Max-Planck-Institut

für

Astrophysik

Annual Report 2009

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. This structure has now been in place for more than a decade. The Managing Directorship rotates every three years, with Wolfgang Hillebrandt in post for the period 2009-2011. In 2007 Martin Asplund arrived as a new director who will replace Wolfgang Hillebrandt on his retirement in 2012. The institute also has three external Scientific Members: Riccardo Giacconi, Rolf Kudritzki and Werner Tscharnuter.

The MPA was founded as an institute for theoretical astrophysics. Its initial mission was to develop the theoretical concepts needed to understand the structure and evolution of stars, the dynamics of magnetised interstellar media and other hot plasmas, the properties of relativistic particle populations, and the transition probabilities and cross–sections important for astrophysical processes, especially in rarified media. These efforts led to a variety of international collaborations and complemented the observational and instrumental activities carried out in other Max-Planck institutes. Since its foundation, the MPA has also had an emphasis on numerical astrophysics that is unparalleled in any other institution of similar size.

In recent years, activities at the MPA have diversified and now include a wide range of data analysis and interpretation activities as well as purely theoretical or numerical work. Resources are channeled into specific 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 our Milky Way and other galaxies, gravitational lensing, the large-scale structure of the Universe and physical cosmology. Several previous research areas (solar and solar system physics, the quantum chemistry of astrophysical molecules, General Relativity and gravitational wave astronomy) have been substantially reduced over the last decade.

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 by the end of 2011) 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. 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). As a result, 10 posts at the computing centre, including that of its director and several other senior figures, are formally part of the MPA's roster. These posts are managed independently by the computing centre and by its governing bodies in consultation with the MPA. 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

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

During the past ten years the steady growth of MPA's personnel has caused severe problems. There is no longer enough office space available, and the lecture room is now much too small even for the "house seminars", let alone for special events such as the Biermann lectures. To remedy this, the MPG approved in 2009 a new extension building which will not only provide more office space, but also a significantly bigger lecture theatre. The construction work is foreseen to start in 2010 and to be finished around the end of 2011.

Library

The library is a shared facility of the MPA and the MPE. The fact that it has to serve the needs of two institutes with differing research emphases – predominantly theoretical astrophysics at MPA and observational/instrumental astrophysics at the MPE – explains its size. At present the library holds about 23000 books and conference proceedings, as well as about 6500 reports and observatory publications, and it holds subscriptions for about 200 journals and manages online subscriptions for about 400 periodicals. The current holdings occupy about 1900 meters of shelf space. 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 300 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 and links to other online publications. This catalogue and the corresponding catalogues of other MPI libraries on the Garching campus and elsewhere are accessible online via the internet from the library and from every office terminal or PC. Internet access to other bibliographical services, including electronic journals and the SCI, is also provided.

Additional technical services such as several PCs and terminals in the library area, copy machines, a microfiche reader/printer, a colour bookscanner, two laser printers, and a fax machine are available to serve the users' and the librarians' needs.

The "General-Verwaltung" (GV) keeps campus licenses for online electronically accessible journals whereas individual institutes subscribe only to print copies of selected journals at a reduced price. The online journals are accessible via the institute's library homepages. In addition, access to the back files from several large publishers is provided via a national license kept by the Deutsche Forschungsgemeinschaft.

In 2003 the GV launched the "Edoc" system in which all institute publications (MPA and MPE) are archived electronically and made accessible internally from the library homepage. The administration and maintenance of this system is carried out by the library staff (e.g. ca. 900 publications in 2009).

For lack of office space elsewhere in the institute four guest desks with PCs are available in the library's reading hall.

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, "Edoc", and relocation of books), and Mrs. Blank (half time; administration of journals).

Computational facilities

Because of the heavy emphasis on numerical astrophysics at MPA, the provision of suitable computers and network connections is a critical element in achieving the institute's scientific goals. In practice, computing needs are satisfied by providing both extensive in-house computer power and access to the supercomputers and the mass storage facilities at the Max Planck Society's Garching Computer Centre (the RZG) and the Leibniz Computer Centre of the state of Bavaria (the LRZ). Scientists at MPA are also very successful in acquiring additional supercomputing time at various additional computer centers.

The design, usage and development of the MPA computer system is organized by the Computer Executive Committee in close consultation with the system administrators. This group also evaluates user requests concerning resources or system structure. In addition it meets RZG representatives on a regular basis to discuss issues concerning MPA's requirements at the Computer Center Garching (RZG). RZG and MPA coordinate their development plans to ensure continuity in the working environment experienced by the users. Furthermore, MPA participates actively in discussions of potential major investments at the RZG. Common hardware acquisitions by the two institutions are not unusual. Presently, MPA has two Linux-clusters (the larger one with 524 processors, 1088 GB core memory, and 46 TB disk space) and one SGI-Altix (128 Intel Madison processors, 256 GB main memory, 2 TB disk space) system located at RZG. The acquisition of an additional cluster system is scheduled for the end of 2009, consisting of at least 512 Quadcore processors and about 1.5 TB of memory. The most important resources provided by the RZG are parallel supercomputers, PByte mass storage facilities (also for backups), and the gateway to GWIN/Internet.

The philosophy of MPA's computer system is to achieve the following requirements:

- every user has full access to all facilities needed
- scientific necessity is the driver for new acquisitions
- desktop PCs are provided for everyone, running under one operating system (Linux) and a fully transparent file and software system
- full data security due to multiple backups
- highest system security due to choice of operating system and firewalls
- fully redundant resources
- no maintenance or system tasks by users needed

With this approach MPA is achieving virtually uninterrupted, continuous service. Data loss over the past few years is below the detection limit, and duty cycles are well beyond the 99% level. 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, to the larger part are younger than 5 years and which (in 2009) amount to more than 180 fully equipped working places, users have access to central number crunchers (about 20 machines, all 64-bit architecture; with up to 16 processor cores and 64 GB memory), mainly through a batch system. The total on-line data capacity is beyond 400 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. There is an increasing number of scientists who prefer to use their own computer (mostly a laptop) over the institute-provided desktop systems. This necessitates an increasing degree of integration, colliding however with security issues.

The basic operating system is relying on Open-Source software and developments. One MPA system manager is actively participating in the Open-Source 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 three 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.

1.3 2009 at the MPA

Planck satellite: coolest spacecraft ever in orbit around L2!

Since 1999, the MPA has participated in the Planck Surveyor Mission to map the cosmic microwave background. Two of the directors, Simon White and Rashid Sunyaev, are project Co-Investigators. The MPA Planck group was first managed by Matthias Bartelmann until 2003, and since then by Torsten Enßlin. Its role is to provide software infrastructure for the Planck data analysis, namely the Planck simulation package, the ProC workflow engine, and a Data Management Component.

Planck is Europe's first mission to study the relic

Figure 1.1: Left: The Ariane 5 on the launchpad. Right: Around a minute after launch. *Image credits: ESA & Chris North, respectively.*

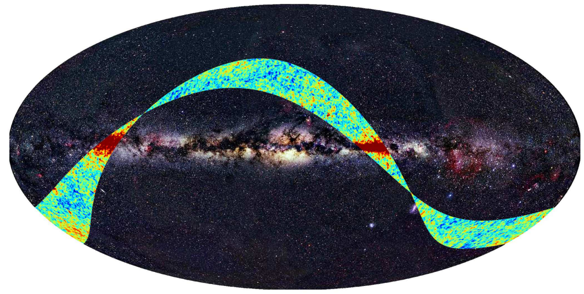

Figure 1.3: First light image of Planck, containing two weeks of data. *Image credit: ESA, LFI and HFI Consortia (Planck); Background image: Axel Mellinger.*

Figure 1.2: Emotional state of a Planck Mission member at the after-launch party. *With friendly permission from Uwe Dörl. Image credit: Torsten Enßlin.*

radiation from the Big Bang. The goal is to map the cosmic microwave background in temperature and polarization in nine frequency bands with an unprecedented combination of accuracy and angular resolution. This will permit a study of structure in this primordial radiation, both in temperature and in polarization, to an accuracy that will allow many cosmological parameters to be determined with percent precision. Planck will test predictions of early universe theories by accurately measuring the power spectrum of the space-time metric perturbations that were seeded during the inflation epoch, thus discriminating between various inflationary scenarios. Planck is the first experiment which has a chance to see the so-called B-modes due to primordial gravitational waves generated during inflation. And of course it will permit a multitude of astrophysical studies of our own Galaxy, visible through radiation from dust and relativistic electrons, of galaxy clusters, visible through the Sunyaev-Zeldovich effect, and of the large-scale structure of the Universe, imprinted via the integrated Sachs-Wolfe effect and gravitational lensing. Thus, Planck will contribute to astrophysics, cosmology and particle physics simultaneously.

After ten years of preparation, and a launch delay of several years, the launch the mission began on May 14^{th} 2009, from the ESA spaceport near Kourou, French Guiana. The local weather was a bit uncertain, but the Ariane 5 carrying the Planck and Herschel satellites took off successfully on the first second of the tight launch window (Fig. 1.1). The relief of all Planck team members at the first broadcast from the satellite at 10:49 is hard to describe, but may be best visualized by inspecting of Fig. 1.2.

It took until mid-August for the instruments to cool down to 0.1 Kelvin, the satellite to reach its position at the second Lagrange point, and the first light survey to start. This survey demonstrated that Planck is working very well, meeting all its performance goals (Fig. 1.3). Since then, routine operations have started and by today (12/11/2009) 72% of the sky is already surveyed. Two complete sky surveys are nominally planned, but more than four may be possible, depending on coolant consumption.

The data analysis is already ongoing, and exciting scientific results can be expected from the mission. MPA will participate in many aspects of the scientific exploitation of this unique data set, from astrophysics to cosmology.

Figure 1.4: KEPLER's launch on March 6, 2009

A long stare at stars

Another important satellite launch took place on March 6, when KEPLER[1], a high-precision photometry space mission started. The satellite flies in an Earth-trailing orbit with a period of 372.5 days and will observe the same star field in the constellation of Cygnus for the next 3.5 years continuously (see Figure 1.5). This field is exceptionally large, 105 square degrees, and contains over 100.000 stars. The telescope has a mirror of 1.4 m diameter and a CCD camera with 95 million pixels, consisting of a mosaic of 42 CCDs. It primarily searches for extra-solar planets by the transit method, where the occultation of a stellar disk by a planet leads to a recurring tiny dimming of the star's brightness.

However, the mission's secondary goal is where the interest of MPA scientists lies. The satellite will also detect and measure small brightness variations of stars, which are due to internal stellar oscillations. They allow to determine stellar properties of stars, such as their mass, age and internal structure. This method of asteroseismology has already been used successfully to learn about our Sun and several other bright stars. With KEPLER more accurate measurements for stars of very different types will deepen our knowledge about stellar struture. Scientists interested in this part of the mission are organized in the KEPLER Asteroseismic Science Consortium (KASC), a US-European group of specialists in asteroseismology.

At the Max-Planck-Institut für Astrophysik Martin Asplund, Achim Weiss, Aldo Serenelli and PhD student Victor Silva are members of KASC. Together with Jerome Ballot (Toulouse) they have successfully submitted a plan for observing stars in two stellar clusters within KEPLER's field of observation. From the analysis of the oscillations the team, and in particular V. Silva, want to learn more about the properties of convective energy transport at the center of stars. Since the Sun does not have such a core, more massive stars have to be observed. Because the stars in a cluster are all of the same age and chemical composition, analyzing many of them allows to determine how convective core properties change with mass, and it is hoped that this will lead to better theoretical models, to be computed at MPA. Convection is one of the biggest uncertainties in stellar evolution theory.

The satellite has already delivered first data and a special issue of ApJ will present first results.

LOFAR's first spectrum

In 2006 the MPA decided to become directly involved in observational radioastronomy through participating in the Low Frequency Array (LOFAR), a Dutch-led project to construct an interferometer at metre wavelengths made up of a very large number of very simple antennas. LOFAR will be the first major telescope where the effective beam is constructed in software during post-processing and it will have much larger computational requirements than traditional radio telescopes. This results in overlap with MPA numerical expertise which complements the project's strong scientific overlap with MPA interests in studying the epoch of reionisation, cosmic magnetism and the evolution of AGN. The MPA is purchasing a remote LOFAR station, a field of antennas which is under construction on 2 hectares of

[1]Kepler is a NASA Discovery mission. NASA's Ames Research Center is the home organization of the Science Principal Investigator and is responsible for the ground system development, mission operations and science data analysis. Kepler mission development is managed by JPL. Ball Aerospace & Technologies Corp., Boulder, Colo., is responsible for developing the Kepler flight system and supporting mission operations.

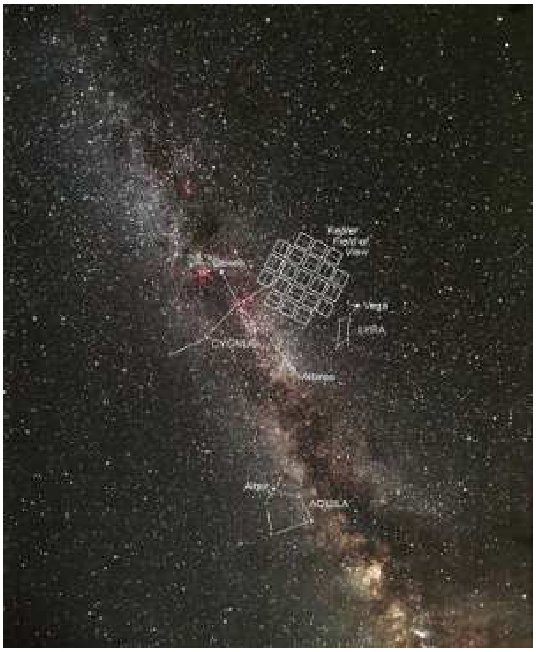

Figure 1.5: Image of the Cygnus region in the Milky Way, overlaid with the constellations of Cygnus, Lyra and Aquila and the CCD mosaic of KEPLER

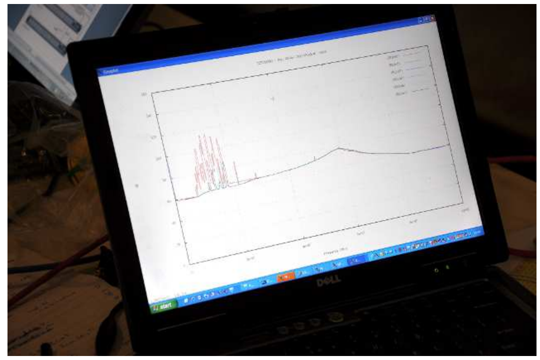

Figure 1.7: LOFAR's first spectrum

Figure 1.8: The GLOW Consortium in front of the MPA

Figure 1.6: The LOFAR low frequency antenna field

agricultural land in a rural area about 50km north of Garching (see Fig. 1.6). This will be one of at least five such stations in Germany and will almost double the north-south resolution of the interferometer. A full set of 96 Low Frequency antennas was assembled in March 2009, and in April the first spectrum from the LBAs was produced (Fig. 1.7). The 96 High-Frequency antennas will follow in spring 2010. The electronics of the LBAs is complete and is connected to Jülich and to the main LOFAR processing centre in Groningen (the Netherlands) and will become active in January 2010. 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. In July 2009 MPA hosted the annual general assembly of the GLOW Consortium (see Fig. 1.8).

