two per cent, even in the most massive and red elliptical galaxies. One question is whether this gas is associated with the central spheroidal component of the galaxy, or is spread over large radii in a disk or a ring. The 4 arcminute Arecibo beam means that the location of the gas is not known, but the MPA scientists used statistical techniques to argue that the gas is not associated with the central spheroid, but must be located in a disk. Interestingly, a population of elliptical galaxies with outer rings of star formation has now been identified by the Hubble Space Telescope (see Fig. 2.9). Taken together, these observations suggest that elliptical galaxies do occasionally accrete gas from the external environment and form new stars.

MPA scientists also used their stacking tool to investigate atomic gas in galaxies residing in galaxy groups. It has long been known that galaxies residing in dense environments, such as groups and clusters, form stars less actively than isolated galaxies. There has been on-going debate about why this is so. One popular theory is that in dense environments, galaxies can no longer accrete gas (the fuel for star formation) from the external environment, and they simply starve to death over a timescale of a few billion years. New results from MPA scientists indicate that groups may be even more deadly

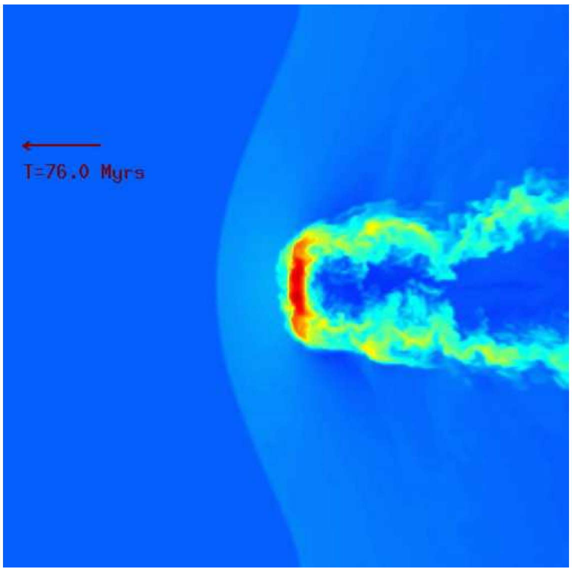

Figure 2.10: A close-up of a simulation of a galaxy that is losing its gas through the process of ram-pressure stripping. In physics, ram pressure is the pressure exerted on a body which is moving through a fluid medium. It causes a strong drag force to be exerted on that body. In the case of a galaxy moving through the intergalactic gas, the ram pressure may be capable of stripping the galaxy of much of its interstellar gas. This will depend on the density of the ambient gas and the velocity of the body. *Image credit: University of Zurich.*

to some galaxies than previously believed. Low mass galaxies appear to actually lose their cold atomic gas if they are in groups. This process is termed "ram-pressure stripping" (see Fig. 2.10) and was previously believed to be effective only in very big clusters. If the MPA results are to be believed, small galaxies are advised to live in the countryside if they want to hang on to their food!

Future radio surveys will be hundreds of times more sensitive than ALFALFA and will map the gas in hundreds of thousands of galaxies over much of the sky. The scientists will thus obtain much more complete information about how galaxies acquire and lose their gas. (Silvia Fabello, Barbara Catinella, Guinevere Kauffmann)

References:

Silvia Fabello, Barbara Catinella, Riccardo Giovanelli, Guinevere Kauffmann, Martha P. Haynes, Timothy M. Heckman, David Schiminovich, "ALFALFA HI data stacking - I. Does the bulge quench ongoing star formation in early-type galaxies?", Mon. Not. R. Astron. Soc. **411**, 993 (2011)

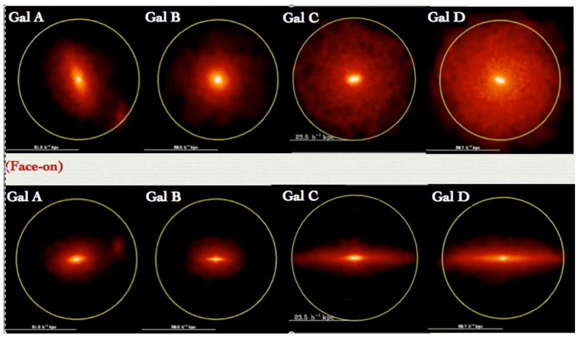

Figure 2.11: Illustration of the structure of four galaxies in our sample with increasing degree of rotational support. The upper and bottom rows show face-on and edge-on projections of the stellar distribution. The yellow circle marks the radius used to define the galaxy.

2.4 What makes a galaxy a disk or a spheroid?

Galaxies exhibit an spectacular variety of morphologies, from spheroids to disks to bars, tidal tails and a zoo of peculiar objects of irregular shapes. Until recently, the major morphological features of a galaxy were thought to be determined by the assembly history and net spin of its surrounding dark matter halo: mergers would create early type elliptical galaxies whereas disks were envisioned to form within quiescently build halos whose angular momentum content exceeds the average of the whole population. However, due to the large computational costs of numerical simulations, most of the progress in our understanding of morphologies have come from simulations of a few individual systems.

Thanks to the combined efforts of several research teams within Europe collaborating as part of the "Virgo Consortium", we have been able to study, for the very first time, the morphology and evolution of a large sample of simulated galaxies that form within the standard cosmological scenario. We focused our attention in objects like our own Galaxy, the Milky Way, and explored the build up of 100 objects selected at random from wide, *representative* volumes of universe. For that, we use the "Galaxies-Intergalactic Medium Interaction Calculation" simulations, (GIMIC, Crain et al. 2009), which follow the evolution of the dark matter, gas and stars within large cosmological volumes throughout cosmic time.

As shown by Fig. 2.11, our simulated galaxies exhibit a wide variety of morphologies, from dispersion-dominated spheroids (left) to pure disk

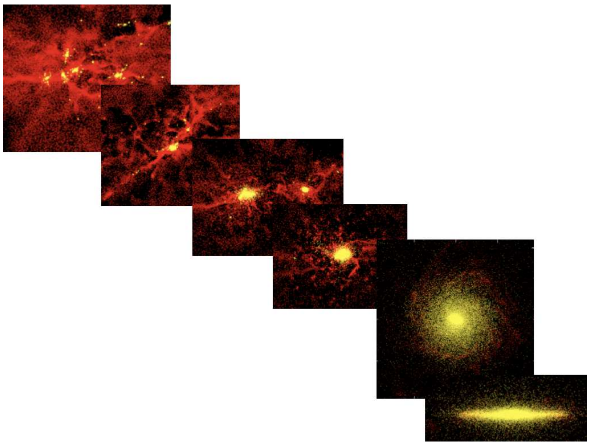

Figure 2.12: This sequence of images shows how a disk-dominated galaxy assembles over time in our simulations. At early times, the proto-galactic material is distributed over large volumes; gas is shown in red and stars in yellow. Baryons aggregate onto larger and larger units until it all collapses to form a single object at the present day.

galaxies (right). Numerical simulations are a powerful tool because they allow us to track the time evolution of each object, gaining fundamental insight into the physical mechanisms that shape a galaxy. For example, Fig. 2.12 shows different stages of the build-up of one of our simulated objects. Different snapshots show the distribution of gas (red) and stars (yellow) that will collapse to form a realistic looking disk-dominated galaxy at the present time.

We quantify morphologies by using the dynamical indicator, $\kappa_{\rm rot}$, which measures the fraction of the kinetic energy of the stars that is in ordered rotation around a well defined axis. That fraction is large for disk-dominated galaxies where most stars move in the same plane and close to circular orbits. On the other hand, $\kappa_{\rm rot}$ is almost null for spheroid-like objects, where the dynamics is dominated by dispersion instead of rotation.

This classification scheme allows us to study systematically the correlations between morphology and properties of the dark matter halos that these galaxies inhabit. Contrary to what is commonly believed, we find that the merger activity and the angular momentum of the dark matter halos relate poorly to the morphology of their central galaxies. However, an interesting hint comes from another correlation: disks preferentially form in objects where the contribution of gas that has cooled from the "hot corona" is large, whereas spheroids dominate for stars born from cold flows that deliver the material directly to the central parts of the halo.

The angular momentum properties of the material accreted hot or cold should differ: gas in the hot corona is forced first to homogenize its spin before being aggregated to the central galaxy, whereas cold gas flows continously to the centers, bringing along their intrinsic spin without any mixing. Therefore, we look for further clues to galaxy morphologies that might be hidden in the primordial angular momentum distribution of each of our objects. Since the spin of the material destined to form a galaxy is imprinted as soon as the object decouples from the expansion of the Universe, which happens around ~ 10 Gyr ago, and remains approximately constant after that; we study the angular momentum distributions of our galaxies at very early times, even before each galaxy has formed.

Surprisingly, in this exercise spheroid- and disk-dominated galaxies showed very different behaviours. Whereas for objects that evolved into spheroids the different parts of the system showed clear misalignments in their angular momentum top panel Fig. 2.13), the spins of different collapsing shells in disk dominated galaxies were remarkably well aligned (bottom panel Fig. 2.13). Moreover, we confirmed that these results are general to our whole sample and not a peculiarity of these two galaxies. (Laura V. Sales, Julio F. Navarro, Tom Theuns, Joop Schaye, Simon D. M. White, Carlos S. Frenk, Robert A. Crain and Claudio Dalla Vecchia)

References:

Crain, R. A., Theuns, T., Dalla Vecchia, C., et al., "Galaxies-intergalactic medium interaction calculation - I. Galaxy formation as a function of large-scale environment", MNRAS **399**, 1773 (2009)

Sales, L. V, et al., "The origin of discs and spheroids in simulated galaxies", MNRAS **423**, 1544 (2012)

2.5 First Light for the Millennium Run Observatory

The famous Millennium Run (MR) simulations now appear in a completely new light - literally. The project, led by Gerard Lemson of the MPA and Roderik Overzier of the University of Texas, combines detailed predictions from cosmological simulations with a virtual observatory in order to produce synthetic astronomical observations. In anal-

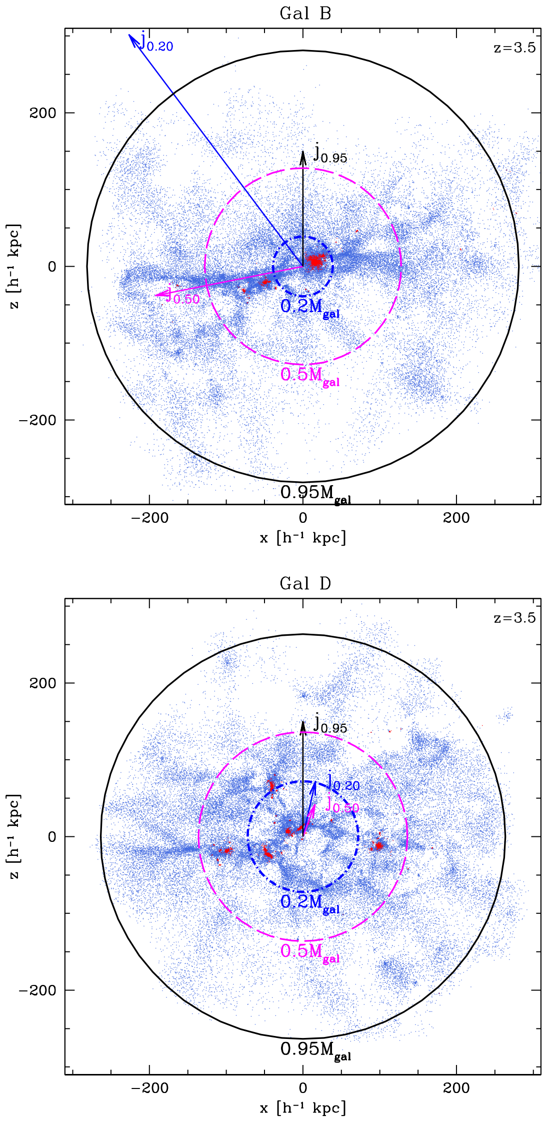

Figure 2.13: For the galaxies B and D shown in Fig. 2.11 these plots show the projected particle distribution near turnaround time, about 10 billion years ago. Stars that have already formed are shown in red, particles still in gaseous form in blue. Concentric circles enclose 20%, 50%, and 95% of the mass, and arrows indicate the angular momentum of all material enclosed within each radius. Arrow lengths are normalized to the total value, which defines the z-axis of the projection. Note the misalignment of the angular momentum of various parts of the system for the spheroid-dominated galaxy B. Angular momentum is more coherently acquired in the case of the disk-dominated galaxy D.

ogy to the moment when newly constructed astronomical observatories receive their "first light", the Millennium Run Observatory (MRObs) has produced its first images of the simulated universe. These virtual observations allow theorists and observers to analyse the purely theoretical data in exactly the same way as they would purely observational data. Building on the success of the Millennium Run Database, the simulated observations are available to the wider astronomical community for further study. The MRObs browser - an online tool - allows users to explore the simulated images and interact with the underlying physical universe as stored in the database. Advantages offered by this approach will lead to a richer collaboration between theoretical and observational astronomers.

Cosmological simulations aim to capture our current understanding of galaxy evolution, aid in the interpretation of complex astronomical observations, and make detailed predictions for future experiments. Simulations and observations, however, are often compared in a somewhat indirect way: physical quantities are estimated from the observational data and compared to the models. An important complication with this approach is that observations typically give a distorted view of the universe, making the process of extracting physical information a challenge.

Many problems in astrophysics could therefore benefit from doing it the other way round: the entire observing process is applied to the simulations, so that the models can be viewed fully from an observer's perspective. The Millennium Run Observatory (MRObs) is a theoretical virtual observatory that uses virtual telescopes to 'observe' semi-analytic galaxy distributions based on the MR dark matter simulations. The MRObs produces data that can be processed and analysed using standard observational software packages developed for real observations.

The MRObs produces fully physically-motivated, synthetic images of the night sky by stringing together a great number of products from cosmological simulations, various existing astronomical software packages, and software newly created for the MRObs. Halo merger trees based on the MR simulation (using only dark matter) form the backbone for the semi-analytic modelling of galaxies inside haloes. This modelling is based on simple recipes for, e.g., gas cooling, star formation, supernova and AGN heating, gas stripping and merging between galaxies. At each time step of the simulation, the physical properties of each galaxy are used to select stellar population

Figure 2.14: False-colour images of the Hubble Ultra Deep Field as predicted by the Millennium Run Observatory (left) and as actually observed by the Hubble Space Telescope (right). The images measure about 5' by 5', and were constructed from virtual and real observations through the filters V (blue), i (green), and z (red). The resemblance between the virtual image constructed using the MRObs and the actual image seen by HST is striking. The MRObs images can be analysed in the same way as the real data, with the advantage that only for the MRObs images the underlying "reality" is known. Comparison of these kinds of simulated and real data will allow astronomers to test their methods, test how well the simulations reproduce the actual universe, and make predictions for future observations.

templates from a library of theoretical spectra to predict the intrinsic spectra. 'Light cones' are constructed that arrange the simulated galaxies in a way that is similar to the way galaxies appear to an observer on the sky. Next, multi-band apparent magnitudes are calculated, including the effects of absorption by the inter-galactic medium. The light cone is then projected onto a virtual sky, and the positions, shapes, sizes and observed-frame apparent magnitudes of the galaxies are used to build a 'perfect' or 'pre-observation' image. The perfect image is fed into the MRObs telescope simulator that applies a detector model (pixel scale, readout noise, dark current, sensitivity and gain), sky background, point spread function, and noise. The result is a realistic, synthetic telescope image. Source extraction algorithms are applied to the simulated image resulting in a catalogue of the apparent properties of all objects detected in the image. This catalogue of objects can be cross-matched with the higher level data available in the MR database in order to compare the real physical properties of the galaxies with those extracted from the images.

The MRObs extends the MR simulations by producing data products that most directly correspond to observations, namely synthetic images and extracted source catalogues. The data simulated with the MRObs so far includes portions of the Sloan Digital Sky Survey (SDSS), the Canada France Hawaii Telescope Legacy Survey (CFHT-LS), the Great Observatories Origins Deep Survey (GOODS), the GOODS WFC3 Early Release Science (ERS), the Hubble Ultra Deep Field (HUDF, see Figure 2.14), as well as the Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey (CANDELS). The information provided covers light cone catalogues linked to structural properties of galaxies, pre-observation model images, mock telescope images and source catalogues that can all be traced back to the dark matter, semi-analytic galaxy and light cone catalogues already available in the MR database. This will aid theorists in testing analytical models against observations, aid observers in making detailed predictions for observations as well as better analyses of observational data, and allow the community to subject the models to new tests. For example, the MRObs can be used to visualize the appearance of galaxy clusters, to predict the structural properties of galaxies across the stellar mass versus star formation rate plane, or to answer the question of how many galaxies could be detected at a redshift of about 10. The data can be explored interactively in the MRObs browser (Figure 2.15).

The development of the MRObs coincides with the celebration of the first 500 papers based on the MR simulations, proving that the MPA-led Millennium Run project is still as successful today as it was 7 years ago. Future expansions of the MRObs project are already underway, such as incorporating the more recent Millennium-Run II and Millennium XXL simulations to extend the dynamic range, implementing improved cosmological parameters and galaxy modelling techniques, and creating a wider range of virtual telescopes and simulated surveys that will aid theorists and observers alike.
(Roderik Overzier, Gerard Lemson)

References:

Overzier, R., Lemson, G., Angulo, R., Bertin, E., Blaizot, J., Henriques, B., Marleau, G., White, S., "The Millennium Run Observatory: first light", MNRAS, **428**, 778 (2013)

Millennium Run Observatory Web Portal and access to the MRObs browser:

http://galformod.mpa-garching.mpg.de/mrobs/

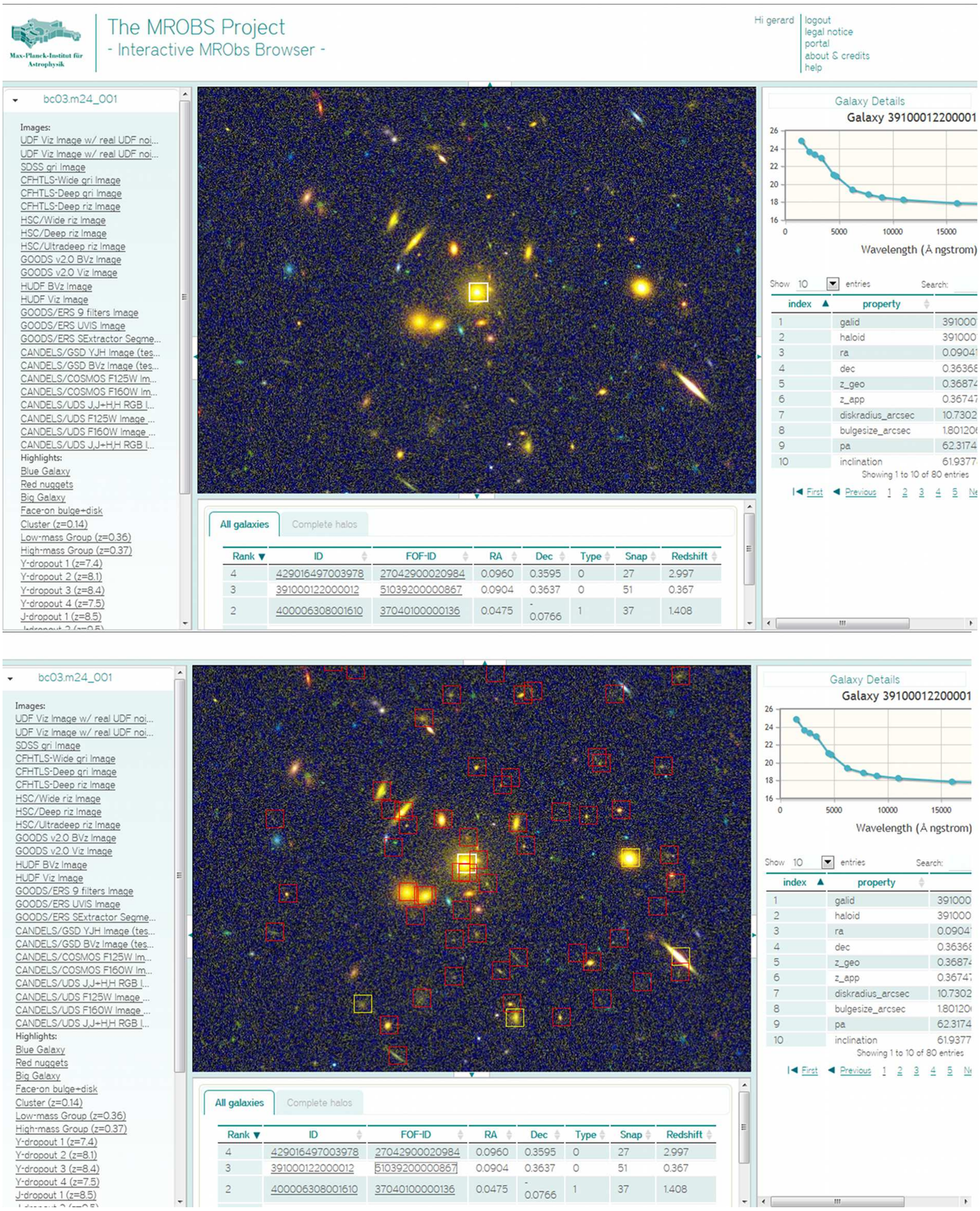

Figure 2.15: A screenshot of the MRObs browser, the new online tool provided by MPA that allows users to explore the virtual observations and interact with the underlying MR database. Top panel: basic view of the browser showing a small region of a synthetic HST/GOODS observation (in V, i, z filters). Users can pan around and zoom the synthetic observation and query the MR database by clicking on a galaxy. Information about the selected object (marked by a white square) is retrieved from the MR database and displayed in the information panel on the right-hand side of the screen. Bottom panel: the user can highlight all galaxies belonging to the same "friends-of-friends" group as the selected galaxy. In this case, the selected galaxy turns out to be the central galaxy of a group at z $\sim$ 0.5.

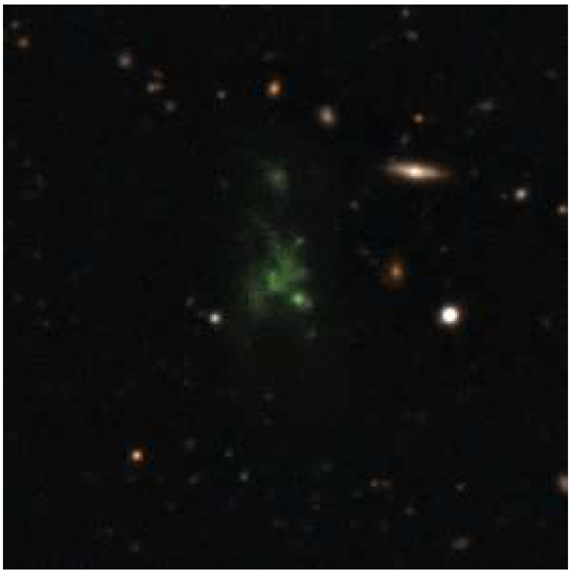

Figure 2.16: This image shows one of the largest known single objects in the Universe, the Lyman-alpha blob LAB-1. The intense Lyman-alpha ultraviolet radiation from the blob appears green after it has been stretched by the expansion of the Universe during its long journey to Earth. *copyright: ESO/M. Hayes*

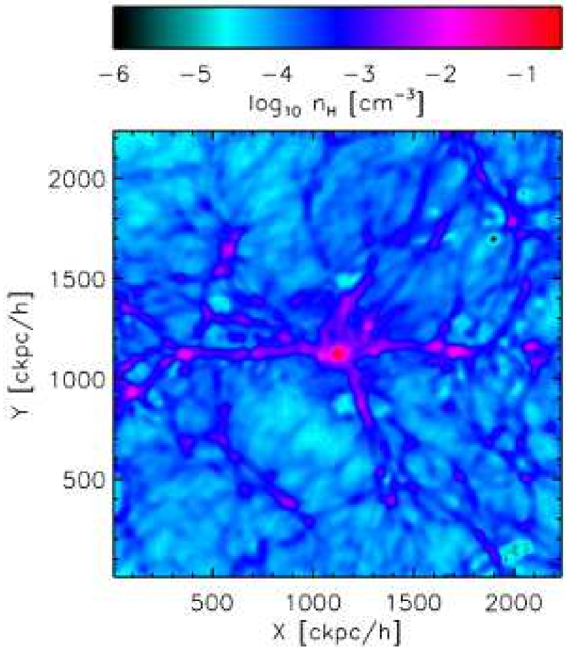

Figure 2.17: Example of the inhomogeneous intergalactic medium around a Lyman-alpha emitter. The colouring indicates the number density of hydrogen atoms with the scale given at the top.

2.6 Lyman Alpha Emitters around the Epoch of Reionization: Tip of the Iceberg

Lyman-alpha emitters (LAEs) are a group of galaxies emitting a significant fraction of their radiation at wavelengths around 121.567 nm, the so called Lyman-alpha line of hydrogen. As this is more easily detectable for far-away objects, where the line has been shifted away from its original UV-wavelength to optical wavelengths which can be detected by ground based telescopes at redshifts up to $z = 8$), when our Universe was less than a billion years old.

However, life is complicated for these Lyman-alpha photons at very high redshifts ($z > 6$). The gas in the inter-galactic medium (IGM) around these galaxies tends to be more and more neutral, leading to increased scattering. Just like fog scatters and dims the headlights of a car, the neutral hydrogen atoms make the LAEs fainter and eventually too faint for detection. On the other hand, this effect can be used to understand the changes in the IGM from a neutral to the highly ionized state at the epoch of reionization.

The probability of scattering is highest when the wavelength of the photon is closest to the original wavelength of the Lyman-alpha line. As the photon travels (unscattered) towards the observer, it is red-shifted towards longer wavelengths due to cosmic expansion. Therefore, the IGM closest to the galaxy has the highest impact on Lyman-alpha photon scattering.

The details of this scattering depend on various properties of the hydrogen in the gas, in particular its density, velocity and level of ionization. Moreover, inhomogeneities in the IGM (See Figure 2.17.) could significantly affect the radiative transfer of the Lyman-alpha photons.

Scientists at MPA performed a new study of this effect, combining detailed cosmological simulations of the IGM close to the galaxy with radiative transfer calculations of the Lyman-alpha radiation. Their analysis shows that the scattering behaviour of Lyman-alpha photons is extremely complex with large variations along different lines of sight (See Figure 2.18). The LAEs appear not as point sources but as extended haloes with complex structure and the total Lyman-alpha flux can vary by a factor of 3 for the same object, depending on the line of sight. This makes it difficult to link the Lyman-alpha flux to galaxy properties.

An additional complication arises from the de-

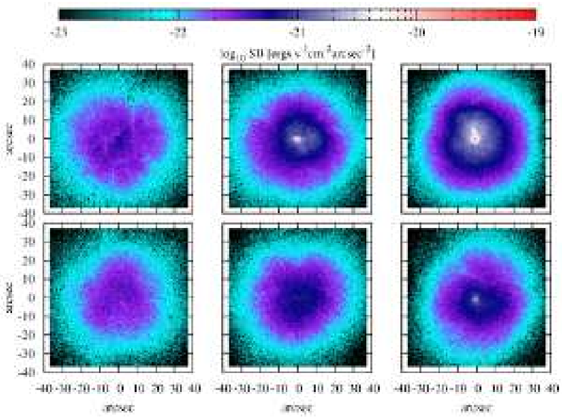

Figure 2.18: Surface brightness maps for a Lyman-alpha emitter as seen along six different lines of sight. In the simulations, these were achieved by rotating the simulation cube and looking through the six different sides. The surface brightness values in each pixel are colour-coded according to the scale at the top.