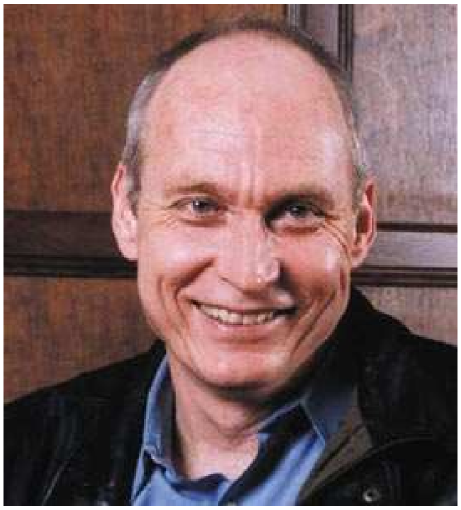

Figure 1.9: Michael Turner (Biermann lecturer 2009)

Figure 1.10: Advertisement walls showing the MPA's astronomy posters at the subway stations of Odensplatz, Universität, and Garching-Hochbrück (picture credit: Andreas Marek, MPA).

Biermann lectures on "Quarks and the Cosmos"

The Biermann Lectures 2009 were presented by Michael Turner from the University of Chicago, a theoretical astrophysicist whose work deals with the earliest moments of the Universe. He also coined the term "dark energy" for the unknown force that is causing the accelerated expansion of the Universe today and showed how quantum fluctuations evolved into the seed perturbations for galaxies during cosmic inflation. As always the lectures were very well attended, only MPE's big lecture theatre offering a barely sufficient number of seats. Also as always, his lecture series offered another opportunity for a "beer and pretzel" party in MPA's backyard in the end.

International Activities

In 2009 the possibility of initiating a more extensive astrophysic collaboration between the MPG and China was initiated under MPA leadership. This may lead to the establishment of a Research Centre in Astrophysics of the University of Science and Technology of China in Hefei, supported by a new national graduate school and with its research programm carried out entirely in collaboration with MPG scientists.

Public Outreach

The public outreach work at the MPA usually encompasses a very broad range of activities. As every year also in 2009 our scientists were involved in educational programs for school teachers, e.g. in connection with the annual General Assembly of the Max Planck Society. They presented public talks as well as lectures to school classes, supervised undergraduates and high school students on small research projects during internships, served as guides for tour groups (including architecture classes) visiting the institute, wrote articles for popular science media, and acted as interview partners for newspaper and television journalists.

The year 2009, however, was a really special one due to the International Year of Astronomy proclaimed by the United Nations in celebration of the 400th anniversaries of the first use of a telescope by the Italian physicist Galileo Galilei to study the wonders of the night sky, and of the publication of the epoch-making book "Astronomia nova" by Johannes Kepler, who shattered mankind's view of the universe by moving the Earth out of the center of the Solar System. Besides its usual outreach activities, some of which were enhanced, MPA therefore also developed and (co)financed a number of special projects:

- On big walls reserved for 10 days first in April than again in October at highly frequented locations in central Munich subway stations (Hauptbahnhof, Marienplatz, Stachus, Odensplatz, Isartor, Universität) as well as in Garching-Hochbrück, astronomy was advertised by large and colorful posters as an old but prospering science with a splendid future (See Figure 1.10.
- MPA's media highlight during 2009 was cer-

Figure 1.11: Opening image of the Co(s)mic "Riding Early Waves" by the Ensslin brothers. The comic strip introduces the physics of the cosmic microwave background by a surfing adventure of two astrophysicists.

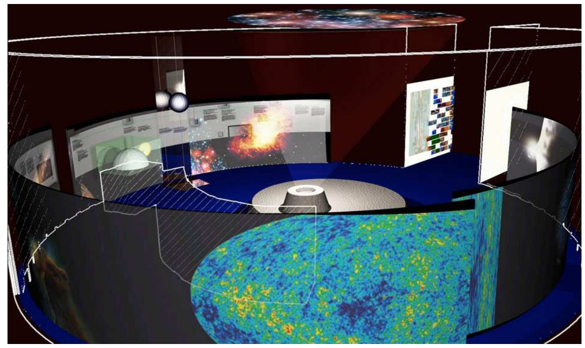

Figure 1.12: Concept of the new cosmology exhibition in the Deutsche Museum Munich viewed from its backward wall with the entrance door to the right. The exhibition takes the visitor on a journey through the evolution of the universe divided into five epochs, starting with its creation in the Big Bang and ending with a glimpse into the distant cosmic future. Credit: Die Werft, München

tainly the successful launch of the **Planck Satellite** on May 14th, followed by its first light on 17th of September. In order to inform everyone about the mission's changing status, MPA created a webpage with the latest headlines, updated regularly between November 2008 and September 2009. By means of a vodcast movie and an interactive comic strip ("co(s)mic") entitled "Riding Early Waves" (see Figure 1.11) and created by the leader of the MPA Planck team, Torsten Ensslin and his brother Jojo, the mission's goals and science were communicated to the general public on paths that broke new grounds for our outreach work. In particular the Co(s)mic has received very wide attention and is a highly innovative idea for bringing astronomical contents to the young generation in an entertaining way.

- In a joint project with the other astronomy institutes of the Max Planck Society, a special issue of the popular astronomy journal "Sterne und Weltraum" was assembled from articles contributed by scientists of all the institutes. Supplemented with class material, the magazine is offered free to high-schools and can be obtained by teachers upon request.

- On the **Girls' Day** in April and for the **Open House** in October, MPA opened its doors to visitors. The available places at the Girls' Day were booked long before the deadline expired, and the Open House also became an enormous crowd puller, attracting more than twice the usual number of guests. Our series of hourly public talks, the Cosmic Cinema and slide presentations, the telescopes for solar observations, our poster shows and astro-consultation corner, and last but not least our kids' lab were overrun by an estimated 3000 adults and children and stressed MPA and the supervising staff to the limits of their capacity.

- On December 9 our outreach activities for the **International Year of Astronomy** reached yet another peak: A new cosmology exhibition on the "Evolution of the Universe, jointly developed and financed by the MPA, MPE, ESO, MPP, and the Excellence Cluster for Fundamental Physics at the TUM and LMU opened its gates for the public. For more than a year a team of scientists and public outreach representatives of the participating institutions, coordinated by Barbara Wankerl of the Excellence Cluster, had worked on a concept for the exhibition, had collected image material and exhibits, written texts, and created several hands-on items to assemble this exhibition in a nearly 100 square meter room provided by the Deutsche Museum in Munich. The realization of the exhibition with the provided material was left at the hands of the professional agency "Die Werft" (See Figure 1.12).

- The MPA is among the sponsors of the **GalileoMobile Project**, a special initiative of the International Year of Astronomy 2009, created and developed by PhD students of

Figure 1.13: Team of the GalileoMobile project

various German Astronomy/Astrophysics institutes. The GalileoMobile Project aimed at bringing the Year of Astronomy to South America by promoting basic science education in schools and communities that have limited access to outreach programs.

The GalileoMobile team traveled for two months across the Andes's Altiplano in the north of Chile, the west of Bolivia, and the South of Peru. This region was chosen for its antique astronomical heritage developed by the pre-Columbian Inca and Tiwanaku civilization, and the clear night sky which is ideal for astronomical observations. The team traveled in two vans and carried along educational and outreach material, and small telescopes for public outreach purposes. The GalileoMobile Project visited around 35 schools, in 20 different cities and villages, reaching close to 3000 children and more than 100 teachers. At each location the team organized hands-on activities for the students to explain basic concepts of astronomy and physics and to stimulate curiosity and critical thinking among the children. When possible, solar and night observations for the students and the entire community were also organized. The teachers were involved in all activities and both professors and students learned how to mount a Galileoscope, that was donated to each school together with other educational material to continue simple science activities in the future.

To ensure sustainability of the project, the GalileoMobile will try to maintain contact with all the schools visited, sending more material and books. For the entire duration of the journey, the team was also accompanied by professional filmmakers who are producing a multilingual documentary of the trip. The documentary will present this original outreach project that combines science education, cultural exchange and traveling, and will be freely distributed in schools and science centers worldwide.

The MPA members that organized this project and still participate in it are: Silvia Bonoli, Victor Silva Aguirre, and Federico Stasyszyn (See Figure 1.13).

More information on these activities can be found on our webpage for the International Year of Astronomy, `http://www.mpa-garching.mpg.de/mpa/institute/news-archives/news-pout//news-out-en.html`.

2 Scientific Highlights

2.1 Mathematics of digital senses: Information Field Theory for signal recognition

The correct interpretation of signals through our senses is not only an essential problem of living creatures, but also of fundamental scientific relevance. Scientists at the Max-Planck-Institute for Astrophysics have shown that mathematical methods from particle physics can be used for developing image reconstruction techniques. These yield optimal results even for incomplete, defective, and distorted data. Information Field Theory, which is used to develop such image reconstruction techniques, provides us with algorithms, i.e. mathematical instructions, for computing complicated perception processes in engineering and science, such as in cosmology.

Human senses like hearing, sight, and touch allow our brain to create a detailed image of our surroundings, even though the human senses are by no means perfect and our field of vision is often limited. Our brain accomplishes this by using its knowledge about the configuration of our surroundings.

Artificial "senses" like cameras, microphones or astronomical telescopes are also not perfect and thus need sophisticated interpretation and the use of additional information. For instance, cosmologists want to precisely measure the distribution of matter in the Universe, but they have the problem that 85 per cent of the matter is invisible. We see the visible matter in form of galaxies, but their light is not always caught by our telescopes. Therefore, the galaxy data only yield an incomplete and noisy image of the cosmic matter distribution. In this example, the signal which we want to reconstruct from the data is the matter distribution.

Since there are a huge number of possible matter distributions, the question is which of them is the correct signal. Unfortunately, the same data could have been created by infinitely many different signals. However, not all of these possibilities are equally plausible. It is, for instance, not very likely that the cosmic matter distribution in the region obscured by our galaxy is completely different from the distribution in the other regions, just because we happen to not be able to observe this region very well. After all, we wouldn't think that a person has three legs just because we cannot see his legs at the time we look at him. That is, we can a priori assign a small probability to exotic signal configurations.

With this in mind, we can ask questions like: Which signal is the most plausible one, given the data and previous knowledge? How large is the uncertainty in this estimate of the signal?

The scientists at the Max-Planck-Institute for Astrophysics have shown that such questions can be formulated as a statistical field theory, the so-called Information Field Theory. The latter is very complex, but thanks to particle physics there exist powerful mathematical tools for handling it. We can, for instance, obtain approximate solutions to our problems by using so-called Feynman diagrams (see Fig. 2.1). These diagrams are graphical descriptions of the data processing steps.

Not all of the resulting algorithms are entirely new. The simplest of the diagrams (Fig. 2.1a) corresponds to the Wiener filter, which has been successfully used for the last 60 years. More complex diagrams (Figs 2.1b&c) can be constructed from the single steps of the Wiener filter, and they allow us to tackle signal recognition problems which are not optimally treated by the Wiener filter. Here, Information Field Theory yields optimal algorithms tailored to the respective signal recognition problem.

The first applications of this new methodology will be in the field of cosmology. Optimal methods for cosmic cartography using galaxy observations, which are supposed to improve existing linear methods, have already been developed.

We can also obtain more accurate insights about the early Universe shortly after the Big Bang using Information Field Theory. We obtain the earliest possible map of the Universe from the cosmic microwave background (CMB). The latter is an image of the hot gas permeating the Universe 380,000 years after the Big Bang. It contains information about the first fractions of a second of our

Universe, when, during the so-called *Inflationary Epoch*, space itself was practically exploding.

The CMB can be measured by satellites like the recently launched Planck Surveyor. But Planck will also measure unwanted signals, which makes it difficult to directly interpret the data. For example, radiation from our own galaxy blocks a part of the CMB sky, and the detectors of the satellites produce unwanted noise in the data. In order to detect the subtle signatures of inflation in the temperature fluctuations in spite of these additional noise signals, Information Field Theory has been used to derive improved analysis techniques (Fig. 2.2).

The utility of Information Field Theory is by no means restricted to cosmology. Imaging techniques inmedicine, geology, and material science could possibly benefit from the theory. Should this happen, it would be one further example of an unexpected spin-off from fundamental research: Methods from mathematical physics, which have been developed for computing very abstract processes in particle physics, would enter medical practices and engineering companies in the form of software. (Torsten Enßlin, Mona Frommert)

Publication: Torsten A. Enßlin, Mona Frommert, Francisco S. Kitaura, *"Information field-theory for cosmological perturbation reconstruction and non-linearsignal analysis"*, Phys. Rev. D 80, 105005 (2009)

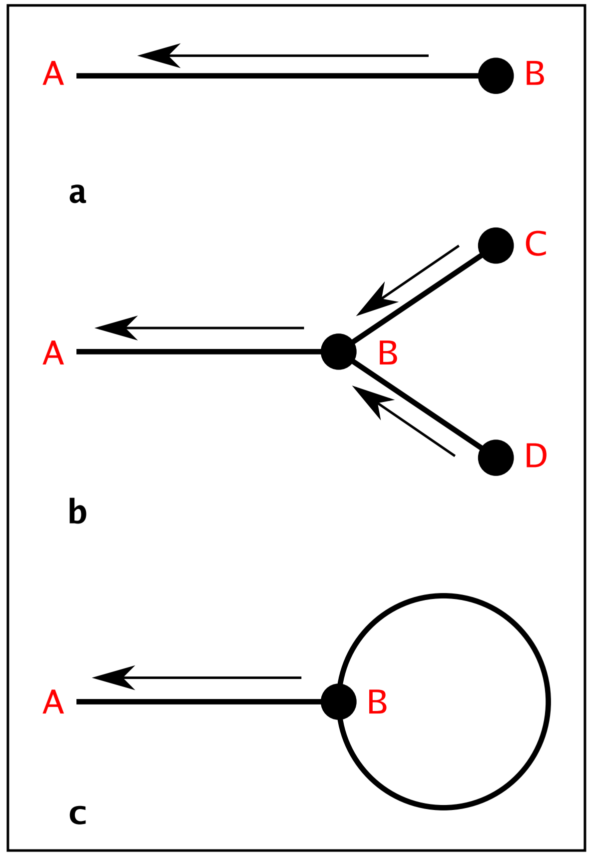

Figure 2.1: The Feynman diagrams consist of points and lines. Points at the end of lines are so-called information sources, i.e. the information about a point in space which is contained in the data (see diagram (a)). Points embedded in several lines stand for data processing steps that combine different pieces of information (see diagram (b)). The lines describe the propagation of information: What does an information source at position B tells us about the signal at position A? Each of the possible diagrams describes a mathematical instruction, an algorithm, which has to be applied to the data. The sum of the results of the respective diagrams yields the desired answer to our problem, e.g. the mean signal given data and previous knowledge.