Figure 2.19: This false colour image shows the galaxy M87. Optical light is shown in white/blue (SDSS), the radio emission in yellow/orange (LOFAR). At the centre, the radio emission has a very high surface brightness, showing where the jet powered by the supermassive black hole is located. *Credits: Francesco de Gasperin, on behalf of the LOFAR collaboration*

tection threshold of observation campaigns. Depending on the depth of an observational survey, only some of the pixels of the surface brightness profile will be above the detection threshold. However, due to the structure in the IGM and the scattering of Lyman-alpha photons, the flux arriving in each pixel of an LAE imaging campaign can vary by several orders of magnitude. This means that only a fraction of the total flux along this particular line of sight would be detected and assigned to the LAE in other words, only the tip of the iceberg actually shows.

Towards higher redshifts, achieving deep detection thresholds becomes increasingly more difficult, which contributes to the effective dimming of LAEs in these observational campaigns. This in turn would affect the estimates of the IGM neutral fraction using the detection of LAEs in observational surveys.

Thus this study emphasises the need for deep observations of the LAEs as well as detailed 3D radiative transfer simulations to properly model these objects. Only then can they be used as accurate probes to study the distant universe and the epoch of reionisation.

(Akila Jeeson-Daniel, Benedetta Ciardi, Umberto Maio, Marco Pierleoni, Mark Dijkstra, Antonella Maselli)

References:

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2.7 Super-massive black hole inflates giant bubble

Astronomers have produced one of the best images ever of a bubble inflated by a supermassive black hole, using LOFAR to detect frequencies from 20 to 160 MHz. The results shows the enormous potential of LOFAR, and provides compelling evidence of the close ties between black holes, host galaxies and their surroundings.

The image was made during the test-phase of LOFAR, and targeted the giant elliptical galaxy Messier 87, at the centre of a galaxy cluster in the constellation of Virgo (See Figure 2.19). This galaxy is 2000 times more massive than our Milky Way and hosts in its centre one of the most massive black holes discovered so far, with a mass six billion times that of our Sun. Every few minutes this black hole swallows an amount of matter similar to that of the whole Earth, converting part of it into radiation and a larger part into powerful jets of ultra-fast particles, which are responsible for the observed radio emission.

To determine the age of the bubble, the authors added radio observations at different frequencies from the Very Large Array in New Mexico (USA), and the Effelsberg 100-meter radio telescope near Bonn (Germany). The team found that this bubble is surprisingly young, just about 40 million years, which is a mere instant on cosmic time scales. The low frequency observation does not reveal any relic emission outside the well-confined bubble bound-

Figure 2.20: The LOFAR antenna array near Unterweilenbach is operated by the MPA. It is one of the 6 stations in Germany and 40 stations in the Netherlands that are combined to study the largely unexplored frequency range between 10 and 240 MHz. *copyright: Rainer Hassfurter/MPA*

aries, this means that the bubble is not just a relic of an activity that happened long ago but is constantly refilled with fresh particles ejected by the central black hole.

The results also provide clues on the violent matter-to-energy conversion that occurs very close to the black hole. In this case the black hole is particularly efficient in accelerating the jet, and much less effective in producing visible emission.

Notes
LOFAR, designed and built by ASTRON, is a revolutionary instrument able to detect radio waves with wavelenghts up to 30-meter. Radio waves this long are typically generated by human activities as radio broadcasts, radar signals or satellite communications. They are also emitted by exotic objects in deep-space, such as accreting black holes, rotating neutron stars and supernovae. To detect these waves, LOFAR uses thousands of antennas spread all over Europe (see Figure 2.20) and combines the signals in a supercomputer located in the Netherlands. The 100 Gigabit per second of data flowing from all antennas are analyzed simultaneously and in real-time to provide the most detailed images ever done at these frequencies.

International LOFAR Telescope operations are coordinated by ASTRON, the Netherlands Institute for Radio Astronomy, on behalf of a consortium consisting of the Netherlands, Germany, France, the UK, and Sweden. Many of the technological solutions developed for LOFAR, in particular the calibration of phased-arrays as well as large-scale data transport and processing, will be highly relevant for future radio telescope projects such as the Square Kilometer Array (SKA). (Francesco De Gasperin)

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2.8 Globular star clusters: The survivors of a massacre 13 billion years ago

Our Milky Way galaxy is surrounded by some 200 compact groups of stars, containing up to a million stars each. At 13 billion years of age, these globular clusters are almost as old as the universe itself and were born when the first generations of stars and galaxies formed. A team of astronomers from Germany and the Netherlands have conducted a novel type of computer simulation that looked at how they were born - and they find that these giant clusters of stars are the only survivors of a 13 billion year-old massacre that destroyed many of their smaller siblings. The new work, led by D. Kruijssen of the Max Planck Institute for Astrophysics in Garching appears in a paper in the journal Monthly Notices of the Royal Astronomical Society.

Globular star clusters have a remarkable characteristic: the typical number of stars they contain appears to be about the same throughout the Universe. This is in contrast to much younger stellar clusters, which can contain almost any number of stars, from fewer than 100 to many thousands. The team of scientists proposes that this difference can be explained by the conditions under which globular clusters formed early on in the evolution of their host galaxies.

The researchers ran simulations of isolated and colliding galaxies, in which they included a model for the formation and destruction of stellar clusters (Fig. 2.21). When galaxies collide, they often generate spectacular bursts of star formation ("starbursts") and a wealth of bright, young stellar clusters of many different sizes (Fig. 2.22). As a result it was always thought that the total number of star clusters increases during starbursts. But the Dutch-German team found the opposite result in their simulations.

While the very brightest and largest clusters were indeed capable of surviving the galaxy collision due to their own gravitational attraction, the numerous smaller clusters were effectively de-

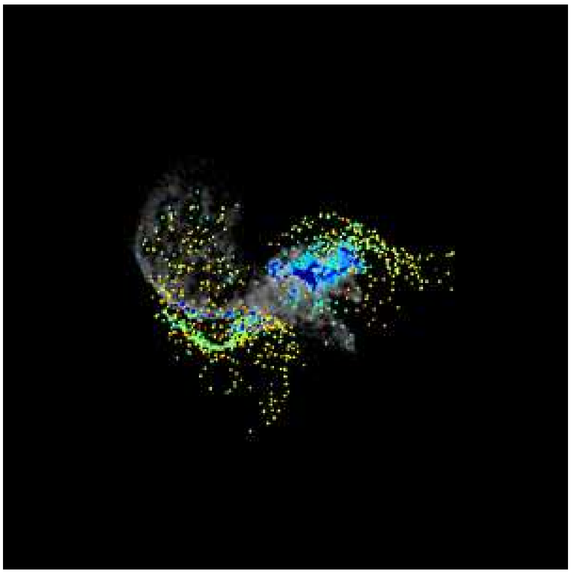

Figure 2.21: An image of two colliding galaxies based on the new simulation. The galaxies eventually merge, destroying many of the stellar clusters (visible here as dots) in the process. (Simulation: Diederik Kruijssen/MPA)

stroyed by the rapidly changing gravitational forces that typically occur during starbursts due to the movement of gas, dust and stars. The wave of starbursts came to an end after about 2 billion years and the researchers were surprised to see that only clusters with high numbers of stars had survived. These clusters had all the characteristics that should be expected for a young population of globular clusters, as they would have looked about 11 billion years ago.

According to the simulations, most of the star clusters were destroyed shortly after their formation, when the galactic environment was still very hostile to the young clusters. After this episode ended, the surviving globular clusters have lived quietly until the present day (Fig. 2.23).

The simulations suggest that most of a globular cluster's traits were established when it formed. The fact that globular clusters are comparable everywhere then indicates that the environments in which they formed were very similar, regardless of the galaxy they currently reside in. Globular clusters can thus be used as fossils to shed more light on the conditions in which the first stars and galaxies were born.

(Diederik Kruijssen, Robert Massey, Hannelore Hämmerle)

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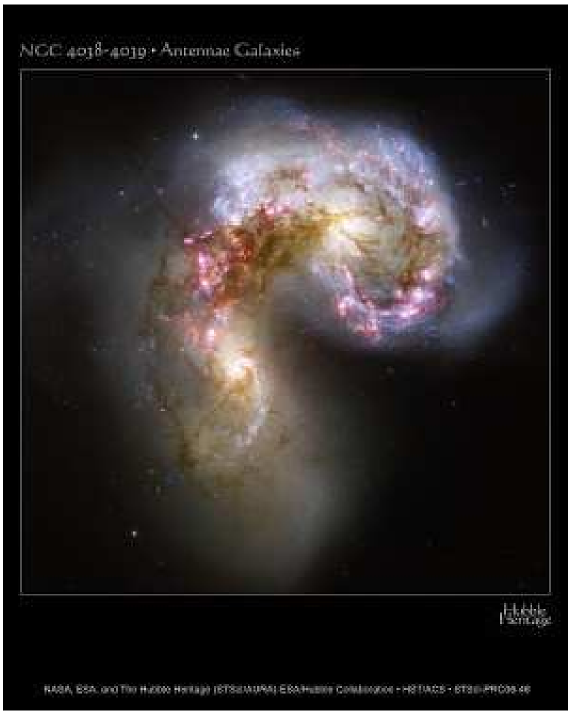

Figure 2.22: This image of the Antennae galaxies shows a multitude of bright young star clusters, groups of stars associated with regions of intense star formation. Credit: NASA, ESA, and the Hubble Heritage Team

Figure 2.23: The Galactic globular cluster M80 in the constellation Scorpius contains several hundred thousand stars. Credit: HST/NASA/ESA

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2.9 Cosmic Vibrations from Neutron Stars

From the sound of church bells, anyone can determine - even from miles away - if the chimes come from a mighty cathedral or a small chapel. Even without actually seeing the bell, one can distinguish between a small bell, which produces a high tone, and a large, heavy bell with a deep rumble. And even when the bells have the same weight, their shape and material influence the pitch. Scientists from the Max Planck Institute for Astrophysics have now found a similar relationship between size and pitch for distant neutron stars. And, like church bells, the researchers want to use the pitch to determine the radii and the composition of neutron stars.

Striking a bell excites sound waves in the air; neutron star oscillations lead to ripples in space-time that propagate with the speed of light away from the source. These gravitational waves have been predicted by Einstein in his general theory of relativity, and scientists hope that they will be able to "hear" the tiny vibrations of space-time in the coming years with the help of highly sophisticated experiments (Fig. 2.24).

But how do you get a neutron star to start vibrating? Above all, the researchers need patience. Many neutron stars occur in binary systems where they orbit each other, slowly getting closer over the course of several 100 million years. Finally, the two stars with diameters of a few ten kilometres collide and form a single star that is much heavier (see Fig. 2.25). The collision excites strong oscillations in the newly formed neutron star and leads to the emission of measurable gravitational waves. According to predictions, there should be a large number of such binary star systems in neighbouring galaxies to our Milky Way. Therefore, chances are not bad to witness such a merger in the future. The latest generation of gravitational wave detectors will be able to monitor thousands of galaxies at the same time. If a collision occurs every 10,000 to 100,000 years in each galaxy (as is expected), the super-sensitive detectors will not miss it.

With computer simulations, the scientists at MPA studied how the pitch of the emitted grav-

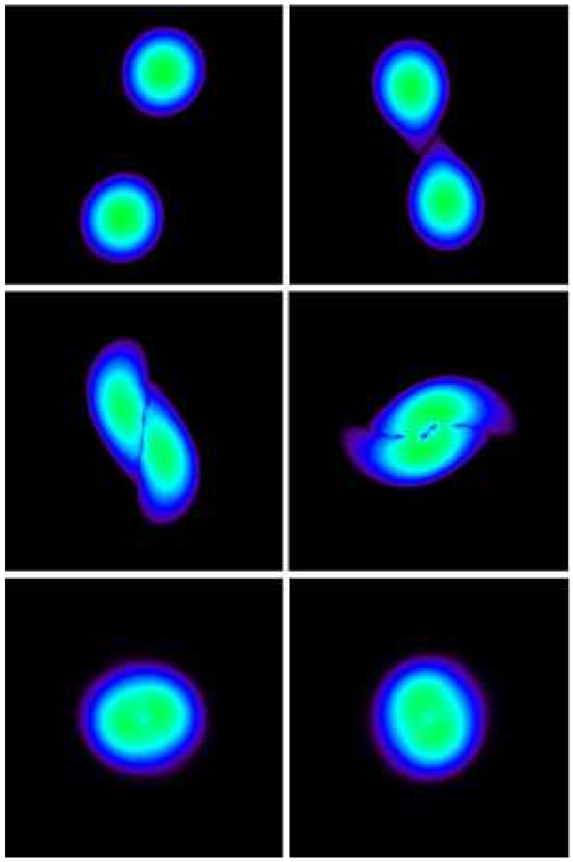

Figure 2.24: Various snapshots of the collision of two neutron stars initially revolving around each other. The sequence simulated by the computer covers only 0.03 seconds. The two stars orbit each other counterclockwise (top left) and quickly come closer (top right). Finally they collide (centre left), merge (centre right), and form a dense, superheavy neutron star (bottom). Strong vibrations of the collision remnant are noticeable as deformations in east-west direction and in north-south direction (bottom panels). (Simulation: Andreas Bauswein and H.-Thomas Janka/MPA)

Figure 2.25: Aerial view of the LIGO gravitational-wave detector at Livingston, U.S.A.; the two monitoring arms containing strong laser beams extend to a length of 4 km. *Copyright: LIGO Laboratory*

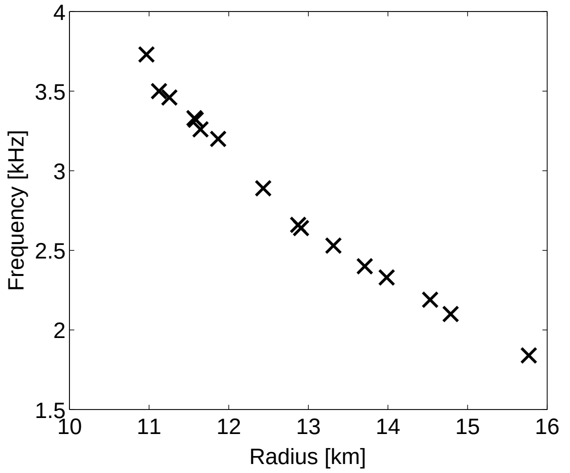

Figure 2.26: Relation between the pitch (frequency) of gravitational waves and the neutron-star radius. The pitch covers one octave. Measuring the pitch with a gravitational-wave detector (Fig. 2.25) allows determining the radius of neutron stars.

itational waves depends on the size of the neutron stars. The star diameter depends on the internal structure and properties of the neutron-star matter. Since the latter are not well known, the researchers used many different suggestions for neutron-star matter in their calculations and determined the corresponding “sound” of the collision. The pitch varies between the tones b”’ and b””. As expected, smaller stars produce higher tones, while more extended objects produce a lower tone (see Fig. 2.26). The simulations of the scientists thus open up the fantastic possibility to accurately measure the size (to within a few 100 metres) of an object that is many million light-years away from Earth.

The new results are particularly exciting, because neutron stars are very extreme objects. With diameters of 20 to 30 kilometers, their mass of 1.5 to 2 times the solar mass is compressed to densities exceeding those in atomic nuclei. Such conditions cannot be created and studied in any laboratory on Earth. Nevertheless, matter at such high densities is of particular interest for many researchers. In such an extreme environment, fundamental processes of nuclear and particle physics emerge, such as interactions between elementary particles, and determine the properties of neutron-star matter. The observation of signals from distant astronomical objects therefore allows a deeper insight into the most fundamental building blocks of nature. (Andreas Bauswein, Hannelore Hämmerle, H.-Thomas Janka)

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2.10 Infrared Beacons in the Universe - Red Supergiant Stars and the Chemical Composition of Galaxies

Chemical composition is one of the key observable characteristics of star forming galaxies in the nearby and in the high redshift universe. So far, most of our information about their metal content has been obtained from the analysis of strong emission lines from H II regions, i.e. low-density clouds of partly ionised hydrogen gas. However, measurements of galaxy metallicities are then uncertain by a large factor because of the systematic uncertainties inherent in this ’strong-line’ method. Furthermore, the method yields only the oxygen abundance, which is then taken as a placeholder for the overall metallicity. In this case, there is no information on abundance ratios, which can be a powerful diagnostic of the chemical enrichment history.

An alternative approach avoiding these weaknesses is the spectroscopic analysis of supergiant stars, the brightest stars in galaxies with luminosities up to one million times brighter than the Sun. Here, much progress has been made through the optical spectroscopy of blue supergiants in the Milky Way (Fig. 2.27) and few other galaxies of the Local group. For extragalactic astrophysics, however, red supergiants (RSGs) are more promising candidates. Their spectral energy distribution peaks in the infrared, where interstellar extinction is reduced. Particularly attractive for quantitative spectroscopy is the J-band (Fig. 2.28), which contains many isolated atomic lines. Spatial resolu-

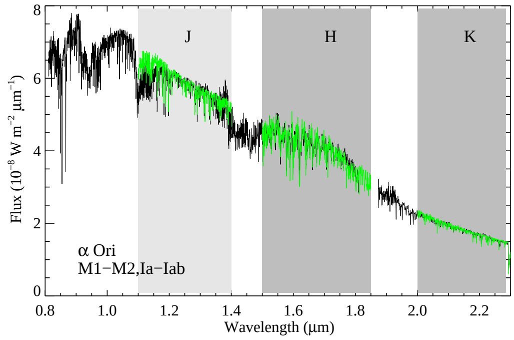

Figure 2.28: A theoretical (green) and observed (black) infrared spectrum of the prototype RSG star, Betelgeuse. The advantage of the J-band over the H- and K-bands is obvious. The observed spectrum was taken from the IRTF spectral library (NASA IRTF, Mauna Kea; Cushing et al. 2005).

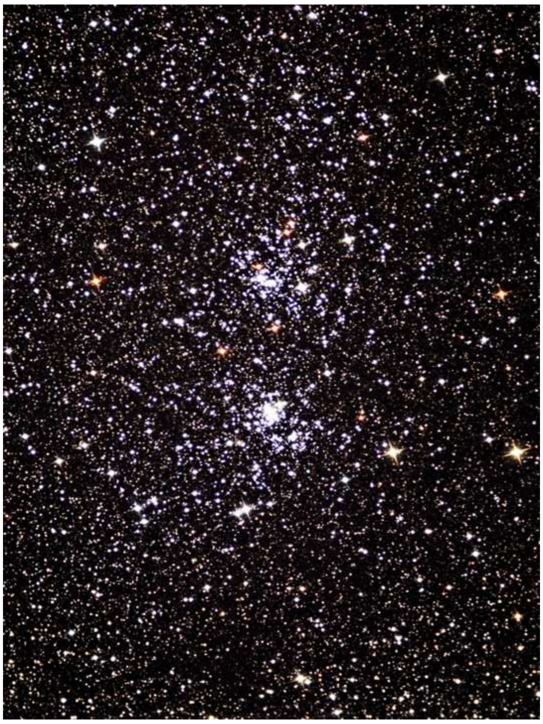

Figure 2.27: An optical image of the young Milky Way stellar association Perseus OB-1, in which about 70 blue (AB-type) and 20 red supergiants were found (appear red on the Figure). *Copyright: F. Calvert and A. Block (NOAO, AURA, NSF, KPNO).*

tion in the infrared is also higher than in the optical and the advantage of instruments supported by adaptive optics can be fully exploited. RSGs are therefore ideal targets for spectroscopy with future telescope facilities, such as the Thirty Meter Telescope (TMT) and the European Extremely Large Telescope (E-ELT). The abundances of various chemical elements will be directly measured out to distances of 70 Mpc, far beyond our Local Group of galaxies.

The analysis of RSG spectra, however, is a challenging task. One major complexity arises due to very low gravities (about 1000 times less than on Earth), stipulating departures from Local Thermodynamic Equilibrium (LTE) in their photospheres. Until now, it has not been possible to compute RSG spectra in non-LTE, as one would need detailed atomic data for constructing the non-LTE atomic models and to model the complex line blanketing, which is dominated by molecules. So far, the atomic data was of insufficient quality. Furthermore, while in LTE the line formation calculation are fairly simple, in the non-LTE case, accurate radiative intensities must be computed at all frequencies where radiative transitions occur in an atom. For iron and titanium this means for wavelengths from UV to far-IR. Such calculations were simply beyond capabilities of current computers.

A team of scientists has now constructed complete atomic models of neutral iron and titanium (Fig. 2.29) and performed, for the first time, non-LTE calculations of these atoms using model atmospheres representative of RSG stars. The inclusion of non-LTE effects changes the titanium abundances dramatically compared to LTE and with

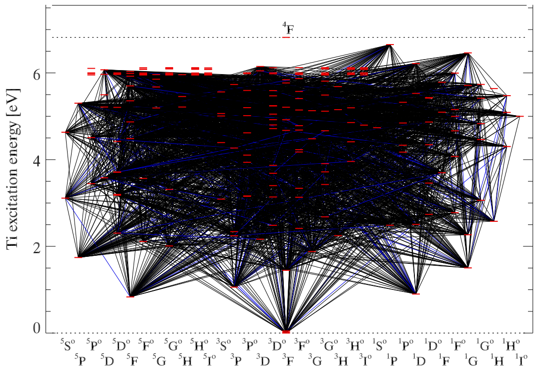

Figure 2.29: Complete atomic model for the neutral Ti.

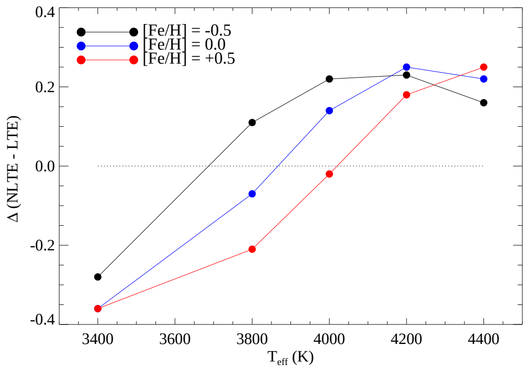

Figure 2.30: The differences between NLTE and LTE Ti abundances derived from the RSG model spectra as a function of T_{eff} for three values of metallicity, [Fe/H] = -0.5 (white), 0 (blue), and +0.5 (red).

different correction factors for different temperatures and metallicities (Fig. 2.30). However, the non-LTE effects on the J-band iron lines are much smaller. Since the RSG metallicity is determined from many lines of different atomic species (iron, titanium, silicon and magnesium), the overall effect of non-LTE corrections may not be as large as for titanium alone. For example, the best non-LTE fit to the J-band spectra of Betelgeuse is shown in (Fig. 2.31).

The next step therefore will be to model the other prominent species in the J-band spectral window, namely silicon and magnesium. These lines also contain important metallicity information, since together with Ti they provide additional constraints on the measurement of galactic abundances of alpha-elements, i.e. elements produced by fusion of alpha-particles. (Maria Bergemann, Rolf-Peter Kudritzki, Karin Lind)

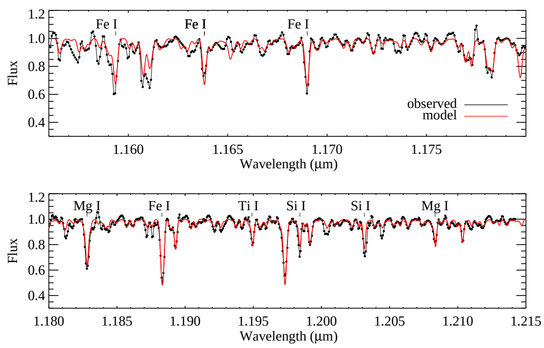

Figure 2.31: Comparison of the observed (black) and theoretical NLTE (red) spectra for Betelgeuse.

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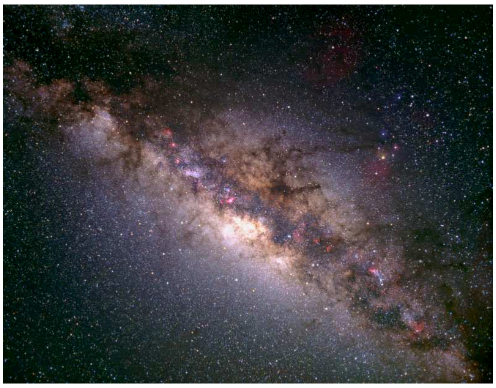

Figure 2.32: The Milky Way contains about 300 billion stars. The galactic disk, which is partly hidden behind gas and dust clouds, is surrounded by a spherical halo of old stars and stellar clusters. *Image: Wei-Hao Wang*

2.11 Chemical composition of old, metal-poor stars poses new questions

In theory, the nucleosynthesis of elements heavier than iron is thought to be well understood. Most of them are formed in the so-called slow (s) or rapid (r) neutron capture processes on lighter seed nuclei. The s-process elements are mainly produced during the late stages of evolution of low-mass stars; a small fraction of these elements originates from massive stars, which explode as core-collapse supernovae.

However, predictions of the stellar models are not fully supported by observations. The observed s-process abundances in the Sun and metal-poor stars, tracing the composition of the interstellar matter in different stages of Galactic evolution, need to be explained by alternative nucleosynthesis scenarios.

Strontium (Sr) and barium (Ba) with magic neutron numbers of 50 and 82, respectively, are the most abundant s-process elements. This is a direct consequence of their nuclear properties, namely very small neutron capture cross-sections. In addition, their strongest absorption lines are in the optical part of a spectrum, accessible with ground-based telescopes, and can be measured even in most metal-poor and distant Galactic halo stars (Fig. 2.32).

The most difficult part, in fact, is to compute the abundance from the observed data points: line profiles are very sensitive to the treatment of radiative transfer in stellar atmosphere models. So far,

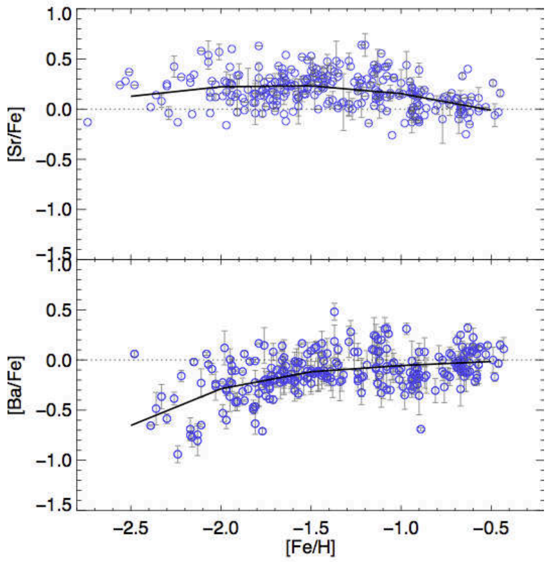

Figure 2.33: The new barium (Ba) and strontium (Sr) abundances for the halo and disk stars as a function of metallicity. The measurements show the difference between the ratio of each element to iron in a star and that of the Sun (i.e., a value of zero means that the star has the same abundance ratio as the Sun). Disc stars with low metallicity (-1.5 < [Fe/H] -0.5) show solar barium abundances, whereas for halo stars the barium abundance is consistent with that predicted from the r-process in supernova explosions. The strontium abundances, however, do not agree with predictions from standard nucleosynthesis models.

most observational studies in the literature relied on highly-simplified models, neglecting the important influence of non-local thermodynamic equilibrium (non-LTE) effects on element abundances.