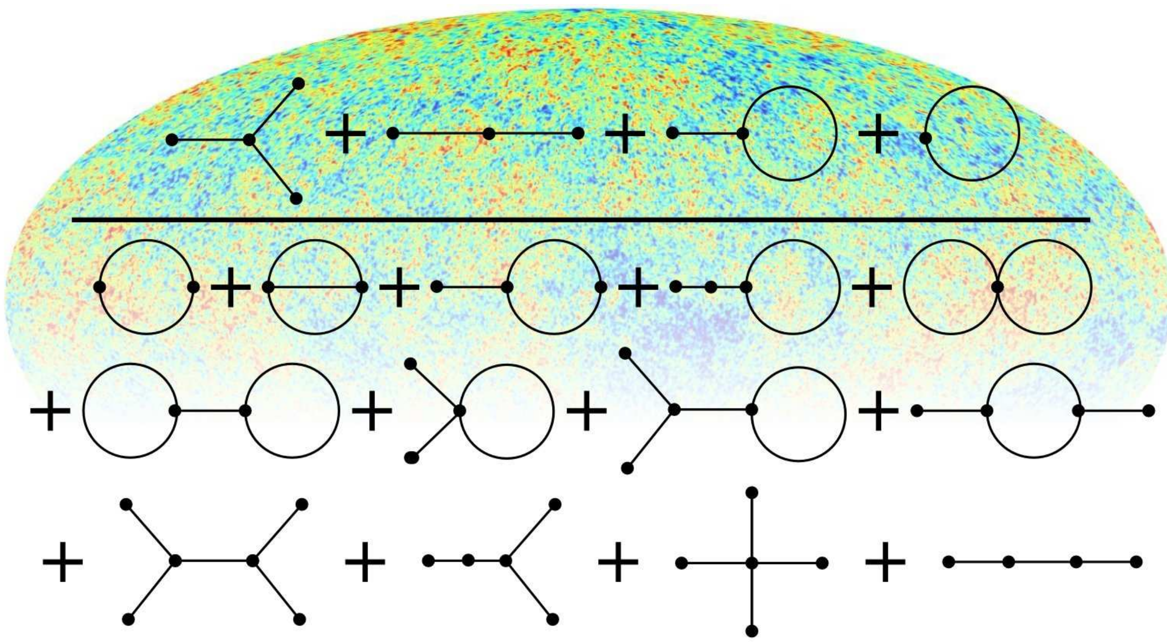

Figure 2.2: Diagrams to determine the deviation of the CMB temperature fluctuations from a normal distribution, which is caused by inflation. The values of the CMB temperature (here encoded in colour) have to pass through the depicted diagrams. The temperature values of every point in the sky are put into the endpoints of every diagram, and are then processed according to the computational prescription given by the diagram. The given combination of the diagrams yields the strength of the statistical deviation, and thus a measurement of a signature of inflation. The numerator of this formula, consisting of four diagrams, is already well-known in a non-diagrammatic form in the technical literature. The denominator, however, which encodes the measurement uncertainty of the method, has only been known in a much cruder form before.

2.2 Quasars in the Early Universe: Smokestacks of the first Cosmic Cities?

Theory and simulations both predict that the highly rare, luminous quasars discovered at $z \sim 6$ (roughly one billion years after the Big Bang) are powered by supermassive black holes in the nuclei of massive galaxies that formed deep inside the gravitational potential wells of the densest regions. Therefore, it has been a longstanding prediction - and widely-used assumption - that the quasars be surrounded by vast numbers of smaller galaxies that trace these dense regions. This prediction is consistent with the fact that the most massive and oldest galaxies and the largest (dormant) black holes in the present-day Universe are found at the centers of massive galaxy clusters. If, however, the prediction is proven to be false, theories of the formation of quasars in the early Universe may have to be revised.

In order to test the theory, attempts have been made to detect faint star-forming galaxies using the Hubble Space Telescope (HST), with mixed results. While the fields surrounding some quasars show a possible excess of galaxies, most quasar fields do not appear any different from random sightlines observed to a similar depth. Also, some studies have found arbitrary regions in the sky that contain structures of galaxies at $z \sim 6$ that substantially outnumber regions near quasars. Thus, it appears that crucial observational evidence relating quasars and overdense regions in the early Universe is currently lacking.

Using the Millennium Run N-body simulations and semi-analytic models, we have simulated a very large region of the early Universe and predicted what a typical HST-based survey of $z \sim 6$ galaxies would detect. This simulated survey, shown in Fig. 2.3, predicts the locations and magnitudes of galaxies and shows how the Universe obtained its characteristic web-like shape as early as $z \sim 6$. This pattern on the sky is analogous to a system of long highways ("filaments") inter-connecting large cities of galaxies between vast open regions ("voids"). Quasars are expected to be hosted by the densest regions seen in Fig. 2.3. However, several important effects combine to explain why the hunt for faint galaxies surrounding quasars is so challenging. First, although current surveys are quite successful at identifying relatively bright galaxies lying roughly at $z \sim 6$, we are not yet able to determine the exact redshifts of these galaxies very

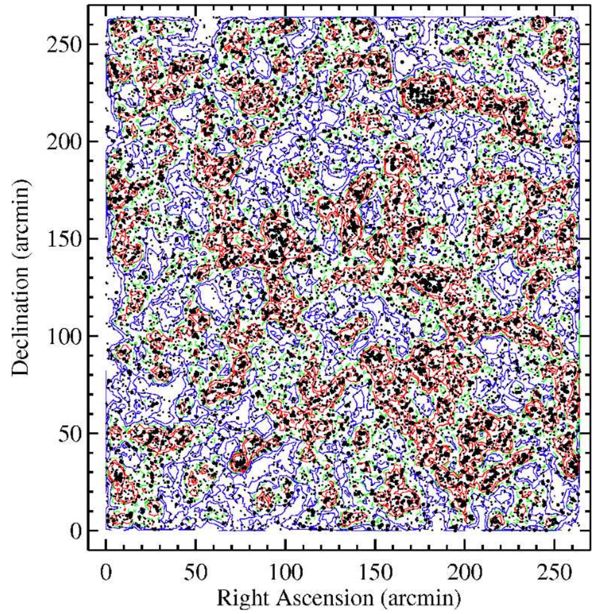

Figure 2.3: The distribution of $z \sim 6$ galaxies on the sky as simulated by the Millennium Run simulations. Contours indicate regions of equal density with over- and underdense regions shown in blue and red, respectively. The mean density is shown in green. Large black circles mark galaxies that end up in galaxy clusters at $z = 0$. These proto-cluster regions stand out as relatively overdense regions already at $z \sim 6$.

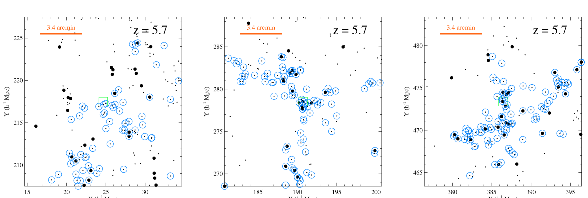

Figure 2.4: Close-up views of three of the richest regions at $z \sim 6$ encountered in the simulations. The green square marks the position of the most massive halo (possibly the quasar). Large and small dots correspond to bright and faint galaxies, respectively. The scale bar at the top left in each panel corresponds to the size of an HST/ACS pointing similar to that used to observe real $z \sim 6$ quasars. Blue circles identify galaxies that will become part of a massive galaxy cluster in the present-day Universe.

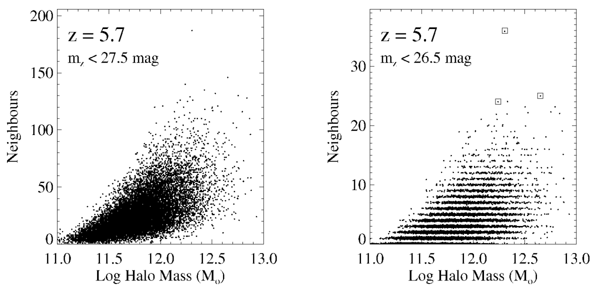

Figure 2.5: The number of companion galaxies in cubic regions of (20 Mpc/h)^3 versus the mass of the most massive halo in each region. The panel on the left shows the results for faint galaxies (27.5 mag), while the panel on the right shows the results for brighter galaxies (26.5 mag). Although at $z \sim 6$ there is a large scatter in the number of companions per halo mass, the most massive halos tend to have the most companions. The scatter reduces when going to fainter magnitudes (left panel). The small squares in the right-hand panel correspond to the three regions shown in Fig. 2.4.

efficiently. In order to prove a physical association between galaxies and the target quasars (of which the redshifts are known), much more precise redshift information would be required. Second, the simulations suggest that the sensitivity and covered area of the surveys performed to date may not be optimal for finding structures of galaxies associated with the quasars. In Fig. 2.4 we show some examples of high density regions found in the simulations. The large black circles indicate the faintest galaxies that can currently be detected in quasar fields. The red bar at the top left corresponds to the diameter of the HST/ACS field-of-view (3.4 arcmin). Because the number of bright galaxies is relatively small and they scatter over an area typically two or three times larger, it is easy to miss any structures, if present, in the observations. By observing fainter galaxies (small dots in Fig. 2.4) the large-scale environments stand out much more clearly making them more easy to detect. Third, we have analysed the number of companion galaxies as a function of the mass of dark matter halos assumed to be hosting the quasars, finding that the two quantities are only mildly correlated (Fig. 2.5). This implies that even if it can be shown through observations that quasars are preferably located in overdense regions, it will be very difficult to determine the exact mass of the quasar halo from the number of companion galaxies observed.

Thanks to the success of the recent NASA HST Servicing Mission, the newly repaired HST will be able to perform new surveys that could target larger regions around the $z \sim 6$ quasars. Alternatively, ground based telescopes should be used in order to determine the exact redshifts of faint galaxies near quasars by targeting the Lyα emission line. Such studies are best performed by targeting quasars at $z \approx 5.7$, corresponding to a good atmospheric transmission window. In the next decade, the James Webb Space Telescope, with its sensitive near-infrared camera and spectrograph able to detect extremely faint galaxies, should be able to provide a definitive answer to the question of whether the luminous quasars formed inside the densest regions in the early Universe (Roderik Overzier).

2.3 Mapping extragalactic dark matter structures through gamma-rays

Although dark matter accounts for most of the matter in the Universe, its nature remains unknown. So far the presence of dark matter has only been inferred through its gravitational effects. However, if dark matter is made of neutralinos, a new particle predicted by Supersymmetry, it would also interact, although very weakly, with ordinary matter, and it might be detected soon in laboratories on Earth. In addition, neutralinos, being Majorana fermions, can self-annihilate to produce ordinary particles like positrons, neutrinos and gamma-ray photons. If these byproducts of the annihilation are copious enough, they could be detected by satellites such as FERMI, which has been mapping the gamma-ray sky since mid 2008.

This gamma-ray radiation is produced most abundantly in high density regions. Thus, it seems best to look for it in very dense nearby regions, such as the centre of our own Galaxy and/or the centres of its satellite galaxies. Actually, it turns out that the best prospects for the detection of gamma-rays from our Galaxy are obtained by looking slightly off-centre to avoid confusion of the signal with other sources of gamma rays residing at the Galactic centre.

However, outside of the Galactic halo, gamma-rays are also produced in large quantities by the annihilation of dark matter in all the many haloes and subhaloes within our past light-cone, contributing to the so-called extragalactic gamma-ray background (EGB) radiation. Although the EGB also receives contributions from other sources, such as blazars and cosmic rays accelerated at structure formation shocks, the energy spectrum and angular power spectrum of the annihilation radiation have distinctive features that may open up effective ways for disentangling the signal. Therefore, a detailed analysis of the EGB is a viable possibility for detecting dark matter.

In a recent study, Jesús Zavala, Volker Springel and Michael Boylan-Kolchin used the state-of-the-art Millennium-II simulation (an MPA project) to generate all-sky maps of the contribution of dark matter annihilation to the EGB radiation. A special map-making procedure was developed that recreates the past light cone of a fiducial galactic observer, taking into account the gamma-ray luminosity of all numerically resolved haloes and their subhaloes. See Figure 2.6 The method also includes corrections for unresolved components of the emission as well as an extrapolation to the minimum mass for bound neutralino dark matter haloes. The angular resolution of the created maps was chosen to be close to that of FERMI, approximately 0.115deg.

It was found that for most of the relevant energy range (0.1-30 GeV), the signal comes mainly from sources up to redshifts $z \sim 2$. In the most optimistic scenario considered, the energy spectrum of the isotropic component of the background radiation lies approximately one order of magnitude below the values of the EGB measured by the telescope EGRET (predecessor of FERMI) in the energy range 1-20 GeV, where an apparent excess of gamma-rays had led to speculations of a possible origin in dark matter annihilations. Preliminary results by FERMI seem to refute such an excess. If this is indeed confirmed, the results of the MPA-team could help to put constraints on the dark matter annihilation processes including some mechanisms which have been proposed and that effectively enhance the annihilation rate, such as the presence of highly dense "spikes" of dark matter formed around intermediate-mass black holes (with masses between a hundred and a million solar masses), or the so-called Sommerfeld enhancement, a quantum-mechanical focusing effect that increases the annihilation cross section.

The MPA-team also studied the anisotropic component of the EGB by computing the angular power spectrum of the simulated maps. This yielded specific predictions for the shape of the power spectrum, which can potentially be used to discriminate against other sources of gamma-rays because the annihilation signal depends in a specific and unique way on the large-scale distribution of haloes, on the distribution of subhaloes within haloes, and on the abundance and internal structure of haloes as a function of time. Also, the shape of the power spectrum was found to depend on the energy of the observations. Interestingly, these differences can be exploited to construct "color" maps that enhance the signal of nearby dark matter structures, akin to hardness ratio maps in X-ray observations. For example, the MPA scientists found that taking the ratio of the maps at energies of 0.1 GeV and 32 GeV greatly enhances the contrast of local dark matter structures, making them clearly visible in the gamma-ray sky. See Figure 2.7 If strong spectral features in the rest-frame emission spectrum of the annihilation radiation are present, this could be especially powerful, perhaps even allowing tomographic observations of dark matter structures (J. Zavala, V. Springel and M. Boylan-Kolchin).

2.4 The surprising solar chemical composition

The solar chemical composition is an important ingredient in our understanding of the formation, structure and evolution of both the Sun and our solar system. The Sun also functions as an astronomical yardstick against which the compositions of all other stars, nebulae and galaxies are referenced. Rather than being constant, as any good ruler should be, however, this elemental abundance scale has in the past few years undergone a substantial revision based on improved modeling of the solar surface layers and the emitted solar spectrum pioneered by MPA scientists.

The chemical composition of a star like the Sun is inferred from its spectrum, which provides the elemental fingerprint in the form of absorption lines. To convert the strength of a spectral line to an elemental abundance requires detailed modeling of the stellar atmosphere and the processes between atoms and radiation that shape the emergent solar spectrum. A major complication here comes from convection, which reaches up to the surface in the Sun and thereby modifies the atmospheric structure and spectrum formation. Instead of the traditional one-dimensional (1D) and hydrostatic modeling, we have employed a 3D, hydrodynamical solar model atmosphere in which the convective energy transport is self-consistently treated together with the interaction between the radiation field and the gas, including the effects of line-blanketing. Our 3D solar model has been confronted with a raft of observational diagnostics and passed all with flying colours, as shown for example in Fig. 2.8. In all

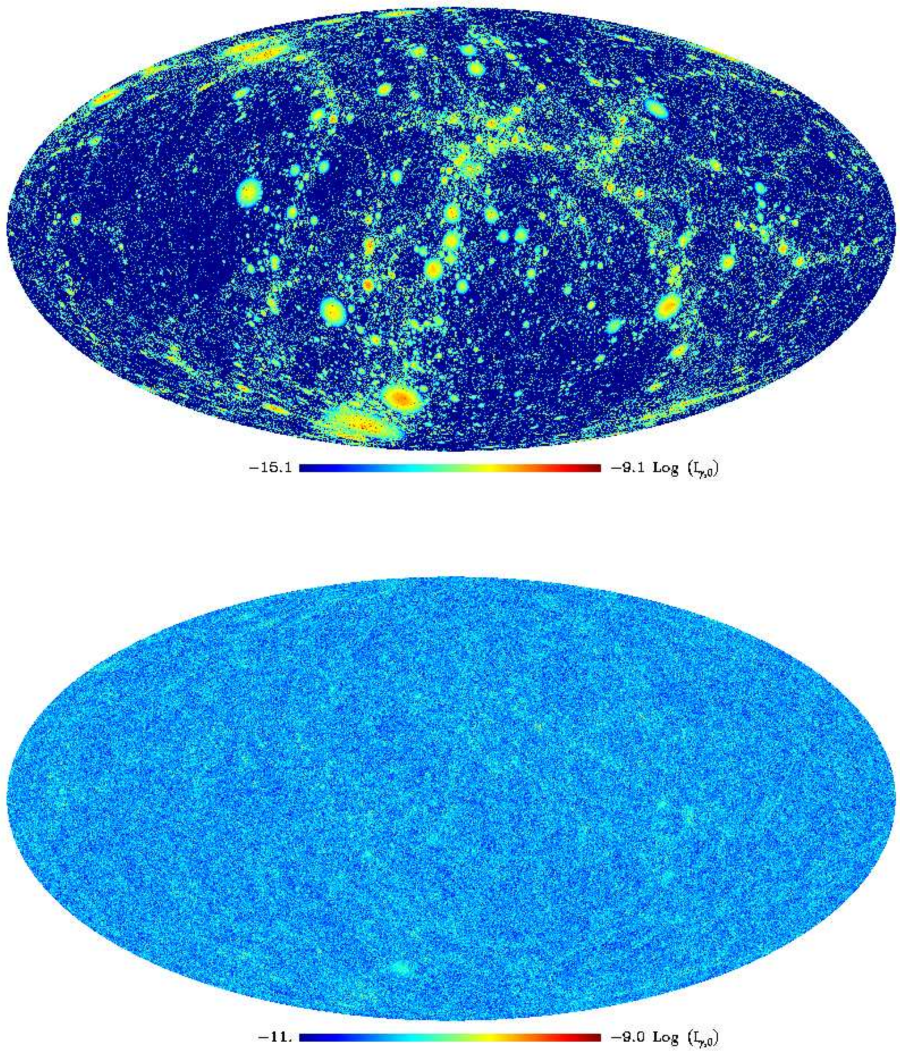

Figure 2.6: *Upper panel:* A partial map showing the extragalactic gamma-ray background produced by dark matter annihilation in nearby structures. Only sources within 68 Mpc from an observer, randomly located in the simulation box, are considered for the map. The color scale gives a visual impression of the values of the specific gamma-ray intensity for each pixel in the map; the red color corresponds to the highest values of specific intensity. The observed energy of the simulated gamma-ray radiation is 10 GeV. *Lower panel:* The full gamma-ray sky map from dark matter annihilation containing sources up to $z \sim 10$. The gamma-ray luminosity of dominant nearby haloes clearly appearing in the map of the upper panel is outshined by a smoother radiation produced by distant haloes, effectively emitting as point sources. In both maps only the contribution of the smallest haloes resolved by the simulation (one billion solar masses) has been taken into account.

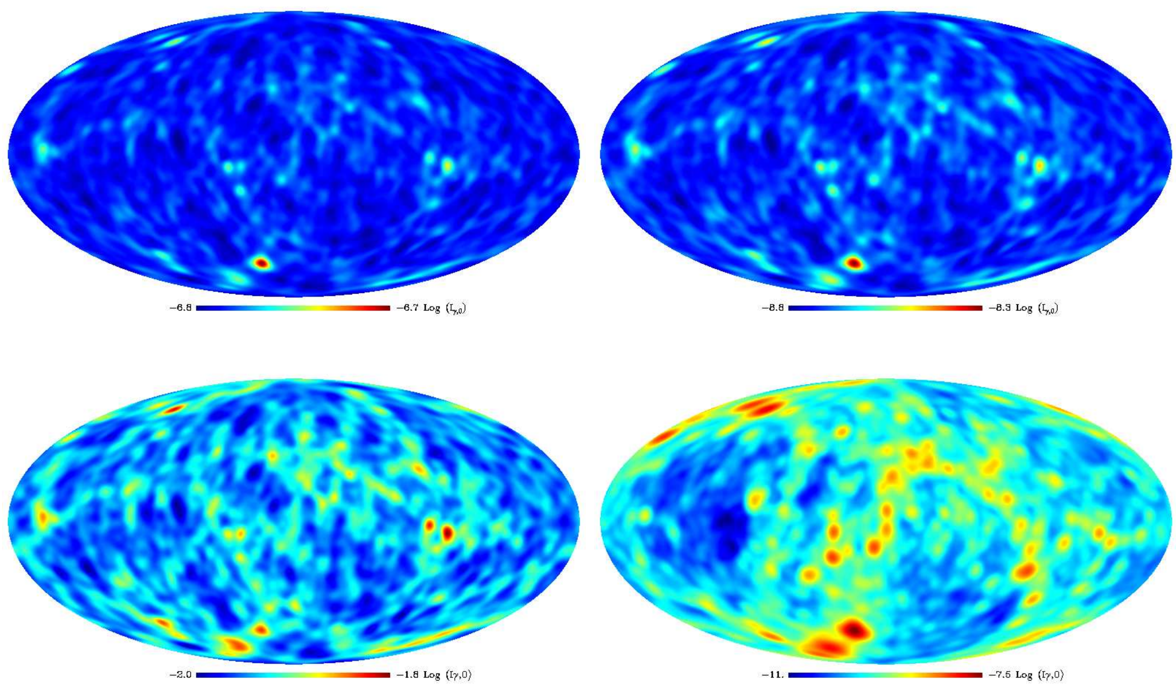

Figure 2.7: *Upper panel:* Full-sky maps at energies 0.1 GeV and 32 GeV in the left and right, respectively. The maps were smoothed with a Gaussian beam with a FWHM of 5 deg. At a single energy, a full-sky map is very smooth, nearby structures are only minimally visible. *Lower panel:* Ratio of the maps in the upper panel (left) and a partial map containing only nearby structures within 68 Mpc for an observed energy of 0.1 GeV (right). Creating difference maps ("color" maps) using different energy channels greatly enhances the signal of nearby structures.

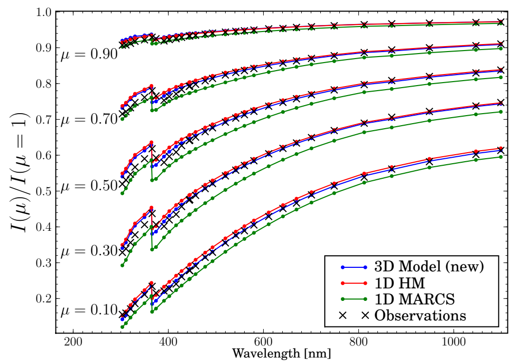

Figure 2.8: Comparison of the predicted continuum center-to-limb variation for different solar model atmospheres against observations. The results for five different viewing angles μ are shown from near disk center ($\mu = 0.9$) to close to the limb ($\mu = 0.1$). Our 3D model agrees extremely well with observations and outperforms all investigated 1D models.

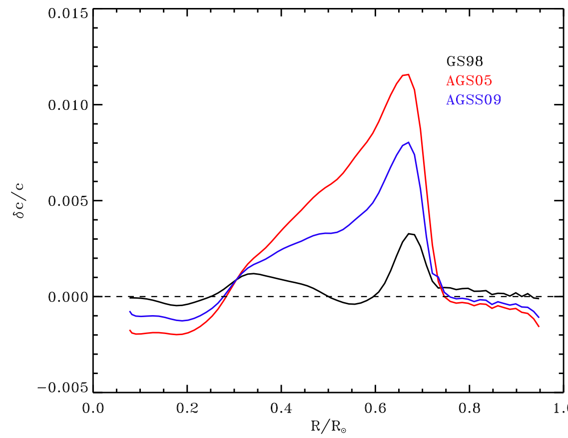

Figure 2.9: The differences between the helioseismic and predicted sound speeds c_s as a function of depth for solar interior models computed with different surface chemical compositions: our new solar abundances presented in Asplund et al. (2009), our preliminary values given in Asplund et al. (2005) and the canonical values from a decade ago (Grevesse & Sauval 1998). The base of the convection zone is at $R = 0.71 R_\odot$.

respects, our model is a very realistic description of the solar photosphere.

Equipped with this new generation of 3D solar model, we have embarked on a complete reanalysis of the solar chemical composition by means of 3D spectral line formation calculations. In addition we have taken into account departures from local thermodynamic equilibrium in the radiative transfer whenever possible. Considerable time has also been spent scouring for the best possible atomic and molecular data necessary for the analysis as well as a careful consideration of all available spectral lines in order to only retain the most trustworthy abundance indicators. All in all new solar abundances of 68 elements have been determined, indeed for every element accessible through solar spectroscopy. Finally we have attempted to quantitatively assess the remaining statistical and systematic uncertainties. The end result is a comprehensive and homogeneous compilation of the solar elemental abundances, which has previously never been achieved. This ambitious analysis has been summarized in an article in Annual Reviews of Astronomy and Astrophysics that appeared in 2009.

Together, these improved analysis ingredients add up to almost half the derived solar abundances of carbon, nitrogen, oxygen, and neon compared with the canonical values from a decade ago. This revision is particularly noteworthy given that these are the four most abundant elements next to hydrogen and helium. The new results seem highly robust as molecular lines and atomic transitions arising from different excitation levels having vastly varying sensitivities to the atmospheric conditions point to the same abundances. For example, for the crucial element O, the high excitation permitted O I, the low excitation forbidden [O I] lines and the infrared vibration and rotation lines of OH all agree essentially perfectly. It is important to stress that the employment of a 3D model, non-LTE effects and improved atomic data all play important roles in the downward revision of the solar abundances. The 3D line formation calculations have been thoroughly tested against new high spectral and spatial resolutions observations taken with the Swedish Solar Telescope on La Palma, Canary Islands, for different center-to-limb positions.

The new solar abundance scale is also supported by a comparison with the solar neighborhood. One long-standing conundrum has been why the Sun that was born 4.5 Gyr ago contained much more heavy elements than the present-day interstellar medium and OB stars in the Galactic neighborhood. The overall content of heavy elements in the Milky Way should steadily increase with time as stars die and spew out their nuclear-processed ashes from which subsequent stellar generations are formed. The revised lower solar content of C, N, and O has finally brought the Sun into line with its surroundings.

Everything is however not rosy with the new solar abundances. The lower content of heavy elements reduces the opacity, thus requiring changes to the computed temperature and density as a function of depth in models of the solar interior. With helioseismology it is possible to map the variation of sound speed with depth from measuring the exact frequencies of the different oscillation modes. Unfortunately, the inferred sound speed is inconsistent with the predicted values from interior models constructed with the new solar chemical composition, as shown in Fig. 2.9. The situation has slightly improved compared to a few years ago using the preliminary solar abundances we had derived with a older, less realistic 3D solar model. Ironically the agreement with helioseismology was much better when relying on the old canonical solar chemical composition.

A large number of possible solutions has been proposed but to date there has been no convincing explanation for this discrepancy with helioseismology. The most obvious panacea would be underestimated opacities by $\sim 15\%$ immediately below the convection zone where the temperatures are $2-5\cdot 10^6\,$K, although atomic physicists argue that their existing opacity calculations are unlikely to be wrong by so much. A promising suggestion is the effects of internal gravity waves modifying the structure immediately below the convection zone but detailed modelling is still lacking. It is important to emphasize that this is not a restricted solar problem but indeed affects stellar astrophysics in general: either it implies that we do not understand the interior workings of even relatively benign stars like the Sun or the new 3D atmospheric and spectroscopic modelling pioneered by the MPA group is untrustworthy for whatever reason in spite of the multitude of observational tests it has been confronted with. Whatever the final resolution, the implications for astronomy will be major. Much work by various groups around the world is currently being devoted to resolving this so-called solar modelling crisis.

Further insight to the Sun's chemical composition can be obtained by a comparison with other stars in the solar neighborhood. We have performed such a study of the Sun and seemingly identical stars, which has revealed some surprising chemical differences with far-reaching implications for planet formation. We have performed a strictly line-by-line differential analysis of some 80 stars all closely resembling the Sun in terms of their effective temperatures, surface gravities and overall metallicities using high quality spectra ($\lambda/\Delta\lambda > 50000$, $S/N > 300$) obtained with the Magellan, Keck and McDonald telescopes. The combination of excellent observations and the differential approach has enabled us to reach unprecedented precision in the derived elemental abundances, in many cases $\sigma < 0.01\,$dex. While the targets were initially selected to be chemically indistinguishable from the Sun, a closer inspection has revealed that the Sun is unusual albeit not unique: only $10-20\%$ of stars share the Sun's detailed abundance pattern. Strikingly, for the majority of stars, the abundance differences correlate extremely strongly with the dust condensation temperature of the element $T_{\rm dust}$, as illustrated in Fig. 2.10.

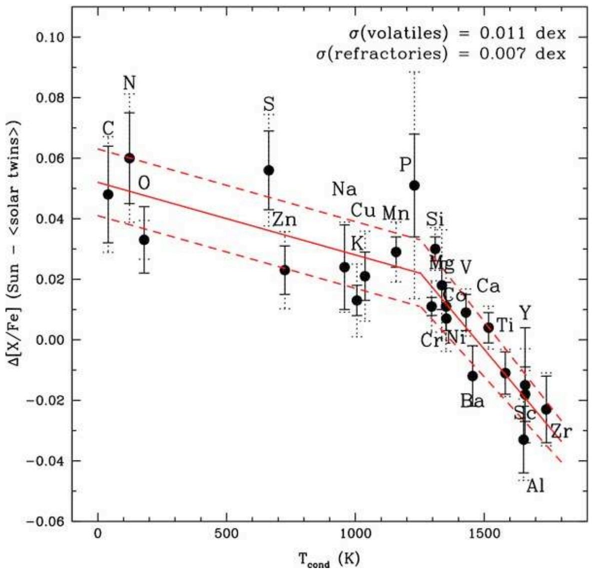

Figure 2.10: The differences between [X/Fe] of the Sun and the mean values in 11 solar twins as a function of dust condensation temperature $T_{\rm dust}$ (Meléndez et al. 2009). Note that the volatile elements would appear normal (Δ[X/Fe]≈ 0.00) while the refractories more depleted had we selected say C as reference element rather than Fe.

We interpret the observed abundance differences as a direct result of the Sun having planets, indeed terrestrial planets. During the early phases of the solar system, the most refractory elements (high $T_{\rm dust}$) condensed into dust, which eventually congregated to planetesimals and later planets. The left-over gas rich in volatile elements (low $T_{\rm dust}$) continued being accreted onto the (proto-)Sun. For whatever reason, for the majority of the solar twins and analogs we studied, the dust condensation and by extension planet formation did not proceed as efficiently as for the Sun. In other words, the specific abundance patterns of stars may signal which harbour planets. The relatively high temperature of the break in the abundance differences ($T_{\rm dust} > 1000\,$K) suggests that they are imprinted by the formation of terrestrial planets rather than giant planets. Indeed, the required material to produce the abundance difference in the Sun are within a factor of a few of the total amount of refractory elements locked up in Mercury, Venus, Earth and Mars. Our study opens up the truly enthralling prospect of identifying stars having terrestrial planets purely from a detailed inspection of the stars' chemical composition. We are currently pursuing this using new UVES/VLT observations of stars being followed by traditional radial velocity monitoring. (Martin Asplund, Ivan Ramírez and Aldo Serenelli)

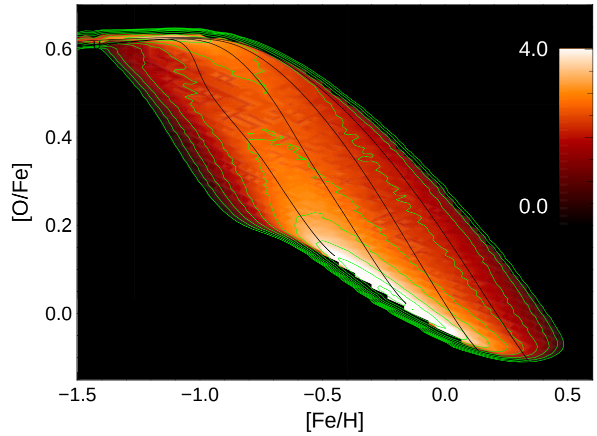

Figure 2.11: Logarithmic probability of stars in the abundance plane of our Galactic chemical evolution model with radial migration. Contours show a 0.5 dex spacing. Clearly visible are the two ridges at high and at low [O/Fe], attributable to the thin and thick disc. Black lines depict the development of the interstellar medium at (from left to right) galactocentric distances of 10, 7.5, 5 and 2.5 kpc

2.5 Challenging the Galactic history

Throughout the history of Galactic astronomy researchers have been struggling with two questions: What is the structure of the Milky Way? And more important: What is its history? While archaeologists have to search for relics from the past, for the astronomer the sky is full of them: main sequence or little evolved stars in the lower mass range basically preserve the abundance composition of the gas clouds from which they were born, back to the earliest times. On the other hand higher mass stars, which live for short timescales, eject their nucleosynthesis products into the interstellar medium, enriching the material from which new stars can form. By comparing the measured abundances to theoretical expectations it should in principle be possible to understand the chemical history of the Galaxy and possibly even conclude where and when a single star was born.