Scientists at MPA have now performed, for the first time, a consistent non-LTE spectroscopic analysis of a large sample of metal-poor stars, which belong to various Galactic populations (halo, thick and thin disks). Non-LTE effects were taken into account both in the determination of the basic stellar parameters and the element abundances (Fig. 2.33), using new quantum-mechanical atomic data.

The disk stars show barium abundances in agreement with scaled solar abundances. This can be fully explained by models of nucleosynthesis in low-mass stars. The halo stars exhibit strong deficiency

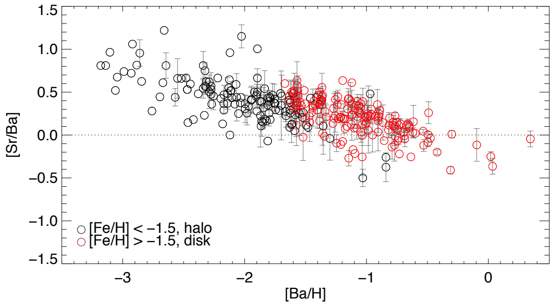

Figure 2.34: Relative abundance of strontium and barium, where disk and halo stars are indicated by red and black circles. Conventional nucleosynthesis scenarios would give a slightly negative value for [Sr/Ba], whereas the observed value is clearly positive, especially for the stars with very low metallicity, [Fe/H] < -1.5.

of barium compared to iron. This is again consistent with stellar models, which predict that only a small range of massive stars contribute to producing barium via r-process. Whereas, iron is made in supernovae explosions of stars with different initial masses.

The strontium abundances, however, increase with decreasing metallicity of a star eventually flattening off at the lowest metallicities. This conflicts with predictions from stellar models. What process could have produced strontium in the early Galaxy? Furthermore, what process overproduced strontium compared to barium at the time when the oldest and very metal-poor stars were born? Summing up all known contributions from both r-process and s-process gives a strontium-to-barium ratio, which is much lower than the one observed for stars with low metallicity (Fig. 2.34).

A few non-standard, exotic nucleosynthesis scenarios, such as the so-called Light Element Primary Process or low-mass electron-capture supernovae, might have the potential to explain these observations. (Gregory Ruchti, Maria Bergemann)

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2.12 Smashing white dwarfs: explaining the brightness of cosmic explosions

Supernovae are among the brightest and most energetic events to occur in nature. However, the origin of a particular type of supernova - the Type Ia supernova - is still a mystery despite decades of research. What type of stars produce these explosions, and how? Researchers at the Max Planck Institute for Astrophysics in Garching, the Australian National University in Canberra, Heidelberg ITS and collaborators have investigated a particular explosion model involving merging white dwarf stars. They found that the explosion brightnesses from the merger models are strikingly similar to the range of explosion brightnesses that is observed for real Type Ia supernovae. This means that violent white dwarf mergers might be a dominant formation channel for these explosions.

Type Ia supernovae (SNe Ia), which make up about one quarter of all supernovae, are believed to come from exploding white dwarf stars, though how the white dwarf reaches the critical conditions to make it explode is still unclear.

More than 95% of stars will end their lives as white dwarfs (including our Sun when it runs out of fuel), but only a small fraction of these will actually explode. A lonely white dwarf star is stable - it won't spontaneously erupt. However, if there is a source of matter nearby - e.g. another star - the white dwarf can steal mass from this companion, with explosive consequences. Thus, astronomers have been trying to find out what types of double star systems including at least one white dwarf can lead to the formation of Type Ia supernovae.

Since white dwarfs are rather faint when they are not exploding, observations alone cannot solve this well-known 'progenitor problem'. Therefore testing of theoretical models has become a critical step in understanding the origin of SNe Ia. (Fig. 2.35)

The biggest mystery shrouding SNe Ia is this: what type of star is 'donating' mass to the white dwarf? Is the companion a normal (Sun-like) star tranquilly passing matter to the white dwarf,

Figure 2.35: An artist's impression of merging white dwarfs. Such mergers are thought to be potential progenitors of Type Ia supernova explosions. Image courtesy of (c) Nature 2010

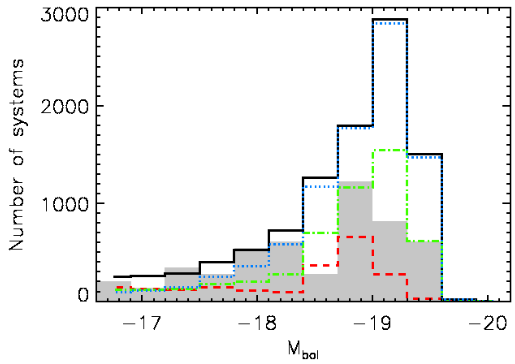

Figure 2.36: Model peak brightness distribution of merging white dwarfs for a range of allowed mass ratios (coloured lines). The observed peak brightness distribution from Type Ia supernovae (from Li et al. 2011) is shown in grey-scale. The observational data have been scaled up in order to easily compare the distribution shapes. The theoretical brightness distributions cover the range and match the shape of the observed distribution fairly well.

thereby slowly pushing it closer and closer to the critical limit, or is it another white dwarf star that violently smashes into the more massive one, immediately causing an explosion?

Using a detailed model for the evolution of double stars, state-of-the-art hydrodynamic explosion models and a sophisticated method for predicting how the energy from the explosion is turned into observable light (spectra), MPA researchers and collaborators determined that white dwarfs which smash violently into each other give rise to a range of brightnesses that matches the range in brightness that is actually observed for Type Ia supernovae. Even more encouraging, the model brightness distribution peaks at about the same value as the one from observations (see Fig. 2.36). Any model scenario that is claimed to account for a large fraction of SNe Ia must be able to explain observational trends. Not only does the violent merger model do very well in terms of reproducing the brightness distribution of real SNe Ia, it also produces the right number of events as a function of time (the 'delay time distribution', see Fig. 2.37).

In this particular model the peak brightness of the explosion is directly related to the mass of the more massive (primary) white dwarf. To get a typical explosion, however, most primary white dwarfs have to grow in mass before they explode. The team has identified an evolutionary pathway which serves to 'beef up' the mass of the primary well before the merger occurs. However, it has yet to be confirmed whether white dwarfs can really be 'beefed up' by their companions sufficiently in large enough numbers.

While the MPA researchers are excited about their result, they remain slightly cautious. It is still

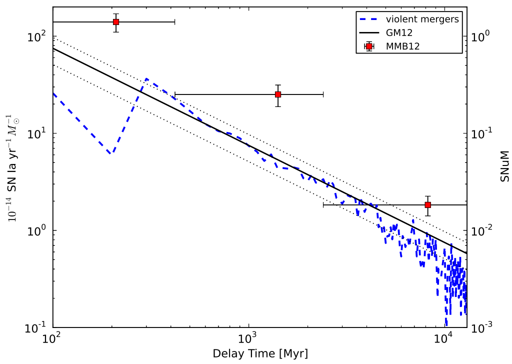

Figure 2.37: This plot shows the number of violent white dwarf mergers as a function of time (from 100 million to 10 billion years after the stars are first born). The blue line represents the violent white dwarf merger model (cf. the blue histogram in fig. 2). Red squares and the black line show the recovered 'delay time distribution' of SNe Ia from two observational studies (see references at the end of the article). The violent white dwarf merger rate matches the fit from GM12 extremely well, implying that there might be enough violent mergers to account for a large fraction of SNe Ia in field galaxies.

unclear if this formation scenario of pre-merging white dwarfs is realized in nature as efficiently as the binary evolution model indicates. Some further work and (probably) future observations are needed to confirm the various aspects of the model.

If it turns out that such an 'evolutionary channel' that leads to more massive primary white dwarfs readily contributes to making white dwarf pairs, then it is likely that violent white dwarf mergers are driving the underlying brightness distribution of SNe Ia. If not, then some other explosion scenario could be dominating the SN Ia scene. (Ashley Ruiter, Stuart Sim, Ruediger Pakmor, Markus Kromer, Ivo Seitenzahl, Stefan Taubenberger)

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2.13 Cosmic Warming by the First Quasars: Did the earliest supermassive black holes slow the growth of the rest?

Figure 2.38: An artist's interpretation of a quasar. Gas falls into the supermassive black hole at the centre of this galaxy, making it grow even more massive. As it falls, the gas speeds and heats up, making it shine brightly. (*copyright: NASA/JLP Caltech.)*

At the heart of virtually every galaxy sits a monster: a supermassive black hole with a mass millions or even billions of times that of our Sun. When dense gas falls into a supermassive black hole, it heats and lights up, much in the same way that water in a waterfall becomes more energetic as it falls. The resulting "quasar" (short for "quasi-stellar object") can outshine entire galaxies for millions of years (Figure 2.38), making them some of the most distant objects astronomers can observe. Because their light has travelled a very long time to reach us, they are excellent astronomical tools for studying the Universe's past.

Observations of the most distant quasars reveal that supermassive black holes weighing billions of solar masses were already in place when the Universe was less than one billion years old. Where did these monster black holes come from, and how did they become so massive so quickly?

The first one billion years marked the rise of the first stars and galaxies. The Universe was expanding and cooling after the Big Bang, and clumps of matter were collapsing under their own gravity. Gas in these clumps formed the very first stars, and then the first galaxies. The ancestors of the monster black holes probably formed alongside the first stars and galaxies, either in the explosions of massive stars or through direct gravitational collapse of giant clouds of hot hydrogen gas. The very first black holes in the centres of galaxies would have had tens or perhaps hundreds of solar masses in the first scenario, and tens of thousands of solar masses in the second.

Regardless of how they began, astrophysicists agree that in order to become supermassive so quickly, the giant black holes powering the most distant quasars must have gained most of their mass by consuming gas from their surroundings at a very high rate. This would mean that the early Universe was filled with powerful quasars powered by their fast growing black holes. The very first quasars (or rather mini-quasars, since the black holes were not yet supermassive) would have emitted an enormous amount of light. In particular, they would have produced a lot of X-rays, which have very high energies and escape easily into intergalactic space. Previous theoretical studies have shown that the X-rays from the growth of the first black holes could have heated intergalactic gas in the early Universe to thousands of degrees. This is significant because gas must be cool and dense not only to form stars and build up galaxies, but also to fuel the growth of black holes.

A new study led by Takamitsu Tanaka at the MPA investigated whether the "cosmic warming" caused by the growth of the first supermassive black holes could have affected the population of massive black holes in general. The authors used a novel technique to simulate the formation and gas-fuelled growth of the earliest massive black holes, their X-ray production, the resulting heating of gas in an expanding Universe, and the effects of this cosmic warming on the supply of cool, dense gas needed for further black hole growth. These calculations showed, for the first time, that the warming of intergalactic gas by the first (mini-)quasars (Figure 2.39) can indeed stunt the growth of supermassive black holes throughout the early Universe (Figure 2.40). Ironically, the very first black holes that are mainly responsible for this warming are the ones least affected by it. By the time that they have heated intergalactic gas significantly, their galaxies have also grown larger and more massive. These massive galaxies can still maintain cool central gas temperatures when exposed to the hot extragalactic gas. Moreover, they collide more often with other massive galaxies, which can provide a fresh supply of cool gas. Black holes that formed later sit in less massive galaxies and end up being the victims of the cosmic climate change caused by their older brethren.

Thus, the cosmic warming of intergalactic gas caused by the first generation of supermassive black holes may explain why so few black holes grew to billions of solar masses. Because this warming also suppresses the formation of small galaxies, it can further help to explain why "dwarf" galaxies are rare in our local Universe. (Takamitsu Tanaka, Rosalba Perna, Zoltán Haiman)

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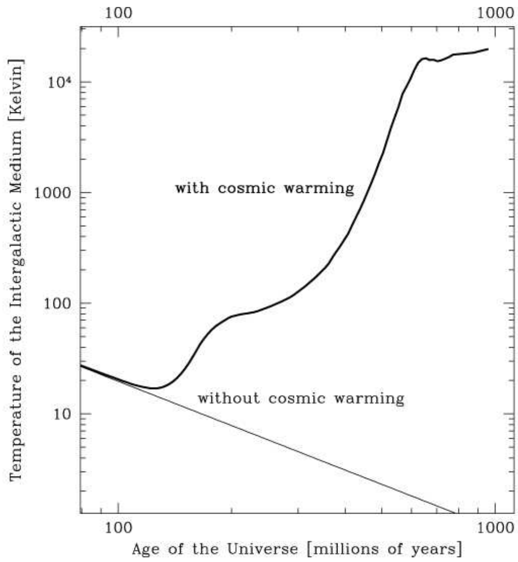

Figure 2.39: The temperature of intergalactic gas, shown with and without cosmic warming by (mini-)quasar X-rays. The thin line indicates the temperature history if there were no heating and the Universe would cool simply by expanding. In the presence of heating, the temperature rises to 20,000 K by the time the Universe is one billion years old.