Models that explore the history of the Galaxy with its successive enrichment were pioneered in the 1960s and since then refined in their prescriptions. It was recognized that not only the overall metal content of the interstellar medium should rise in time, but that the abundance ratios can set a natural clock: Shortly after onset of star formation the most massive objects explode as supernovae type II, freeing large amounts of heavy elements and among them mainly the "alpha" elements, like O, Mg or Ca. Most of the iron will be produced significantly later by supernovae of type Ia, which are explosions of white dwarfs. So the ratio of alpha elements to iron in a star allows to conclude how long star formation had taken place, when the star was formed: Young stars have a lower abundance of alpha-elements relative to iron, while it is higher in old stars.

Chemistry is not the only source that teaches us about Galactic history. Stellar populations still have distinct spatial distributions and kinematics related to their origin. However, there is one common assumption to all classical chemical evolution models: The Galaxy is separated into concentric rings, which are assumed to evolve independently from each other, so there is no exchange of model stars between different galactocentric radii, while kinematics are in most cases not traced.

A collaboration from MPA and the University of Oxford developed the first chemical evolution model that allows for significant exchange across the Galaxy, i.e. for radial migration of stars and radial flows of gas, and keeps track of the kinematics of all stellar populations. While the intensity of these exchanges across the Galactic disc was estimated exclusively from the metallicity distribution of the solar neighbourhood, its inclusion enabled the model to explain all known links of chemistry and kinematics. The colour scale in 2.11 shows the abundance pattern of our Galactic chemical evolution model - the logarithmic densities in the abundance plane are shown by green contours and colours in units of dex. Like in most observations there are two denser regions - one at high [O/Fe] and one at low [O/Fe], which we assign to the older "thick" and younger "thin" disc components. The researchers from MPA and the University of Oxford could show that by the inclusion of radial migration the observed chemical pattern is fully re-

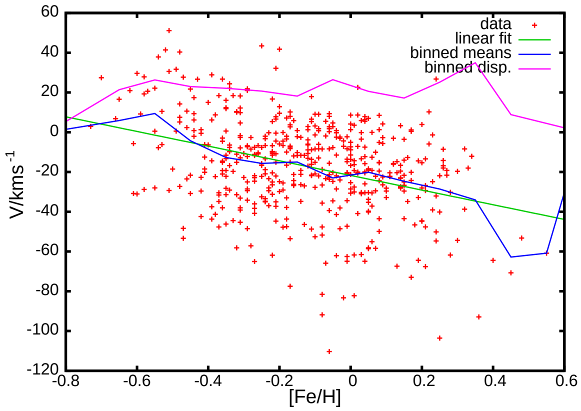

Figure 2.12: Rotational velocities vs. metallicities of thin disc stars, selected for [Mg/Fe] < 0.18, in the compiled dataset of Borkova & Marsakov (2005). The blue line gives the means, binned in [Fe/H] and the green line is a linear regression. The purple line shows the rotational velocity dispersions.

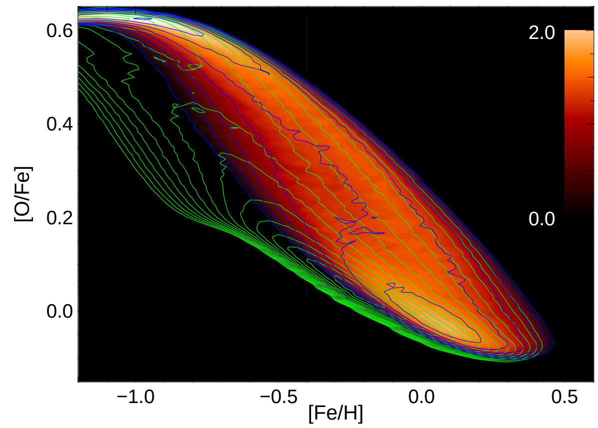

Figure 2.13: Densities in the abundance plane of our model in dex with green contours. Blue contours along with the reddish colour scale show the density of stars that have been kinematically selected into the thick disc. Also note that the thick disc nicely joins the thin disc ridge around solar metallicity ([Fe/H] ~ 0) as it has been observed. Contour spacing is 0.3 dex.

produced and does not require any bimodality in the star formation history is not required.

Radial migration changes the chemical evolution history derived for the Galactic disc. In 2.11 the trajectories of the interstellar medium in metallicity space run by no means parallel to the density ridge of young, thin disc stars at low [O/Fe]. It rather connects their endpoints. The ridge is formed by stars, which migrate to the solar neighbourhood, and so in contrast to classical approaches the dynamic model does not have to follow the density ridges.

Can it be decided, which view is right? Kinematics is in this respect very helpful. If the chemical evolution followed the density ridges, we would have to expect two findings that contrast with our model: In the classical picture the metal-poor side of the thin disc ridge is occupied by older stars, which have by their age higher velocity dispersions. On the other hand our model demands a significant downtrend of velocity with increasing metallicity, since the metal-rich populations still have a tendency to reside on average inside the Sun. Spectroscopic data of thin disc stars, as seen in 2.12, give a clear indication, showing no trend in dispersion with metallicity, but a highly significant downtrend in mean rotational velocity.

Not only model histories have to be revisited, but our understanding for the origin of the disc itself, in particular of the thick disc component. In 1982 Gilmore and Reid found that the vertical structure of the Milky Way disc can be matched by a sum of two exponentials. Later measurements on larger samples confirmed this structure, which suggests the Milky Way disc to consist of two separate components - a relatively young thin (scaleheight $\sim 300\,\mathrm{kpc}$) and an old thick (scaleheight $\sim 900\,\mathrm{kpc}$) disc. It was shown that the two components display distinct chemistry, when kinematically preselected, the thick disc being more metal-rich at the same [α/Fe]. This was commonly interpreted as proof for some catastrophic event in the history of our Galaxy, like a merger of the Milky Way with a smaller galaxy. The new model produces not only the measured vertical density profile, but also the chemical signature, when applying the same kinematic selections in model and observations. This is illustrated in 2.13. However, the model has smooth dynamics and star formation rates and especially no merger. Matching also any other known properties of the thick disc, it gives a very natural alternative explanation for its presence: by the outwards migration of inner disc stars, which are by their origin dynamically hotter and have also higher [Fe/H] at the same alpha enhancement level. This does by itself not exclude the possibility for some violent merger in the far past, but it is not necessary for having a thick disc.

The model has various applications, including a robust reevaluation of the local standard of rest, which has recently been performed. However, our model still has large uncertainties, as it relies in part on the parametrization of certain poorly understood physical processes. Future struggles will be to confront the model with data more distant from the solar neighbourhood using for example the SDSS and to improve the physical fundamentation and gauging of some model parameters, especially of radial migration. (Ralph Schönrich)

2.6 Unravelling the mechanism how stars explode

Understanding how massive stars end their lives in supernova explosions is one of the most important problems in stellar astrophysics. With highly sophisticated computer simulations at the forefront of present modeling efforts, researchers at the Max Planck Institute for Astrophysics in Garching are making progress in deciphering the complex interplay of hydrodynamics and particle physics that reverses the collapse of the stellar core and initiates the violent disruption of the star.

Astrophysical context.— Roughly five times a second somewhere in the Universe the life of a star with more than eight times the mass of our Sun is terminated in a gigantic supernova explosion. These cosmic catastrophies are the most violent events after the Big Bang. Within only fractions of a second more energy is released than the Sun produces during all its evolution. The hot plasma of the destroyed star, expanding into interstellar space with a tenth of the speed of light, can outshine a whole galaxy for several weeks.

It is these cataclysmic blasts that we owe our existence to. They enrich the galaxy with carbon, oxygen, silicon, and iron, the building blocks of the earth and of all the creatures on it. Assembled during millions of years of nuclear burning as the dying star has been aging, or forged in the inferno of its final explosion, these chemical elements are disseminated into the galactic medium when the star is disrupted in the supernova event.

Observations of supernova remnants tell us that not all the stellar gas is ejected in the outburst. The core of the star with the size of the Moon but more massive than the Sun, collapses to an ultra-compact object, a neutron star, which has only the diameter of a big city. Such a neutron star is still visible as a point source in many of the gaseous clouds that are left behind as heralds of past explosions.

The supernova puzzle.— The gravitational binding energy released in the neutron star formation is hundred times more than needed for powering the supernova. But how does this happen? How is the implosion of the stellar core reversed to the explo-

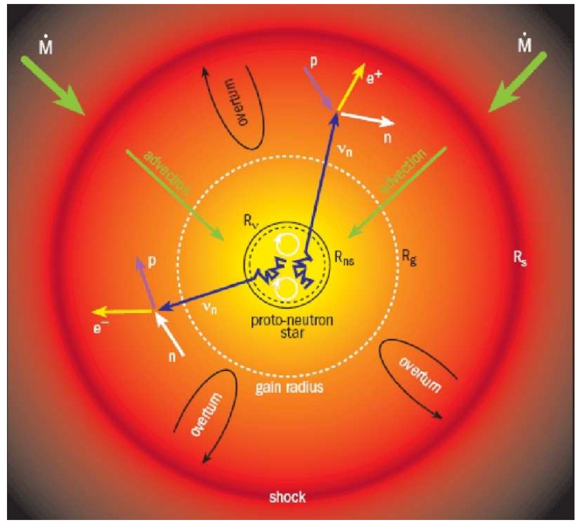

Figure 2.14: Neutrinos, radiated from the newly formed neutron star at the centre of a collapsing star, deposit the energy to drive the shock wave that causes the supernova explosion of the star.

sion of the overlying layers of the star? This is still a puzzle that challenges theorists' intuition and modeling abilities. One of the most popular ideas involves neutrinos as the driving agents. These elementary particles are produced in huge numbers at the extreme conditions in the newly formed neutron star, where the matter is denser than in atomic nuclei and reaches temperatures of several hundred billion degrees. Neutrinos are the leak by which the collapsing stellar core loses its gravitational binding energy within a period of seconds. But some fraction of the emitted neutrinos is still able to deposit its energy in the matter surrounding the compact remnant (see Fig. 2.14). This energy transfer could be enough powerful to accelerate the supernova shock front and to expel the overlying shells of the star. The question whether this happens or not is a central problem in supernova theory.

Goals of this project.— Answering this question would mean a major breakthrough in stellar astrophysics. It would not only allow us to better link the properties of supernova explosions and their remnants to the different types of progenitor stars. It would also bring us closer to an answer of the question whether supernovae are the still mysterious source of rare elements like gold, lead, thorium, and uranium. And it would allow us to more reliably predict the neutrino and gravitational wave signals, which are planned to be measured for future Galactic supernovae by a new generation of big experiments, and which are the only ways to observationally probe the processes deep inside the

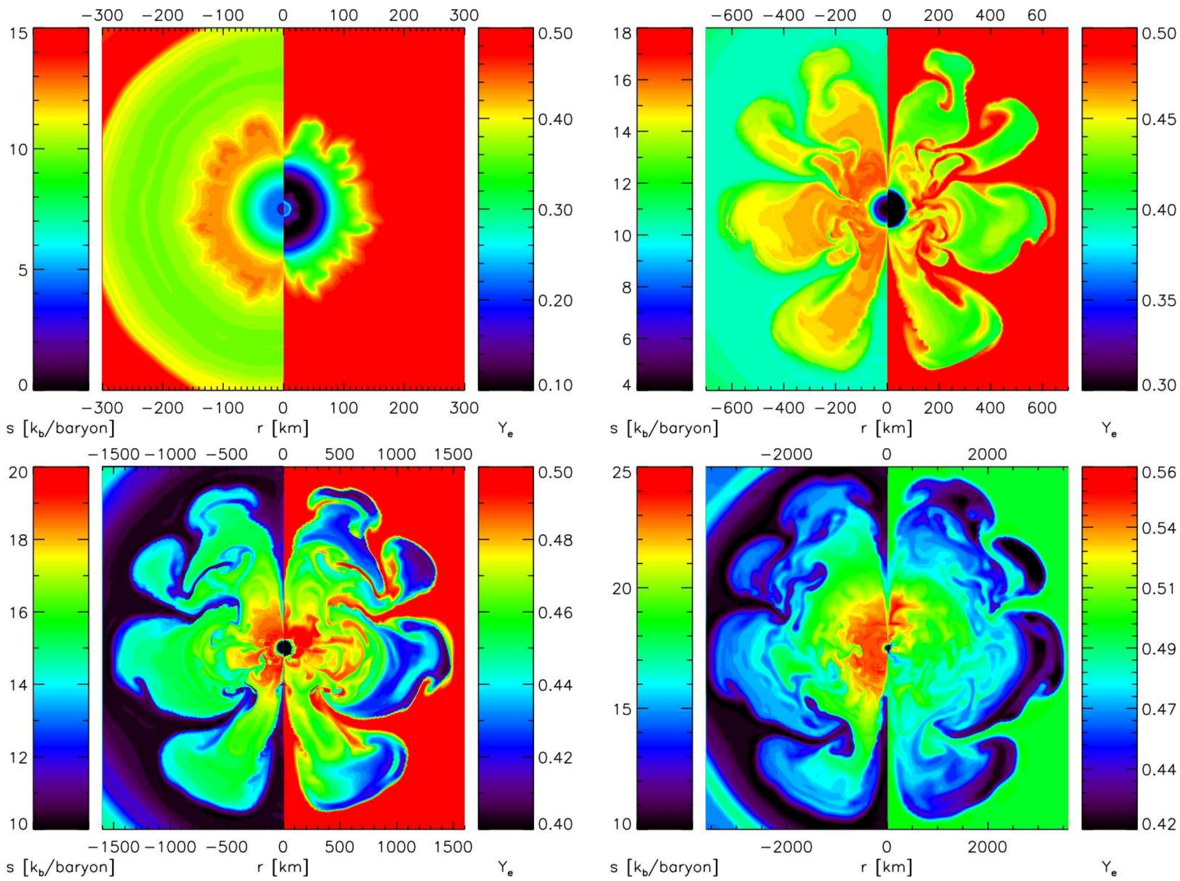

Figure 2.15: Gas entropy (left half of each picture) and electron-to-nucleon ratio (right half of each figure) during the early stages (0.097, 0.144, 0.185, and 0.262 seconds) of the explosion of a star with 8.8 solar masses. Convection causes anisotropies of the ejected gas. Important properties of this explosion model agree with characteristic observational features of the Crab Supernova.

core of a dying star.

Until then, computer models are an indispensable tool for promoting our theoretical insight. At Garching, we have developed numerical codes that allow us to perform, with unprecedented accuracy, simulations of the complex particle physics, nuclear physics, and plasma dynamics that determine the destiny of collapsing and exploding stars.

Computational Challenges.— The modeling of supernova explosions is in fact one of the most difficult problems in computational astrophysics. Largely different time scales, varying between microseconds and seconds, and length scales that extend from tens of meters to millions of kilometers, have to be resolved to follow neutrino interactions, nuclear reactions, turbulent convection, and sound wave propagation in different regions of the collapsing core and of the ejected outer layers of exploding stars. This is computationally extremely demanding: half a second of evolution requires 500,000 time steps and in two spatial dimensions (2D) with 500−1000 radial zones and typically 196 lateral bins needs up to 10^{19} floating point operations.

Besides integrating the Euler equations that describe the time-dependent motion of the stellar fluid, one needs to solve the transport of neutrinos in the dense stellar matter. Different from the stellar gas, where very fast electromagnetic and strong interactions ensure that equilibrium is established on dynamical timescales, neutrinos couple with matter only through weak reactions. Thus they require a transport treatment in phase space by the Boltzmann equation and its moment equations. This constitutes a high-dimensional, time-dependent problem — in spherically symmetric models the transport is three-dimensional, for axisymmetric models five-dimensional, and in full generality six-dimensional — and poses the major computational challenge: the neutrino trans-

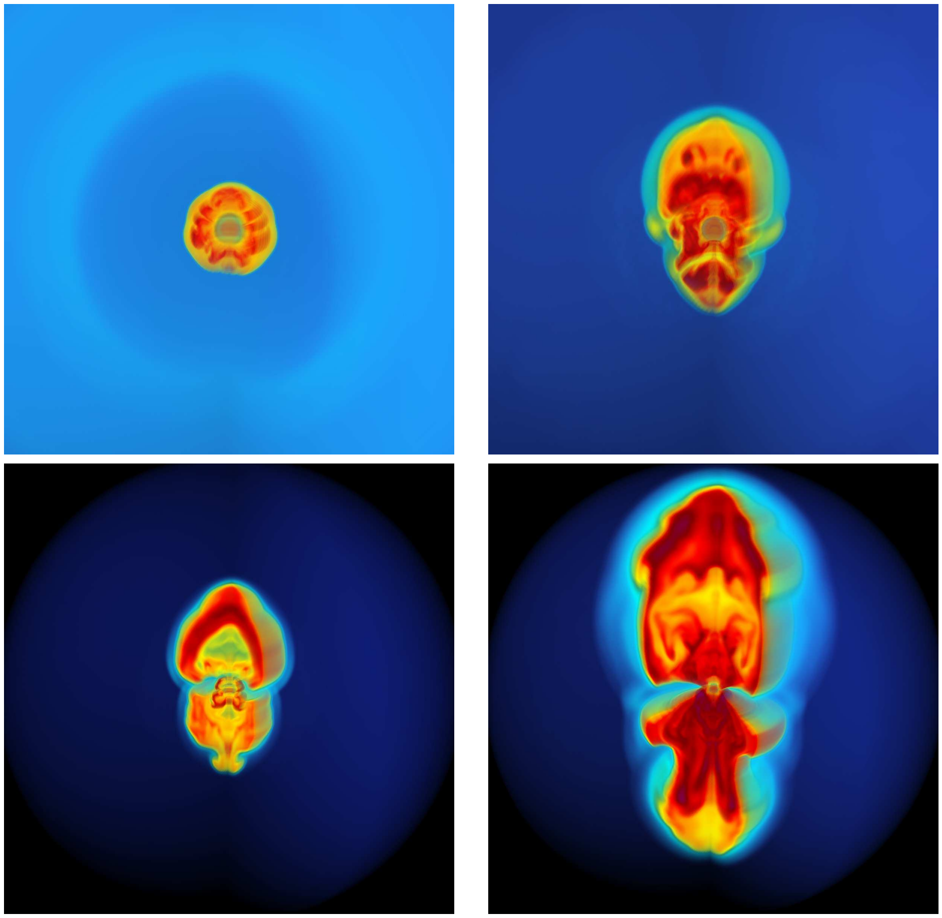

Figure 2.16: Onset of the supernova explosion of a star with 11.2 solar masses. The images from top left to bottom right show a sequence of volume-rendered snapshots of a 2D computer simulation at 0.1, 0.18, 0.26, and 0.32 seconds after the stellar core has collapsed to a neutron star. The supernova shock separating the yellow-red hot-bubble region of neutrino-heated gas from the blue-dark blue infall layer has an average radius of about 200 km, 250 km, 500 km, and 1000 km, respectively (Visualization: Markus Rampp, Rechenzentrum Garching).

port consumes by far the dominant amount of CPU time during supernova simulations. The problem is also hard to be implemented efficiently on massively parallel computers. In particular the neutrino transport module has resisted such efforts so far and currently prevents us from using distributed memory architectures. Because the interaction timescale of neutrinos in neutron star matter is extremely short and the neutrino propagation happens with the speed of light after decoupling, the nonlinear transport equations of neutrinos, which as fermions are subject to phase-space blocking effects, need to be solved with fully implicit time stepping. In our current numerical implementation this leads to big, densely filled matrices that have to be inverted several times on every time level of the calculated evolution. This is computationally very expensive and defies easy parallelization.

Recent progress.— With our most sophisticated simulations carried out so far, we have learned that the neutrino energy deposition around the newly formed neutron star (see Fig. 2.14) is supported by different fluid instabilities developing in the gas flow that continuously adds more matter from the collapsing stellar core to the compact remnant at the center. The neutrino-heated gas is stirred up by vigorous convective overturn as hot matter becomes buoyant and begins to rise while cooler fluid sinks inward and is partly absorbed into the neutron star (Fig. 2.15).

In addition to this phenomenon, which has been known already for 15 years, we have observed a global non-radial instability of the gas flow towards the center named "standing accretion shock instability". The layer between neutron star and

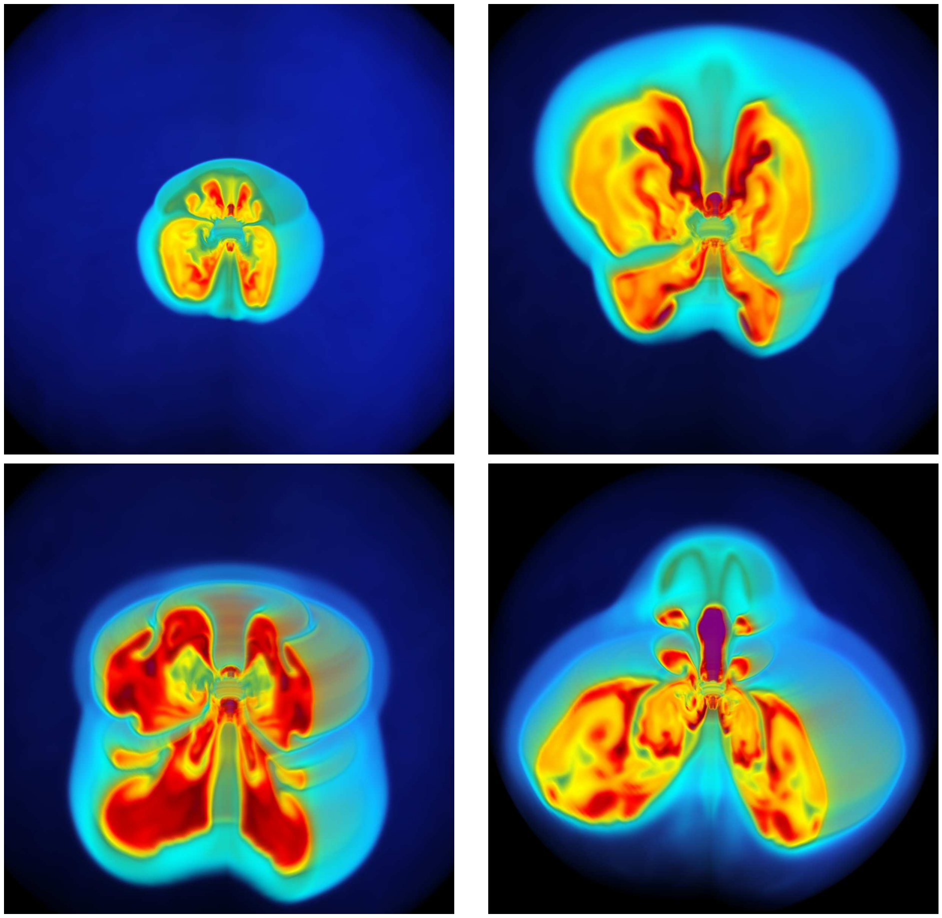

Figure 2.17: Onset of the supernova explosion of a star with 15 solar masses. The images from top left to bottom right show a sequence of volume-rendered snapshots of a 2D computer simulation at 0.53, 0.61, 0.65, and 0.7 seconds after the stellar core has collapsed to a neutron star. The supernova shock separating the light-blue layer of postshock gas around the yellow-red hot-bubble region of neutrino-heated gas from the dark-blue infall layer has an average radius of about 200 km, 300 km, 400 km, and 600 km, respectively (Visualization: Markus Rampp, Rechenzentrum Garching).

supernova shock front is unstable by a so-called advective-acoustic cycle, which constitutes an amplifying feedback cycle of inward advected vorticity perturbations and outward propagating sound waves. This instability was shown to be able to grow even in situations where convection remains weak. It can instigate violent secondary convection (Fig. 2.16) and thus improves the conditions for ongoing strong neutrino energy transfer to the supernova shock. In fact, our simulations demonstrate that for stars from about eight solar masses to at least 15 solar masses neutrino energy deposition, supported to different extent by both hydrodynamic instabilities, can initiate and drive the supernova explosion (Figs. 2.15–2.17).

The onset of the explosion thus turns out to be a generically multi-dimensional phenomenon. The highly aspherical initiation of the blast (Figs. 2.16, 2.17), even in the absence of rapid rotation, suggests explanations for a variety of observations. The fast motions of many young neutron stars, which are measured to have average velocities of several hundred kilometers per second, some of them even of more than 1000 km/s, may be explained by the recoil imparted to the compact remnant by the anisotropically ejected supernova gas. The asymmetry of the developing explosion also triggers large-scale mixing instabilities in the outer layers of the disrupted star, thus accounting for the clumpiness seen in many supernovae and the asymmetric appearance of gaseous supernova remnants.

Outlook.— Despite the significant progress of our understanding of the fundamental processes that conspire in starting the explosion, many more simulations and in particular long-time simulations are needed to establish the properties of self-consistently calculated explosions. The different structures of stars with different masses require studies for a wider range of supernova progenitors. And the incomplete knowledge of the initial conditions (e.g., of the angular momentum in the stellar core) and of various aspects of the microphysics (e.g., of the equation of state of hot neutron star matter) make it necessary to explore the full range of variability. Ultimately, three-dimensional simulations will have to be performed to confirm our findings of the present two-dimensional models. But for that to be possible, we still need to wait for the next generations of even more powerful supercomputers, and we presently advance our modeling tools to massively parallel application. (H.-Thomas Janka, Andreas Marek, Bernhard Müller)

2.7 Type Ia Supernovae from mergers of white dwarf stars

Supernovae are among the brightest objects in the Universe. For a few weeks they can be nearly as bright as their host galaxy. A particular class of supernovae, the so-called supernovae of type Ia (SNe Ia), looks remarkably homogeneous. For SNe Ia there exists an empirical relation between their brightness and the rate at which they fade. This relation can be used to calibrate their peak luminosity. With that SN Ia can be used as cosmological distance indicators and hence they provide a unique possibility to map out the expansion history of our Universe. This led to the discovery of its accelerating expansion.

However, despite the tremendous success of their empirical calibration, the nature of the progenitor systems of SNe Ia remains a riddle. There is general agreement only in that SN Ia are explained by thermonuclear explosions of carbon/oxygen white dwarfs (WDs). A single WD is permanently stable, as it is supported against gravitational collapse by the Fermi pressure of its degenerate electron gas. Therefore the thermonuclear explosion of the WD has to be triggered externally by a companion in a binary system.

There are essentially two different progenitor scenarios that differ in the nature of the companion star. The *single degenerate scenario* assumes a main sequence or red giant companion star. This star at some point of its evolution transfers material to the WD either by Roche-lobe overflow or by stellar winds. At the surface of the WD the accreted material is hydrostatically burned to carbon and the WD grows until reaching the Chandrasekhar mass $M_{\rm Ch} \approx 1.4 M_\odot$, where ultimately a thermonuclear runaway occurs.

The *double degenerate scenario*, in contrast, assumes a binary system of two carbon/oxygen WDs, that looses angular momentum due to gravitational wave emission and finally merges. Its fate then depends on the total mass of both WDs and the mass ratio between the more massive and the less massive WD.

For a small mass ratio, i.e. a large mass difference between the two WDs, stable mass transfer is expected: after the WDs have come close enough, the less massive and therefore larger WD fills its Roche-lobe and starts to transfer mass to the more massive WD. If the total mass of the system exceeds the Chandrasekhar mass, it may explode in a SN Ia, otherwise at the end one single, massive WD remains.

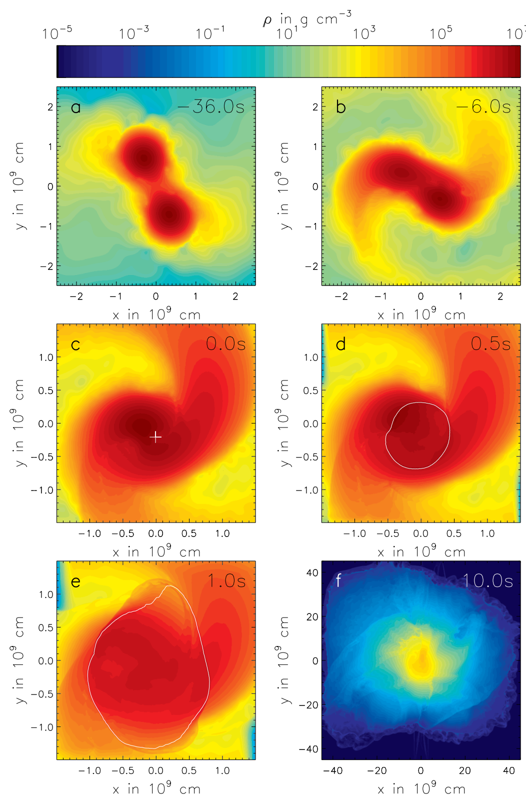

Figure 2.18: Density slices in the z=0 plane at different times. At $t = 0$ the detonation is ignited. The white contour indicates the position of the detonation shock.

For an intermediate mass ratio, the mass transfer becomes unstable. This leads to the disruption of the less massive WD, after which its material builds up a thin envelope around the more massive WD from which material is accreted onto it.

This accretion is expected to ignite the carbon at the surface of the WD and over a few thousand years it will be transformed by the burning into an ONeMg WD. If further mass is accreted, this WD collapses rather then explodes in a SN Ia.

For a mass ratio close to one, i.e. a system of two equally massive WDs, the fate of the system has been unclear. While it was clear that the system would undergo a violent merger, it was not known whether this merger may lead to a SN Ia.

To investigate this scenario, 3D hydrodynamical simulations of a merger of two WDs of $0.89 M_{\odot}$ each were carried out. The dynamics of the merger was followed with the smoothed particle hydrodynamics code GADGET3 into which an equation of state for degenerate matter and a state-of-the-art nuclear reaction network were implemented.

The simulations showed that dynamical interactions between the two WDs lead to the disruption of one of the stars. Its matter is violently accreted onto the remaining WD. At the interface, material is compressed and heated up. Some hotspots ignite carbon fusion and conditions necessary for triggering a detonation are reached.

After mapping the state of the simulation onto a grid, we follow the detonation using the MPA SN Ia code. The detonation wave propagates outward from the ignition spot with supersonic velocities and consumes nearly all the material of the merged object. The energy release from the nuclear burning is sufficient to overcome the gravitational binding energy, therefore the object is disrupted and finally reaches a state of homologous expansion.