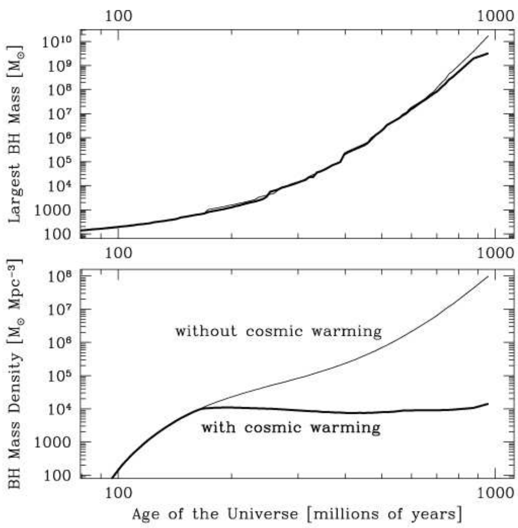

Figure 2.40: The growth histories of supermassive black holes for two simulations, one that accounts for the cosmic warming by (mini-) quasar X-rays (thick lines), and one that does not (thin lines). Top panel: The growth history of the most massive black hole in each simulation. Bottom panel: The total density of all black holes in the centres of galaxies. Cosmic warming only slightly affects the growth of the most massive black holes, but drastically reduces the universal density by stunting the growth of smaller black holes.

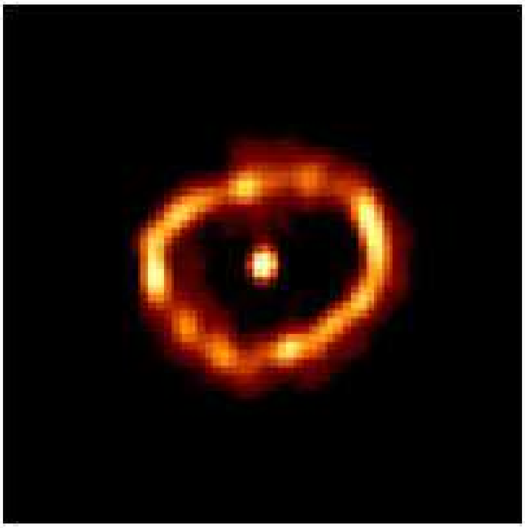

Figure 2.41: Expanding shell of Nova Cygni 1992, the brightest nova in recent history. This picture was taken by the Hubble Space Telescope in 1994. It shows a ring-like clumpy structure, which in projection appears slightly elliptical for the observer.

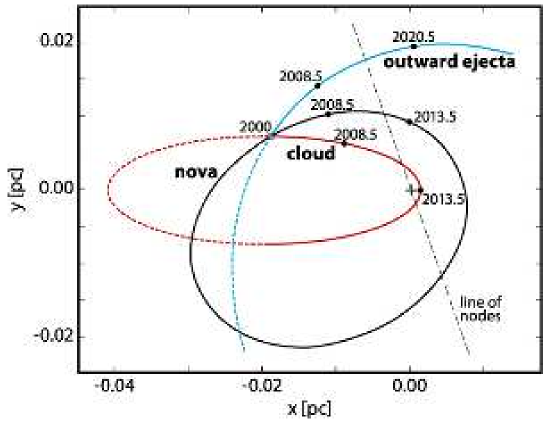

Figure 2.42: Three orbits around the supermassive black hole at the Galactic Center. The red line shows the orbit of the gas cloud as determined by the observations, which is interpreted as the inward ejecta of a nova explosion. The black line shows the orbit of the nova that produced it, while the blue line shows the orbit of the outward ejecta, which are interpreted as the 'tail' feature in the observations. The cross marks the position of the black hole. The line of nodes marks the intersection of the plane of all three orbits with the plane of sky, which are highly inclined to each other.

2.14 A nova origin of the gas cloud at the Galactic Center?

It was a big surprise when a group of astronomers at the Max Planck Institute for Extraterrestrial Physics recently found a gas cloud that is falling nearly straight towards the central black hole of our galaxy. Over the next few years, the gas cloud will be completely disrupted and ultimately parts will be swallowed by the black hole, resulting in largely increased X-ray emission. While this will tell the scientists more about the processes in the very close surroundings of the Galactic Center, the detection also immediately raised the question of the origin of this strange phenomenon. Right away several suggestions were made. Now scientists at MPA propose an interesting new model: The cloud could be the shell of gas ejected at high velocity by a nova that exploded some ten years ago.

Novae are a well-known phenomenon in close binary systems where a very compact white dwarf star accretes matter from an ordinary low-mass companion star. Because of the high gravity at the white dwarf surface the material collecting there becomes strongly compressed and extremely hot. Once a critical amount of matter has been accumulated, a thermonuclear explosion sets in that expels a large part of this envelope, expanding with high velocity. Nova shells appear in different shapes, some more spherical, others more ring-like. Fig. 2.41 shows an example of a ring-like nova, Nova Cygni 1992, in visible light, two years after its explosion. If such a nova were located near the Galactic Center, dust would have completely obscured its visible light.

The scientists noticed that the properties of the observed gas cloud, in particular its mass (about 1/100000 solar mass), its speed (on the order of 1000km/s), and the appearance of the dust are in surprising agreement with those of observed nova shells. The observers derived these properties by analyzing detailed long-wavelength infrared images. The observations of the cloud show two bright parts, a 'head' and a 'tail', with more diffuse emission located in the region closer to the black hole is already influenced by the increasing gravity. Now, a ring-like shell of tenuous radiating gas, seen nearly edge-on, appears as a strongly squeezed ellipse and then shows two bright outer edges because there our line of sight passes through the largest column density of gas. This can indeed explain the two structures, head and tail, observed in the expanding cloud.

The scientists at MPA calculated orbits of ejecta from a nova explosion to investigate how such a ring structure will appear to the observer. They took an explosion around the year 2000 and a typical expansion velocity of 500 km/s, which corresponds to the presently observed separation of head and tail. As the ejecta have differently directed velocities the different parts of the ring move on different orbits around the central black hole. The projection of these parts on the sky traces the observed motions of the gas cloud. Fig. 2.42 shows the orbits of the two brightest visible parts. The cloud (the prominent head feature) is interpreted as the inward ejecta of the nova. The outward ejecta of the nova move on an orbit of lower eccentricity whose projection on the plane of the sky yields the tail structure.

The peculiar extreme eccentricity of the observed cloud orbit would seem to require some explanation, but here in the nova model it naturally results from the addition of two differently directed velocities, that of the nova system itself and that of the inward ejecta.

The surprising agreement between several basic parameters of a nova explosion and the new cloud observations appears to strongly support a nova origin model. If true, this raises important questions about stellar evolution close to the Galactic Center, as the occurrence of such a low-mass binary system bears witness of a stellar population much older than that of the young luminous stars presently observed there. (Friedrich Meyer, Emmi Meyer-Hofmeister)

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3 Publications and Invited Talks

3.1 Publications in Journals

3.1.1 Publications that appeared in 2012 (217)

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Tanaka, M., K. Kawabata et al. (incl. P. Mazzali): Spectropolarimetry of type Ibc supernovae. In: Death of Massive Stars: Supernovae and Gamma-Ray Bursts. Eds. P. Roming, N. Kawai, and E. Pian, Proc. of the International Astronomical Union, **7**, Cambridge, UK: Cambridge University Press. 138-141 (2012).

Thöne, C.C., A. de Ugarte et al. (incl. H.-Th. Janka): GRB 101225A – an unusual stellar death on Christmas Day. In: GRBs as probes - from the progenitors environment to the high redshift universe, Eds. S. Campana, P. D'Avanzo and A. Melandri. Mem. S. A. It. Suppl., **21**, 177-180 (2012).

Ugliano, M., H.-Th. Janka, A. Arcones and A. Marek: Explosion and Remnant systematics of neutrino-driven supernovae for spherically symmetric models. In: Astronomical Society of the Pacific Conference Series, **453**, 91-94 (2012).

Weiss, A.: Helium burning in moderate-mass stars In: Red Giants as Probes of the Structure and Evolution of the Milky Way, Eds. A. Miglio, J. Montalban and A. Noels. Astrophys. Space Sci. Proc., Springer, Heidelberg, 77-86 (2012).

Wongwathanarat, A., H.-Th. Janka and E. Müller: Three-dimensional core-collapse supernova simulations on the Yin-Yang grid. In: Astronomical Society of the Pacific Conference Series, **453**, 95-98 (2012).

Wongwathanarat, A., H.-Th. Janka and E. Müller: 3D core-collapse supernova simulations: neutron star kicks and nickel distribution. In: Death of Massive Stars: Supernovae and Gamma-Ray Bursts. Eds. P. Roming, N. Kawai, and E. Pian, Proc. of the International Astronomical Union, **7**, Cambridge, UK: Cambridge University Press. 150-153 (2012).

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 7.17 and 7.18). `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. Bell: Sydney Magnetic Fields Workshop, (Sydney, Australia, 7.5)

B. Catinella:
– 'The physics of star formation and its role in galaxy evolution' (Trieste, Italy, 17.10.)
– 'Disc galaxy formation in a cosmological context' (Heidelberg, 15.5.)
– 'Global Properties of HI in Galaxies' (Green Bank, WV, USA, 1.4.)

E. Churazov:
– First German ATHENA Science Workshop, (Garching, 13.1.)
– Turbulence in Cosmic Structure Formation, (Tempe, AZ, 5.3. - 8.3.)
– Science with eRosita and ART-XC aboard SRG, (Kazan, 3.9. - 7.9.)
– Saint Petersburg Scientific Forum (Saint Petersburg, 8.10. - 12.10.)
– High Energy Astrophysics, (Moscow, 24.12. - 27.12.)

B. Ciardi:
– 'CosmoBias: International Meeting on Physical Bias in Cosmology" (Marseille, 22.5. - 25.7.)
– 'The Epoch of Reionization: Theory - Simulations - Observations" (Strasbourg, 23.4. - 27.7.)

M. Dijkstra:
– 220th summer AAS, (Anchorage, Alaska, 10.6 - 14.6.)
– 39th Cospar Meeting (Mysore, India, 14.7. - 22.7.)

T. Enßlin: The CTA EBL and cosmology physics case, (Munich, 28.11. - 30.11.)

M. Gilfanov:
– Non-linear waves - 2012 (Nizhnii Novgorod, Russia, 29.2. - 6.3.)
– Annual meeting of the Russian Astronomical Society (Moscow, Russia, 28.5. - 1.6.)
– X-ray sky: from stars and black holes to cosmology (Kazan, Russia, 4.9. - 7.9.)
– 2nd LOFT science meeting (Toulouse, 24.9. - 27.9.)

– The physics of accretion on to BH (Bern, Switzerland, 8.10.-12.10.)
– Observable signatures of stellar evolution (N.Arkhyz, Russia, 15.10.-19.10.)

W. Hillebrandt:
– Facets of Strong-Interaction Physics (Hirschegg, Austria, 15.1. - 21.1.)
– Spring Meeting of the DPG (Göttingen, 27.2. - 2.3.)
– European Week of Astronomy and Space Science (Rome, Italy 1.7 - 6.7.)

H.-Th. Janka:
– Workshop 'Connecting the Electromagnetic and Gravitational Wave Skies in the Era of Advanced LIGO', (Princeton, New Jersey, 30.4.–4.5.)
– 'CompStar: the Physics and Astrophysics of Compact Stars',(Papeete, Tahiti, 4.6. - 8.6.)
– 'Outstanding Problems in Massive Star Research the Final Stages', (St. Paul, MN, 30.9. - 3.10.)
– 'Quarks to Universe in Computational Science (QUCS 2012)', (Nara, Japan, 13.12. - 16.12.)

G. Kauffmann:
– Parameterisation of Galaxies in HI, (Cape Town, South Africa, 20.1. - 2.2.)
– 2012 STScI May Symposium, Gas Flows in Galaxies, (Baltimore, USA, 7.5. - 10.5.)
– European Week of Astrophysics and Space Science , (Rome, Italy, 1.7. - 6.7.)
– Galaxy surveys using Integral Field Spectroscopy (Potsdam, Germany, 10.9. - 13.9.)

E. Komatsu:
– International Workshop on Grand Unified Theories, (Kyoto, 15.3. - 17.3.)
– Astronomische Gesellschaft, (Hamburg, 24.9. - 28.9.)
– From Quantum to Cosmos 5 (Cologne, 9.10. - 12.10.)
– Gravity and Cosmology 2012 (Kyoto, 18.11. - 22.12.)

D. Kruijssen: The current state of cluster formation simulations, (Sexten, Italy, 23.7. - 27.7.)

K. Lind:
– Lithium in the Cosmos (IAP, Paris, 27.2. - 29.2.)
– Gaia-ESO Survey Workshop: Spectrum analysis of FGK stars (OCA, Nice, France, 18.4. - 19.4.)
– XII International Symposium on Nuclei in the Cosmos (Cairns, Australia, 5.8. - 10.8.)
– Large Area Optical Spectroscopic Surveys: Science with 4MOST (AIP, Potsdam, 13.11. - 15.11.)

P. Mazzali: – GRBs and SNe, IAU Symp., (Nikko, Japan, 12.3.-16.3.
– SNe and GRBs, Compact stars, (Tahiti, 4.6.-8.6.)
– SNe Ib/c, SN Conference, (Garching, 10.9.-14.9.)

B. Müller:
– Formations of Compact Objects: from the cradle to the grave (Tokyo, 7.3.-9.3.)
–Supernovae Illuminating the Universe: from Individuals to Population (Garching, 10.9.-14.9.)
–Workshop on Outstanding Problems in Massive Star Research (Minneapolis, 30.9.-3.10.)

E. Müller:
– 'The role of magnetic fields in core collapse supernovae', DPG Spring Meeting, (Stuttgart, 12.3.)
– 'Core Collapse Supernovae: simulations and observable', Workshop on Nuclear Astrophysics, (Russbach, Austria, 11.3. - 17.3.)
– 'Simulation of Nuclear Burning in Astrophysics', EMMI-JINA Workshop, (GSI Darmstadt, 13.10.)
– 'Early mixing in core-collapse supernova ejecta', Conference on Dust in Core-collapse Supernovae near & far: understanding its formation and evolution (Ascona, Switzerland, 5.11. - 8.11.)

Th. Naab:
– Finnish Astronomical Society meeting (Helsinki, 4.6. - 6.6.)
– IAU 2012 (Beijing, China 27.8. - 31.8.)
– Galaxy and Black Hole ISF conference (Jerusalem, 12.10. - 15.10.)

A. J. Ruiter: Supernovae Illuminating the Universe: from Individuals to Populations, (Garching, 10.9. - 14.9.)

Laura Sales: Disc Galaxy Formation in a Cosmological Context, (Heidelberg, 14.5. - 18.5.)

H.C. Spruit: 'Workshop to celebrate the 50-year anniversary of the SHAO' (Shanghai, 27.4.)
– H.C. Spruit: Helioseismology workshop (ISSI Bern, 25.9.)

S. Walch: Triggered star formation, (Crete, 18.6. - 22.6.)

S. White: Conference on New Horizons in Computational Astrophysics, (Davos, Switzerland, ??)

3.4 Colloquia talks

T. W. Baumgarte: Physikalisch-Astronomische Fakultät, Universität Jena, 5.11.

M. Bergemann:
– Case Western Reserve University, USA, 29.6.
– Landessternwarte Heidelberg, 10.4.
– Dr. Karl Remeis-Observatory Bamberg, 22.2.

B. Catinella:
– Leiden Observatory, 22.11.
– ASTRON, Dwingeloo, The Netherlands, 10.09.
– Observatoire de Paris, 8.6.
– Swinburne University of Technology, Melbourne, 31.7.
– Sydney Institute for Astronomy, 27.7.
– CSIRO Astronomy and Space Science, Epping, Sydney, 26.7.
– Contributed talk at the 'Islands in the cosmos' workshop ESO, Garching, 28.11.
– Contributed talk at the 'Gas for cosmology in the nearby Universe' EWASS Symposium Rome, Italy, 3.7.

E. Churazov:
– Astrophysics Colloquium Oxford, 6.2. – Astrophysics Colloquium Lebedev Institute, Moscow, 3.9.

B. Ciardi: Potsdam, Germany, 24.2.

Dijkstra, M.:
– University of Gottingen, 15.3.
– Ramann Institute, Bangalore, India 30.7.
– 'Near Infrared Background and the Epoch of Reionization'-workshop Austin, TX, USA, 14.5.–15.5.

T. Enßlin:
– Universe Cluster Garching, 4.7.
– Technical University Munich, 14.9.
– Stockholm University, 16.10.

M. Gilfanov:
– Amsterdam University, 23.3.
– Pulkovo Observatory, St.Petersburg, 3.12.
– Ioffe Institute, St.Petersburg, 4.12.
– Astrophysical seminar of the Lebedev Physical Institute LPI, Moscow, 12.12.

B.M.B Henriques: Invited Talk Leiden Observatory, 16.5.

J. Johansson:
- MPI for Extraterrestrial Physics, Garching, 20.3.
- Nanjing University, Nanjing, 5.9.
- Shanghai Observatory, Shanghai, 7.9.

G. Kauffmann: MPI of Astronomy, Heidelberg, 12.3.

E. Komatsu:
- Texas A & M Univ., 23.2.
- Institute for Advanced Study, 3.4.
- Academia Sinica, Taipei, 16.7.
- Institut d'Astrophysique de Paris, 9.11.

D. Kruijssen:
- ETH Zürich, Switzerland, 15.5.
- ESTEC/ESA Noordwijk, The Netherlands, 5.10.

Th. Naab:
- Instituto Nazionale di Astrofisica, Trieste 14.3.
- University of Helsinki 30.5.

A. J. Ruiter:
- University of Montreal, 23.3.
- Warsaw University, 16.10.

H.C. Spruit:
- Pontificia Universidad Catolica, Chile, 8.5.
- Colloquium ESO Vitacura, Chile, 11.5.

R. Sunyaev:

S. Walch: ITA Heidelberg, 9.5.

A. Weiss: MPI f. Chemistry, Mainz, 9.5.

S. White:

3.5 Public talks and popular articles

C.L. Bennett, D. Larson, et al. (incl. E. Komatsu): Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Astrophysicla Journal Suppl. 176 p.

M. Bergemann: MPA, Girl's Day, 26.4.

G. Börner: Excellence Cluster Universe, "Kosmologie" Dachau bei Lehrerfortbildung (Dachau, 6.7.)
– *book contribution* Die Entwicklung des Kosmos: Vom Urknall zum komplexen Universum. Nova Acta Leopoldina NF116, **394**, 41-68.

V. Bromm, and T. Greif: Kosmologie: Die ersten Sterne im Universum. Geheimnisvoller Kosmos: Astrophysik und Kosmologie im 21. Jahrhundert. Verlag Weinheim, Wiley-VCH, 150-157.

C. Frenk and S. White: Dark matter and cosmic structure: Annalen der Physik, **524**, 507–534.

H.-Th. Janka: Congress Center Hamburg (19.6.)
- Lehrerakademie Dillingen (19.9.)
- Universität Bochum (27.10.)

R. Kippenhahn, A. Weigert and A. Weiss: Stellar Structure and Evolution. Book, Springer, Heidelberg 604.p

E. Komatsu: Institute for Physical and Mathematics of the Universe, Tokyo, Japan (28.7.)
– Deutsches Museum (22.11.)
– National Museum of Emerging Science and Innovation, Tokyo, Japan (2.12.)

D. Kruijssen: Volkssterrenwacht Bussloo, The Netherlands (21.12.)

Z. Magic: ANITA workshop, Monash Centre for Astrophysics, Melbourne (13.2.)
–Fest of Facts, MSO/ANU, Canberra (18.5.)

B. Müller: Volkssternwarte Winzer (24.3.)
–Astronomie-Club Vilshofen (10.10.)

E. Müller: VHS Garching (26.1.)
– Fachhochschule Rosenheim (25.4.)
– Lehrerfortbildung, Dachau (5.7.)

T. Padmanabhan, B. Schmidt et al. (incl. B. Ciardi): Commission 47: Cosmology (Book) Reports on Astronomy Cambridge, UK, Cambridge University Press, 260-267.

H.C. Spruit: Olbers Gesellschaft Bremen (9.10.)
– Sternfreunde Nordenham (10.10.)

A. Weiss: Ludwig-Maximilians-Universität München (24.5.)

3.6 Lectures

T. Enßlin, SS 2012, LMU München

W. Hillebrandt, WS 2011/2012, TU München

H.-Th. Janka, WS 2011/2012 and SS 2012, TU München

E. Müller, WS11/12 and SS2012, TU München

H. Ritter, WS 12/13, LMU München

A. Weiss, SS 2012, LMU München

Shorter lecture

A. Pawlik: “Cosmological Simulations” (Postdoc/Staff Lecture Series on Cosmology, Garching, 14.11.)

H.C. Spruit: "Astrophysical fluid dynamics and MHD" (Huazhong University of Science and technology, Wuhan, 31.5.–1.6.)

H.C. Spruit: "Physics of jets" (Shanghai Obervatory, 12.4.–15.4.)

R. Sunyaev: Sackler Lecture in Astrophysics, (IAS, Princeton 10.4.)
– Bohdan Paczynki Memorial Colloquium, Nicolaus Copernicus (Astronomical Center, Warsaw, Poland)

S. White: Marsilius-Lecture, Universität Heidelberg

4 Personnel

4.1 Scientific staff members

Directors

W. Hillebrandt (until 28.2.), E. Komatsu (since 1.1.), R. Sunyaev, S.D.M. White (managing director)

Research Group Leader

E. Churazov, B. Ciardi, T. Enßlin, 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 (until 30.9.), A. Bauswein, M. Bell, M. Bergemann, B. Catinella, E. Churazov, F. Ciaraldi-Schoolmann (1.9.-31.12.), B. Ciardi, A. Cooper (until 31.8.), I. Cordero-Carrión, F. De Gasperin (1.9.-31.10.), M. Dijkstra, T. Enßlin, S. Fabello (1.4.-31.8.), J. Fu, M. Gabler, M. Gaspari (since 1.9.), M. Gilfanov, P. Girichidis (since 1.4.), L. Graziani (since 1.4.), T. Greif (until 30.9.), A. Gualandris (until 30.9.), B. Henriques, S. Hilbert (since 1.10.), G. Hütsi, F. Iannuzzi (1.5.-31.8.), H.-T. Janka, A. Jeeson-Daniel (1.3.-31.8.) J. Johansson, O. Just (since 1.7.), G. Kauffmann, R. Khatri, S. Khedekar, J. Kim (since 1.8.), R. Krivonos (until 30.9.), M. Kromer, D. Kruijssen, T.Y. Lam (since 1.9.), K. Lind, G. Lemson, A. Marino (until 31.12.), P. Mazzali, P. Montero, B. Moster, B. Müller, E. Müller, T. Naab, L. Oser (1.8.-31.10.) B. Pandey, A. Pawlik (since 1.9.), D. Prokhorov (since 1.10.), M. Reinecke, G. Ruchti (until 30.9.), A. Ruiter, L. Sales, X. Shi (since 1.10.), V. Silva (until 31.1.), R. Smith (since 1.10.), H.C. Spruit, A. Sternberg, T. Tanaka, S. Taubenberger, M. Ugliano (1.6.-31.10.), M. Viallet (since 1.11.), C. Wagner (since 1.10.), S. Walch, J. Wang (since 1.1.) A. Weiss, A. Wongwathanarat, Z. Zhang (1.1.-31.10.) I. Zhuravleva (until 30.11.)

Ph.D. Students

[1] R. Andrassy*, M. Aumer, P. Baumann, S. Benitez, V. Biffi* (until 31.5.), C.T. Chiang (since 1.9.), A. Chung*, B. Ciambur*, F. Ciaraldi-Schoolmann (until 30.8.), R. D'Souza (since 1.9.), F. De Gasperin (until 30.8.), P. Edelmann, S. Fabello* (until 31.3.), A. Gatto (since 1.6.), L. Graziani* (until 31.3.), F. Hanke, N. Hariharan*, M. Herzog (until 31.10.), M. Hilz (until 31.3.), L. Hüdepohl, C.H. Hu* (since 1.9.), M.L. Huang, F. Ianuzzi* (until 30.4.), A. Jendreieck*, A. Jeeson-Daniel* (until 28.2.), H. Junklewitz, O. Just (until 30.6.), K. Kakiichi* (since 1.9.), F. Koliopanos*, A. Kolodzig*, S. Komarov (since 1.9.), C. Laporte*, M. Li, Z.W. Liu, N. Lyskova*, Z. Magic*, F. Miczek (until 31.5.), M. Molaro* (since 1.9.) U. Nöbauer, D. Oliveira (since 1.11.), N. Oppermann, L. Oser (until 31.7.), E. Pllumbi*, L. Porter*, S. Rau, T. Rembiasz*, M. Sasdelli*, M. Selig, S. Shi (since 1.10.), M. Soraism (since 1.9.), I. Thaler*, M. Ugliano* (until 30.5.), M. van Daalen* (until 31.8.), J. von Groote, M. Wadepuhl (until 31.1.), H. Wei* (since 1.9.), T. Woods*, P. Wullstein (since 1.5.), R. Yates.

[1] *IMPRS Ph.D. Students

Diploma students

L. Chang (since 1.11.), T. Ertl (until 30.11.), M. Gänsler (until 31.12.), M. Greiner (since 1.5.), N. Heners (until 30.5.), M. Klauser (until 31.5.), T. Melson (until 31.12.), B. Röttgers (since 1.1.), A. Schnell (since 1.11.), H. Übler (since 1.9.), A. Voth (since 1.4.), L. Winderling (until 30.9.).

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, F. Matthai (until 30.6.), J. Rachen (until 30.3.), M. Reinecke, T. Riller (until 29.2.)
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.

Associated Scientists:

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

4.1.1 Staff news

Barbara Catinella: Australian Research Council Future Fellowship.

Benedetta Ciardi: W2 position at MPA

Mark Dijkstra: Gauss Visiting Professorship from the University of Göttingen for research for 3 months in 2012.

Michael Gabler: *Universe PhD Award Theory* for the dissertation "Coupled core-crust-magnetosphere oscillations of magnetars".

Wolfgang Hillebrandt: Lodewijk Woltjer Prize Lecture, European Astronomical Society. (Retirement, 28.2.)

Guinevere Kauffmann: elected to the US National Academy of Sciences

Eiichiro Komatsu: *Gruber Cosmology Prize* for the WMAP mission

Ralph Schönrich: received the *Rudolf-Kippenhahn Prize* for the best MPA student publication 2011.

Rashid Sunyaev: Benjamin Franklin Medal in Physics, Franklin Institute, Philadelphia.

4.2 PhD Thesis 2012/Diploma thesis 2012

4.2.1 Ph.D. theses 2012

Alves-Cruz, Monique: S-process in extremely metal-poor stars. Ludwig-Maximilians Universität München.

Biffi, Veronica: Studying the physics of galaxy clusters by simulations and X-ray observations. Ludwig-Maximilians Universität München.

Ciaraldi-Schoolmann, Franco: Modeling delayed detonations of Chandrasekhar-mass white dwarfs. Technische Universität München.

de Gasperin, Francesco: The impact of radio-emitting supermassive black holes on their environment: the LOFAR view of the Virgo cluster. Ludwig-Maximilians Universität München.

Fabello, Silvia: HI properties of massive galaxies from stacking. Quenching mechanisms. Ludwig-Maximilians Universität München.

Graziani, Luca: Cosmological radiative transfer through metals in CRASH. Ludwig-Maximilians Universität München.

Herzog, Matthias: Hydrodynamical simulations of combustion processes at high densities in compact stars. Technische Universität München.

Hilz, Michael: Dissipationless merging and the evolution of early-type galaxies. Ludwig-Maximilians Universität München.