This evolution starting from the separated binary system though the merger and the explosion phases is shown in Fig. 2.18.

As the nuclear burning in the merged object takes place at low densities, only small amounts ($\approx 0.1 M_{\odot}$) of radioactive ^{56}Ni are synthesized. Its decay powers the optical display of SNe Ia and the fact that only a small mass is synthesized in the explosion leads to a faint event. The ejecta consist mostly of intermediate mass elements ($1.1 M_{\odot}$) and oxygen ($0.5 M_{\odot}$).

In an additional postprocessing step, we used trajectories from tracer particles that were advected with the flow during the explosion to reconstruct the detailed nuclear composition of the ejecta. We then used the final density structure of the ejecta and its detailed chemical composition to derive synthetic lightcurves and spectra using the Monte Carlo radiative transport code ARTIS. The result is shown in Fig. 2.19 together with observational data of several SNe Ia. It shows, that

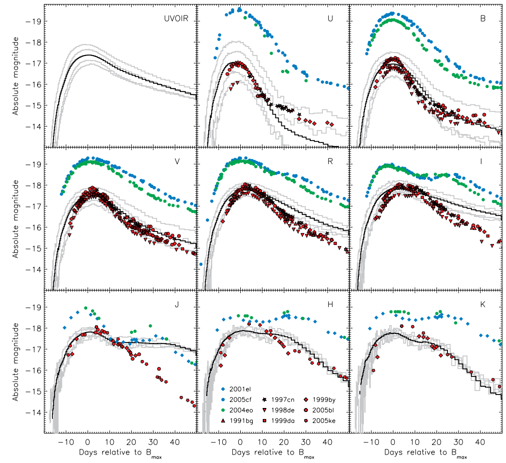

Figure 2.19: Synthetic lightcurves for different broadband filters. The black lines show the angle averaged lightcurves, gray lines illustrate the scatter for different line-of-sights. Symbols show observational data.

the (color) lightcurves of our model are in excellent agreement with a particular faint subclass of SNe Ia, the so-called 1991bg-like SNe Ia. The good match of our model with several other particular properties of this subclass, provides confidence in that the proposed scenario solves the mystery of this previously theoretically unexplained SN Ia subclass.

In addition, we have shown for the first time, that mergers of white dwarfs can indeed lead to SNe Ia, which sheds light on the long-standing question of progenitor systems of SNe Ia. (Rüdiger Pakmor, Markus Kromer, Fritz Röpke, Stuart Sim, Ashley Ruiter, Wolfgang Hillebrandt). *For further details see Nature, January 7, 2009*

2.8 Large jets from small-scale magnetic fields

Many astronomical objects contain elongated high-velocity flows of plasma a.k.a. jets. Exactly how jets form is not clear, the "central engine" being (largely) unresolved by today's telescopes. The most promising models include a magnetic field that gets twisted by the rotation of the central object, e.g. an accretion disk or a star. The free energy in the twisted magnetic field component drives the jet in this scenario. As the geometry of the magnetic field is not well constrained by observations, it is usually assumed to have "ideal" properties: ordered, symmetric about the axis of rotation, uniformly polarized and extending to very

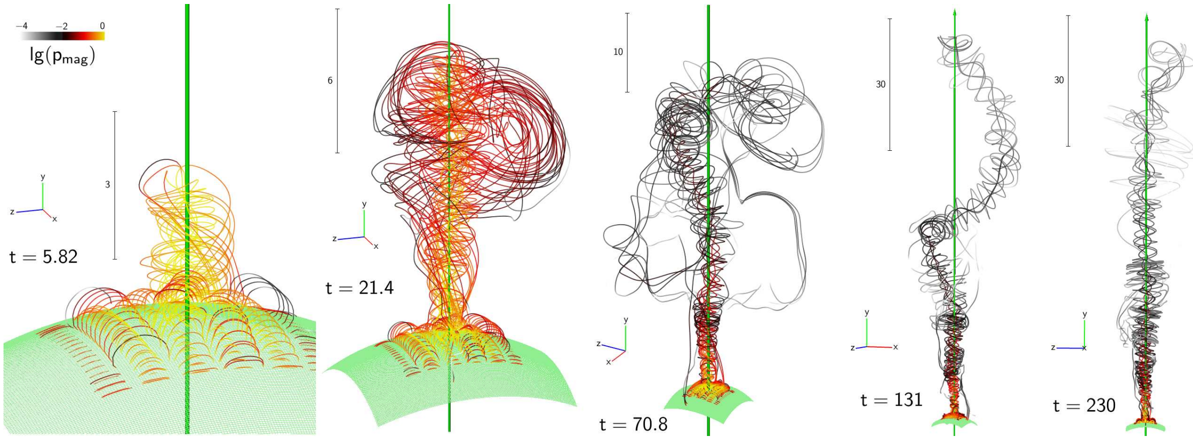

Figure 2.20: Selected magnetic field lines in a simulation in which arcade-shaped magnetic fields emerge from the lower boundary and get twisted by imposed rotation. A jet with helically shaped field lines forms along the axis of rotation and is subject to kink instabilities.

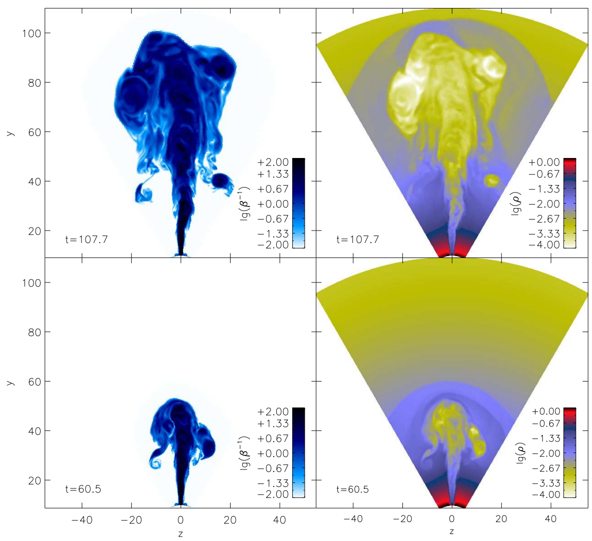

Figure 2.21: Slices through a simulated jet, showing the inverse plasma-β value (*left*) and the density (*right*) after 77 (*bottom*) and 103 (*top*) rotations at the base. The jet is accelerated into a non-magnetic atmosphere, penetrating through denser material.

large distances from the source. While such fields allow for an efficient conversion of rotational energy into outflows, the question of whether they actually exist in the concerned objects is still quite open. Indeed, there are arguments against the existence of such fields. It is unlikely that they are created in situ and there are complications with advecting them in accretion flows.

To see if the magnetic driving mechanism can work efficiently also in the absence of large-scale magnetic fields, R. Moll (with H. C. Spruit and M. Obergaulinger) has conducted numerical simulations in which small magnetic arcades are twisted to form a jet in an unmagnetized medium stratified under gravity. A spherical grid was used to follow the jets to distances of up to 100 times the size of the source. The magnetic field at the jet's base was maintained with boundary conditions that allow for an inflow of magnetic field, so compensating for the dissipation that arises as field lines with opposite polarity become entangled by the rotation.

Different magnetic field geometries were tested. It turned out that an efficient twisting of the magnetic field requires that the footpoints of individual magnetic field loops rotate differentially. The magnetic field lines are then stretched in azimuthal direction; they assume a helical shape and rise with the flow, see Fig. 2.20. The conversion of magnetic enthalpy (integrated Poynting flux) to kinetic energy is very efficient ($\gtrsim 75\%$) in these jets. With fast rotation of the footpoints of the field loops (of the order of the escape velocity from the source), the jets become "strong" enough to penetrate the dense layers of the stratified atmosphere, see Fig. 2.21, and the flow becomes fast enough to escape from the potential well of the central mass.

On the contrary, we find no jetlike outflows for uniformly rotating arcades. The shear between the rotating loop and the stationary atmosphere surrounding is much less effective in producing a toroidal field than direct shearing of field lines inside the rotating source. If there is extensive dissipation of rotational energy, there are outflows driven by thermal buoyancy, but these flows do not have the coherence and collimation expected from jets.

The magnetic fields are strongly wound, with the field lines making many turns along the length of the jets. Current-driven instabilities, in particular the non-axisymmetric kink modes, are therefore to be expected and can indeed be found in the simulations. The turbulent "wiggling" created by the kink instabilities leads to an increased interaction with the ambient medium in the form of entrainment. Large deflections of up to 10 degrees are observed in the largest simulations, but the instabilities do not appear to be fatal. As the atmosphere thins out with distance, there is not sufficient interaction with the jet to disrupt it.

Overall, it was found that, given basic prerequisites, jets launched by twisted small-scale field loops have similar properties as jets from axisymmetric large-scale fields. While still idealized, this could be a viable model for flows in an external unmagnetized atmosphere, e.g. protostellar jets launched into dense molecular clouds. It also applies to situations in which ordered, axisymmetric magnetic fields are not available for the generation of jets, e.g. collapsar cores. (Rainer Moll)
Animated plots from the simulations can be found at URL http://www.mpa-garching.mpg.de/ rmo/pap3/index.html

2.9 Galaxy Clusters as Mirrors of the Distant Universe

The Cosmic Microwave Background (CMB) radiation was released when the Universe was only $\sim 370,000$ years old, less than 3% of its current age. Until that time, this radiation could not propagate freely since it would scatter free electrons on its way, changing constantly its direction. This situation changed dramatically as soon as electrons recombined protons to form neutral matter: by first time the CMB radiation could escape and travel freely throughout space. This epoch is known as the *epoch of recombination* or the *epoch of decoupling*. Since then, the CMB has been traveling *mostly* unperturbed throughout the entire universe until reaching us, the observer.

However, a small fraction of the CMB photons have crossed clusters of galaxies in their journey to the observer. Clusters of galaxies are the largest bound structures in the Universe, that is, the biggest objects that are self gravitating in a relaxed way. These sytems, of masses ranging typically between 5×10^{13} and 5×10^{15} $M_{\odot}$,

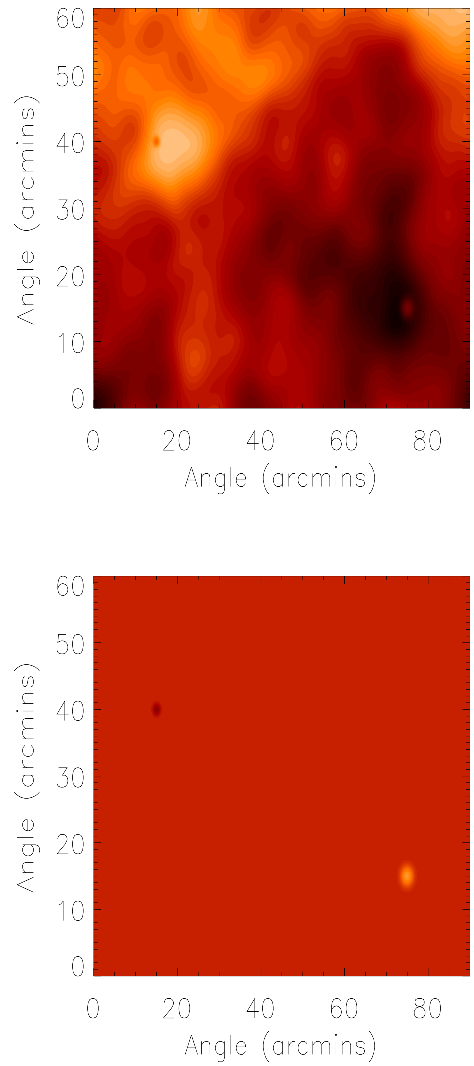

Figure 2.22: *Top panel:* Total CMB map with two clusters for which the tSZ and the kSZ contributions have been removed. *Bottom panel:* Isolated contribution of the bSZ from the clusters: the left cluster is sitting on an intrinsic CMB bright spot and hence gives rise to a negative bSZ, whereas the right cluster is aligned with a CMB trough and its bSZ introduces a relative enhancement of the CMB brightness.

usually contain huge *reservoirs* of ionized plasma, where electrons again scatter CMB photons. Due to this interaction, the CMB photons change their direction of propagation and, in cases where the electron plasma is very hot, receive energy in the encounter. This energetic transfer is called the *thermal Sunyaev-Zel'dovich* effect [hereafter tSZ] and describes the distortion of the initial frequency spectrum of the CMB radiation. But even in the case where the temperature of electrons is not high enough to transfer a significant amount of energy, the scattering of CMB photons on free electrons is sensitive to the peculiar motion of the electrons with respect to the CMB radiation bath. Indeed, if the cloud of electrons has a non-zero velocity with respect to the photon background, it leaves a signature in the photon field that is proportional to the line of sight relative velocity of the cloud. This signature, which preserves the initial CMB energy spectrum, is known as the *kinetic Sunyaev-Zel'dovich* (kSZ) effect.

Researchers of MPA have given a further step in the study of this electron – CMB photon interaction in galaxy clusters by focusing in the erasing of initial CMB intensity anisotropies. The CMB photon field is very homogeneous, showing small spatial fluctuations in the number of photons (of the order of one part in 100,000), which however respect the thermal CMB energy spectrum of a black body. As a consequence, any arbitrary observer detects *small* anisotropies in the CMB brightness arriving at different directions. If that observer were placed close to a galaxy cluster, s/he would find that the CMB angular anisotropies are partially blurred when looking through the electron cloud. This is another effect of the electron - CMB photon interaction (called *Thomson scattering*), by which the anistropies of the radiation field become attenuated when crossing media with free electrons. This *blurring* effect (hereafter bSZ) is depicted in Figure (2.22), where two galaxy clusters are placed in the same sky field on the top of intrinsic CMB intensity anisotropies of different sign (top panel). Since this bSZ effect is *attenuating* intrinsic CMB anisotropies, it has opposite sign to those, as shown in the bottom panel of the same figure.