Iannuzzi, Francesca: Simulating structure formation with high precision: numerical techniques, dynamics and the evolution of substructures. Ludwig-Maximilians Universität München.

Jeeson-Daniel, Akila: Effect of inter-galactic medium on the observability of lyman alpha emitters around the epoch of reionization. Ludwig-Maximilians Universität München.

Just, Oliver: Multidimensional, two-moment multi-group neutrino transport and its application to black-hole accretion tori as remnants of neutron-star mergers. Technische Universität München.

Miczek, Fabian: Simulation of low Mach number astrophysical flows. Technische Universität München (submitted).

Oser, Ludwig: Formation and evolution of massive early-type galaxies. Ludwig-Maximilians Universität München.

Ugliano, Marcella: Explosion and remnant systematics of core-collapse supernovae in one dimension. Technische Universität München.

Wadepuhl, Markus: Simulations of the formation of a Milky Way like galaxy. Technische Universität München.

Zhang, Zhongli: Study of populations of low-mass X-ray binaries in elliptical galaxies. Ludwig-Maximilians Universität München.

4.2.2 Diploma theses 2012

Ertl, Thomas: Spherical simulations of stellar core collapse and supernova explosions for systemic exploration of the progenitor-remnant connection. Technische Universität München.

Gänsler, Marc: Eccentricity evolution of hierarchical triples of black holes under Kozai perturbations. Ludwig-Maximilians-Universität München.

Heners, Nikolaus: Uncertainties in stellar evolution calculations due to the treatment of convection. Karlsruher Institut für Technologie.

Klauser, Michael: Mixing of iron group elements in type Ia supernova ejecta and effects on synthetic oservables. Ludwig-Maximilians Universität München.

Melson, Tobias: Core-collapse supernova hydrodynamics on the Yin-Yang grid with PROMETHEUS-VERTEX. Ludwig-Maximilians-Universität München.

Winderling, Lars: On the Theory of Calibration. Ludwig-Maximilians-Universität München.

4.2.3 PhD Thesis (work being undertaken)

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.

Chi-Ting, Chiang:Sparse sampling and position-dependent power spectrum: new and efficient approaches to galaxy redshift surveys and searches for non-Gaussianity. LMU
Survey observations of three-dimensional locations of galaxies are a powerful way to measure the distribution of matter in the universe, which can be used to learn about the nature of dark energy, physics of inflation, etc. Yet, a competitive survey requires a huge volume to be covered, and thus demands many resources. The first part of my thesis is to find a new and efficient method, sparse sampling, for galaxy redshift surveys with limited resources. I shall show that using the observed power spectrum from sparse sampling, one obtains unbiased constraints on cosmological parameters. In the second part of my thesis, I will measure primordial non-Gaussianity in galaxy surveys. Because of the presence of squeezed non-Gaussianity, the power spectrum measured from a local region would depend on the mean density of the local region, and thus becomes position-dependent. If significant amount of primordial squeezed non-Gaussianity is measured, then one can either rule out the single filed inflation model, or needs a non-Bunch-Davis initial condition.

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.

Richard D'Souza: Stellar Halos of Galaxies. LMU
Stellar halos of galaxies provide vital clues about the formation history of the galaxy due to their large relaxation time. In this thesis, we systematically and statistically study the stellar halos of a large number of galaxies in terms of their luminosity, mass and color profiles, metal and abundance ratios, and compare them with simulations.

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.

Thomas Ertl: Progenitor-remnant connection of core-collapse supernovae. TUM
Abstract:I am investigating the progenitor-remnant and progenitor-explosion connection of iron-core supernova progenitor models in a systematic study.The employed modelling approach is based on a calibration of free parameters fitting the observed quantities of supernova 1987A and its progenitor star. My thesis aims at connecting properties of a progenitor star to the most important observable properties of core collapse supernovae.These properties include explosion energy and nickel ejecta mass, in case of a successful explosion, as well as the type of the compact remnant, black hole or neutron star.

Andrea Gatto: The impact of stellar feedback on the formation and evolution of molecular clouds. LMU
Abstract:This thesis is focused on how stellar feedback (winds and Supernovae) affects the physical conditions under which star formation occurs. To study this particular scenario we use massively parallel, three-dimensional simulations with a hydrodynamical, Adaptive Mesh Refinement code (FLASH).

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.

Wei Hao: Supermassive black hole binaries in Galaxy centres. LMU
This thesis is focuses on merging process of black holes in the Galactic centre. To study the merging time scale of supermassive black holes, we carry out direct N-body simulation on GPU to model the

interactions at the galaxy centre and its vicinity. We found Kozai mechanism and other resonances may affectively accelerate the merging process of black hole binaries.

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.

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.

Chia-Yu, Hu: A new star formation recipe for large-scale SPH simulations. LMU
We present a new sub-grid model for star formation in large-scale SPH simulations based on the turbulent nature of interstellar medium. We model the internal density distribution for a gas particle with a log-normal probability function as derived in small scale, high-resolution simulations of driven, supersonic turbulence.

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.

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 astero-seismology 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.

Kakiichi Koki: The high redshift universe: galaxy formation and the IGM. LMU

Abstract: Lyman-alpha and 21cm line contain the wealth of information about the high-redshift universe z>6 when the first galaxies were born and reionized the surrounding intergalactic medium. My thesis concerns with the observability of 21cm signals, for example from high-redshift QSOs, with radio interferometric telescope LOFAR, which may provide further constraints on the epoch of reionization. In order to simulate the 21cm signals from the epoch of reionization, a proper treatment of the radiative transfer of Lyman-alpha line and the thermal history of the IGM as well as reionization process is required.

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.

Shao Li:

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.*

Margherita Molaro: X-ray binaries' contribution to the Galactic ridge X-ray emission. LMU
Abstract: The Galactic ridge X-ray emission (GRXE), together with the cosmic X-ray background (CXB), is one of the two main large-scale extended features of the Galaxy's radiative output in the X-ray band. This apparently diffuse emission has been known to exist for decades, yet its origin remains unexplained. Despite the difficulty in resolving the emission even at present-day instrumental sensitivity, which seems to indicate the GRXE could truly be diffuse, it is believed it should eventually be possible to resolve it into a number of discrete sources. In a current project we make use of a Monte Carlo simulation of the distribution of high mass and low mass X-ray binaries in our Galaxy to study their contribution to this emission.

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.

David Oliveira: Cosmology and Dark Matter Dynamics with a GPU accelerated Tree Code. LMU
Abstract: The emerging computational paradigm of GPGPU - General-purpose computing on graphics processing units, GPUs - allows for unprecedented gains in computation efficiency. We aim to leverage these new computational methods in high resolution simulations probing the nature of Dark Matter in particular, and Cosmology in general, in the context of galaxy formation, and so forth.

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.

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.

Shao Shi: Disk dynamics in live halos. NAOC, China

Abstract: We investigate the dynamical interactions between live stellar disks and their dark matter haloes, using LCDM haloes similar in mass to that of the Milky Way taken from the Aquarius Project (DeBuhr, Ma and White 2012). Disks have been reorientated by the their dark matter haloes throughtout these simulations commonly show strong warps which are mainly regarded as three aspects: (a) Misalignment between the disk and halo. (b) Triaxiality of the halo. (c) Misaligned cosmic infall by substructure. The goal of this project is to understand how stellar disk changes with repect to live dark matter halo and the response of the halo to the disk.

Monika Soraism: Progenitors of Type Ia Supernovae. LMU

Abstract: If the progenitors of type Ia supernovae (SNe Ia) in the single degenerate (SD) scenario are assumed to be in the lower accretion regime, the white dwarf in the progenitor system undergoes novae outbursts. Thereby, a relation could be drawn between the SNe Ia rate and the classical *novae rate. In my project, I am trying to predict the rate of such novae which would undergo type Ia explosions in a particular galaxy. The detection efficiency for such novae with respect to a particular survey in the galaxy is to be estimated for comparison with the actual observations. This result could then be used for constraining the SD scenario from this regime.*

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.

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.

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.

Philipp Wullstein: How does gas follow dark matter? Galaxy-Lyman-alpha-forest cross-correlation as a probe of a coupling between dark matter and dark energy. LMU
What is the nature of dark energy? What is the nature of dark matter? Given our ignorance of their nature, it is entirely possible that these two components, which make up 96universe, are coupled to each other. If so, what would be the signatures of the coupling? Given that gas is not coupled to dark energy or dark matter, the dark energy-dark matter coupling changes the way gas and dark matter halos (in which galaxies reside) follow each other. We shall investigate this by cross-correlating the distribution of galaxies obtained from the Hobby Eberly Telescope Dark Energy Experiment (HETDEX) at a redshift of two and the distribution of gas obtained from Lyman-alpha forest measurements of the Sloan Digital Sky Survey (SDSS) at the same redshift.

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.

4.3 Visiting scientists

Name	home institution	Duration of stay at MPA
Yacine Ali-Haimoud	(IAS Princeton)	5.7. - 9.8.
Monique Alves Cruz	(Univ. Sao Paolo, Brazil)	26.9. - 23.12.
Patricia Arevalo	(Univ. Cat. Chile)	6.2. - 28.2.
		9.7.-3.8.
Maria Celeste Artale	(IAFE, Argentina)	2.5. - 30.10.
Jorge Cuadra	(Univ. Cat. Chile)	6.2. - 28.2.
Thomas Baumgarte	(Bowdoin College, USA)	since 01.08.
Andrey Belyaev	(St. Petersburg, Russia)	16.10. - 20.12
Sergey Blinnikov	(ITEP Moscow, Russia)	17.7. - 4.8.
Julia Bryant	(Sydney University, Australia)	15.8. - 30.8.
Pablo Cerda-Duran	(Valencia, Spain)	25.9. - 30.10.
Yanmei Chen	(Nanjing Univ., China)	1.6.- 30.7.
Dalong Cheng	(Hong Kong University China)	31.10.- 14.11.
Chi-Ting Chiang	(Texas Cosmo Ctr., USA)	11.3. - 24.3.
Ena Choi	(Princeton, USA)	1.3. - 23.3.
Alexandra Crai	(Jacobs Univ. Germany)	1.7. - 26.8.
Rafael de Souza	(Sao Paulo, Brazil)	23.01. - 22.2.
		and 1.5.-23.6.
Santiago Ismael Ferrero	(Cordoba, Argentina)	until 31.1.
Michael Gabler	(University of Valencia)	long-term guest
Jonathan Ganc	(Austin University Texas USA)	29.8. - 8.12.
Giannios Dimitrios	(Princeton, USA)	11.8. - 15.9.
Nicolas Gonzalez-Jimenez	(Univ. Catolica de Chile)	2.3. - 4.6.
Hannes Grimm-Strele	(Technical Univ, Wien, Austria)	1.9. - 31.10.
Carlos Hernandez-Monteagudo	(CEFCA, Spain)	17.6. - 1.7.
Shaun Hotchkiss	(Helsinki Univ.)	30.4. - 13.5.
Nail Inogamov	(IKI Moscow, Russia)	16.7. - 19.8.
		and 12.11.-14.12.
Emille Ishida	(Sao Paulo, Brazil)	23.1. - 22.4.
Ildar Khabibullin	(IKI Moscow, Russia)	24.7. - 26.8.
Baerbel Koribalski	(CSIRO, Australia)	15.4. - 30.4.
Rolf Kudritzki	(Hawaii Univ.)	1.5. - 31.12.
Kerstin Kunze	(Salamanca, Spain)	4.11. - 24.11.
Panos Labropoulos	(Dwingeloo, The Netherlands)	9.4. - 22.4.
Jounghun Lee	(Seoul, South Korea)	18.9. - 17.10.
Cheng Li	(Shanghai Obs. China)	15.6. - 8.7.

Name	home institution	Duration of stay at MPA
Marcelo Miller Bertolami	(La Plata Univ., Argentina)	15.6. - 15.8.
Stefano Mineo	(Cambridge, USA)	1.6. - 15.6.
		and 12.11. - 18.12.
Takashi Moriya	(IPMU, Tokyo, Japan)	10.7. - 31.7.
Dmitrij, Nadyozhin	(ITEP, Moscow, Russia)	22.3. - 21.4.
Atsushi Naruko	(Kyoto University Japan)	4.11. - 18.11.
Ken Nomoto	(Univ. Tokyo)	24.3. - 5.4.
Martin Obergaulinger	(Univ. Valencia)	6.8. - 30.8.
Carlos Pachajoa	(TUM, Munich)	1.8. - 19.10.
Elena Pian	(INAF, Italy)	3.4. - 13.4.
		30.4. - 11.5.
Chris Reynolds	(Maryland, USA)	18.6. - 20.7.
Aditya Rotti	(IUCAA Pune Indien)	10.9. - 31.10.
Sergey Sazonov	(IKI, Moscow, Russia)	6.1. - 3.3.
		and 2.7. - 8.8.
Ralph Schönrich	(Springfiels, USA)	1.11. - 30.11.
Nikolai Shakura	(IKI, Moscow, Russia)	1.11. - 30.11.
Lionel Siess	(Univ. Libre de Bruxelles, Belgium)	1.6. - 31.7.
Kazuyuki Sugimura	(Kyoto University Japan)	04.09. - 9.11.
Brankica Surlan	(ASU, CAS, Czech Republic)	26.11. - 15.12.
Victor Utrobin	(ITEP, Moscow, Russia)	1.9. - 31.10.
Shinya Wanajo	(NAO, Tokyo, Japan)	until 31.3.
Enci Wang	(Shanghai Obs. China)	until 15.2.
Wenting Wang	(Shanghai Obs. China)	untill 30.4.
Lizhi Xie	(NAO, Beijing, China)	1.3. - 31.8.
Wei Zhang	(NAO, Beijing, China)	15.6. - 15.7.