The bSZ has the same spectral dependence as the kSZ, and therefore may constitute a significant bias when attempting to estimate peculiar velocity of galaxy clusters through CMB observations. Radial velocities of galaxy clusters are predicted to

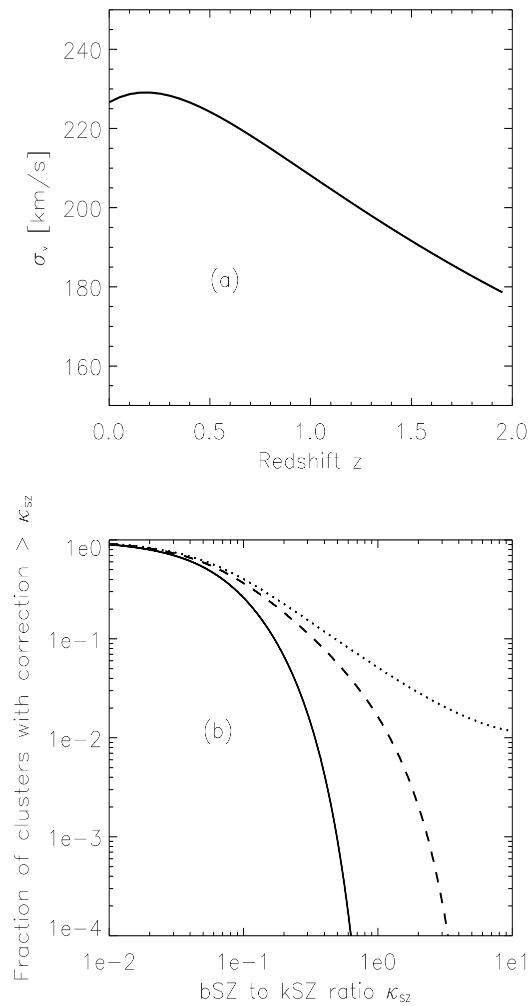

Figure 2.23: *(a)* Amplitude of the linear rms radial peculiar velocity in a WMAPV cosmology for a 2×10^{14} h^{-1} $M_\odot$ cluster of galaxies. *(b)* Fraction of clusters in the sky above a given fractional level of correction on the kSZ induced by the bSZ term. Solid, dashed and dotted lines correspond to a level of residual (instrumental noise related) radial velocity of 60, 10 and 0 km s^{-1}.

be roughly Gaussian distributed around zero (i.e., clusters can be approaching us or receding from us with equal probability), with a typical dispersion at the level of 200 km s^{-1}. There exists some dependence of this peculiar velocity amplitude with cosmic time, which in the top panel of Figure (2.23) is represented by redshift (z). Increasing values of redshift correspond to younger ages of our universe, such that for $z = 1$ the age of the universe was roughly half its current one. The bottom panel shows the relative correction of the bSZ to the kSZ for different levels of instrumental noise in the determination of the clusters' peculiar velocity. A perfect experiment (depicted by the dotted line) would find that as many as $\sim 7\%$ of all galaxy clusters would have kSZ estimates affected by the bSZ at the 100% level or higher. For 20% of clusters, this contamination level should be above the 20% of the real kSZ amplitude. This correction to the kSZ can however be predicted and accounted for *if* an estimate of the intrinsic CMB anisotropies *behind* the cluster is available. This is the situation in most of the occasions, since the majority of galaxy clusters subtend an angle that is smaller than the typical positive and negative spots of the CMB intensity field. Hence, the CMB behind clusters can be estimated from the CMB *around* clusters. Since the amplitude of the blurring is also determined by the amount of mass in the clusters, a comparison of the theoretical prediction for the bSZ with its actual measurement should provide an estimate of the electron content of the cluster.

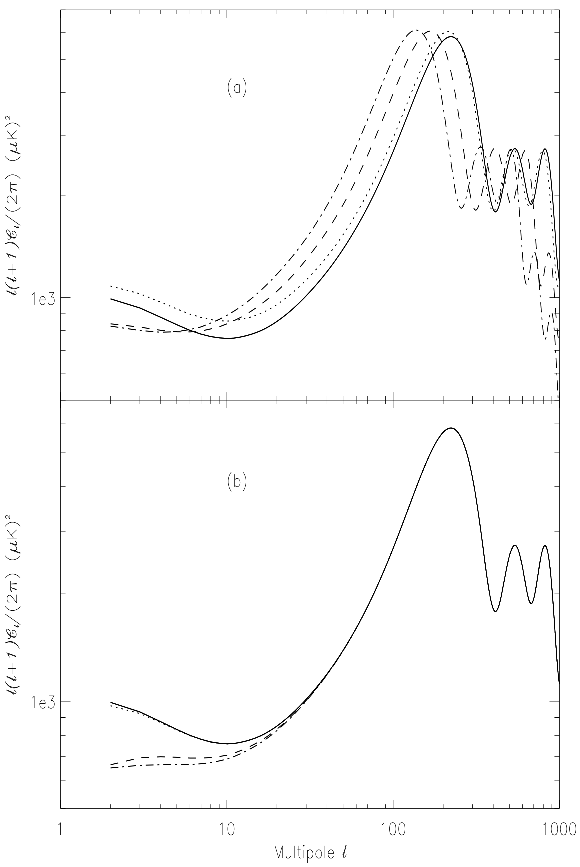

Figure 2.24: *(a)* CMB intensity angular power spectrum as seen by observers placed at redshifts $z = 0, 0.1, 1$ and 2 (solid, dotted, dashed and dot-dashed lines, respectively). *(b)* Same power spectra as in *(a)* after being free streamed to the present moment.

Part of the interest on the bSZ comes from the fact that clusters erase CMB anisotropies as seen at *different* epochs of the past universe. The CMB angular anisotropies have a given pattern predicted by our cosmological theory. For a local observer, most of the CMB fluctuations subtend a size of a degree in the sky, but for clusters scattering CMB radiation when the universe was significantly younger, the typical size of CMB anisotropies were bigger, since these observers were closer to the surface where the CMB was released. This is shown in Figure (2.24). It displays the amount of angular anisotropy of the CMB for different angular scales (given by the multipole l, which scales inversely with the angular scale on the sky, $l \sim \pi/\theta$). The top panel provides the amount of anisotropy per unit of solid angle ($l(l+1)C_l/(2\pi)$) in units of CMB thermodynamic temperature, $(\mu K)^2$, for observers placed at different redshifts/cosmological epochs: the solid line corresponds to a local observer ($z = 0$), whereas the dotted, dashed and dot-dashed lines correspond to more and more distant observers ($z = 0.1, 1$, and 2). As these observers are closer to the surface where the CMB was released (Last Scattering Surface or LSS), the angular pattern of the CMB anisotropies is shifted to larger angular scales (or smaller multipoles l's). These are the CMB fluctuation fields that galaxy clusters placed at those redshifts effectively scatter, which are significantly different from what a local observer sees. However, after the scattering, the CMB photons free stream towards the observer, and the typical angular pattern of scattered CMB photons as seen by us is given in the bottom panel of Figure (2.24). The main difference arises at low multipoles or large angular scales, especially for CMB photons scattered at high redshifts ($z > 1$). This difference is due to a component of CMB intensity anisotropies that arises *at late times ($z < 1$), after the scattering in clusters*: our understanding of the universe predicts that new CMB fluctuations should be introduced by the late accelerated expansion of the universe. This accelerated phase should affect the large scale gravitational wells, which should become shallower: CMB photons crossing them should leave a potential well that is shallower than the potential they entered, and therefore the CMB radiation should *gain* some energy. This is known as the *Integrated Sachs-Wolfe* effect (ISW), and is the only probe that CMB studies on the so-called *Dark Energy* content of the universe causing this late accelerated expansion. The CMB anisotropies blurred in galaxy clusters may or may not have had an ISW component, depending upon the redshift/cosmological epoch where the scattering took place, and hence the bSZ should be sensitive to this ISW component. For high scattering redshifts, the ISW has not arised yet, and this is the difference present at the low multipole range in the bottom panel of Figure (2.24). By measuring the bSZ in galaxy clusters placed at different cosmological epochs, it should be possible to trace the growth of ISW (and thus the presence of Dark Energy) at late cosmological times. The galaxy clusters therefore act as mirrors of distant, past universes, telling us about changes in the CMB anisotropy pattern occurring in the last seven billion years. (Carlos Hernández-Monteagudo and Rashid A. Sunyaev).

2.10 Chandra unveils the nature of progenitors of Type Ia Supernovae

Type Ia Supernovae are used as standard candles to determine the cosmological distance scale. As such, they played a major role in establishing that expansion of the Universe accelerated with time, the fact that directly pointed at the existence of the dark energy. Although there is near universal agreement that SNeIa are associated with the thermonuclear disruption of a carbon/oxygen white dwarf, details are still being debated, two scenarios competing each other with alternating success. Nuclear runaway can start in a white dwarf gradually accumulating matter from a companion star until it reaches the Chandrasekhar limit (the so called single degenerate scenario). Alternatively, it can be a result of a merger of two white dwarfs in a compact binary (the double degenerate scenario). The X-ray signatures of the two possible paths are very different. While coalescence of two white dwarfs spiraling onto each other in a compact binary system can become a powerful source of gravitational waves, no strong electromagnetic emission is expected in the merger scenario until shortly before the Supernova. A white dwarf accreting material from the normal star, on the other hand, becomes a source of copious X-rays for $\sim 10^7$ yr *before* the explosion. This offers a method to determine which path dominates.

In fact, a carbon-oxygen white dwarf (WD) formed through standard stellar evolution can not be more massive than $\approx 1.1 - 1.2 M_\odot$. Thus, in order to reach the Chandrasekhar mass[1] of $\approx 1.38 M_\odot$ the WD needs to accrete at least $\Delta M \gtrsim 0.2 M_\odot$ of matter. Accretion of hydrogen-rich material onto a white dwarf is accompanied by hydrogen fusion on its surface, converting it to helium. It has been shown theoretically and confirmed by observations that at small values of the mass accretion rate $\dot{M}$ hydrogen burning is unstable, giving rise to Classical Nova events. Because most of the accreted envelope and some of the original WD material is lost in Nova outbursts, the WD does not grow in mass if nuclear burning is unstable. Therefore, a steady burning regime is required in the accretion scenario; this limits the range of the mass accretion rate relevant to the problem of SNIa progenitors to $\dot{M} \gtrsim 10^{-7}\ M_\odot$/yr. In this regime, the

[1] Sub-Chandrasekhar models have been unsuccessful so far in reproducing observed properties of Type Ia Supernovae (SNIa), despite continuing effort.

Table 2.1: Comparison of the accretion scenario with observations. Listed for each galaxy are: name, K-band luminosity, number of accreting WDs and X-ray luminosities in the soft (0.3–0.7 keV) band. The columns marked 'predicted' show total number and combined X-ray luminosity (absorption applied) of accreting WDs in the galaxy predicted if the single degenerate scenario would produce all SNeIa. They were computed assuming $\dot{M} = 10^{-7}\ M_{\odot}/\text{yr}$ and initial WD mass of $1.2M_{\odot}$.

Name	L_K $[L_{K,\odot}]$	$N_{\rm WD}$	$L_{\rm X}$ [erg/s]	
	observed	predicted	observed	predicted
M32	$8.5 \cdot 10^8$	25	$1.5 \cdot 10^{36}$	$7.1 \cdot 10^{37}$
NGC3377	$2.0 \cdot 10^{10}$	$5.8 \cdot 10^2$	$4.7 \cdot 10^{37}$	$2.7 \cdot 10^{39}$
M31 bulge	$3.7 \cdot 10^{10}$	$1.1 \cdot 10^3$	$6.3 \cdot 10^{37}$	$2.3 \cdot 10^{39}$
M105	$4.1 \cdot 10^{10}$	$1.2 \cdot 10^3$	$8.3 \cdot 10^{37}$	$5.5 \cdot 10^{39}$
NGC4278	$5.5 \cdot 10^{10}$	$1.6 \cdot 10^3$	$1.5 \cdot 10^{38}$	$7.6 \cdot 10^{39}$
NGC3585	$1.5 \cdot 10^{11}$	$4.4 \cdot 10^3$	$3.8 \cdot 10^{38}$	$1.4 \cdot 10^{40}$

energy of hydrogen fusion is liberated in the form of electromagnetic radiation, with luminosity of

$$L_{\rm nuc} = \epsilon_{\rm H}\dot{M} \sim 10^{37}\ \text{erg/s}$$

where $\epsilon_H \approx 6 \cdot 10^{18}$ erg/g is the energy release per unit mass and X the hydrogen mass fraction (the solar value of $X = 0.72$ is assumed). The nuclear luminosity exceeds by more than an order of magnitude the gravitational energy of accretion, $L_{grav} = GM\dot{M}/R$, and maintains the effective temperature of the WD surface at the level (using the Stefan-Boltzmann law):

$$T_{\rm eff} \approx 67 \left(\frac{\dot{M}}{5 \cdot 10^{-7} M_{\odot}/\text{yr}}\right)^{1/4} \left(\frac{R_{\rm WD}}{10^{-2} R_{\odot}}\right)^{-1/2} \text{eV}$$

Such a soft spectrum is prone to absorption by interstellar gas and dust, especially at lower temperatures. Because the radius $R_{\rm WD}$ of a WD decreases with its mass, the $T_{\rm eff}$ increases as the WD approaches the Chandrasekhar limit. Hence the signal, detectable at X-ray wavelengths, will be dominated by the most massive WDs.

From observations, it is known that the Type Ia Supernova rate in a galaxy scales with its near-infrared luminosity: for E/S0 galaxies $\dot{N}_{SNIa} \approx 3.5 \cdot 10^{-4}\ \text{yr}^{-1}$ per $10^{10}\ L_{K,\odot}$. If the WD mass grows at a rate $\dot{M}$, a population of

$$N_{\rm WD} \sim \frac{\Delta M}{\dot{M}\,\langle \Delta t \rangle} \sim \frac{\Delta M}{\dot{M}} \dot{N}_{\rm SNIa}$$

accreting WDs is needed in order for one Supernova to explode on average every $\langle \Delta t \rangle = \dot{N}_{\rm SNIa}^{-1}$ years. Thus, the accretion scenario predicts a numerous population of accreting white dwarfs, $N_{\rm WD} \sim$ few $\times\ (10^2 - 10^3)$ for a typical galaxy, much more than numbers of soft X-ray sources actually observed. Therefore, although the brightest and hottest of them may indeed reveal themselves as super-soft sources, the vast majority must remain unresolved or hidden from the observer, for example by interstellar absorption. The combined luminosity of this 'sea' of accreting WDs is

$$L_{\rm tot} = L_{\rm nuc} \times N_{\rm WD} = \epsilon X \Delta M \dot{N}_{\rm SNIa}$$

where ΔM is the difference between the Chandrasekhar mass and the initial WD mass. This predicted luminosity can be compared with observations, after absorption and bolometric corrections have been accounted for.

To this end we collected archival data of X-ray (Chandra) and near-infrared (Spitzer and 2MASS) observations of several nearby gas-poor elliptical galaxies and of the bulge of M31 (Table 2.1). Using K-band measurements to predict the SNIa rates, we computed the combined X-ray luminosities of SNIa progenitors expected in the accretion scenario and compared them with Chandra observations. Obviously, the observed values represent upper limits to the luminosity of the hypothetical population of accreting WD, as there may be other types of X-ray sources contributing to the observed emission. As is clear from the Table 2.1, the predicted luminosities surpass the observed ones by a factor of $\sim 30 - 50$, demonstrating that the accretion scenario is inconsistent with observations by a large margin.

Thus, no more than ~ 5 per cent of Type Ia Supernovae in early type galaxies can be produced by accreting white dwarfs in binary systems, unless explosions of sub-Chandrasekhar white dwarfs make a significant contribution to the observed SNIa rate. As the only currently viable alternative is the merger of two WDs, this suggests that

SNeIa in early-type galaxies are predominantly due to white dwarf mergers. In late-type galaxies, on the other hand, massive donor stars are available, making the mass budget less prohibitive, so that WDs can grow to the Chandrasekhar mass entirely inside an optically thick wind or, via accretion of He-rich material from a He donor star. In addition, a star-forming environment is usually characterized by large amounts of neutral gas and dust, leading to increased absorption, obscuring the soft X-ray radiation from accreting WDs. Therefore in late-type galaxies the accretion scenario may still play a significant role. (Marat Gilfanov and Ákos Bogdán)

3 Research Activities

3.1 Solar Physics

The solar chemical composition is an important ingredient for our understanding of the formation, structure and evolution of both the Sun and our solar system. Furthermore, it is an essential reference standard against which the elemental contents of other astronomical objects are compared. M. Asplund in collaboration with his PhD student T. Pereira (ANU), N. Grevesse (Liege), A.J. Sauval (Brussels) and P. Scott (Stockholm) have undertaken a complete re-determination of all spectroscopically accessible elements with a realistic 3D hydrodynamical model of the solar atmosphere as the theoretical foundation. Non-LTE spectral line formation has been accounted for whenever possible and particular care has been exercised in employing the best possible atomic/molecular input data and avoiding problematic lines due to e.g. blends. The results were published in ARAA with the new solar chemical composition likely to become a standard reference in astronomy for many years to come. Particularly noteworthy findings are significantly lower abundances of carbon, nitrogen, oxygen and neon compared with the widely-used values of a decade ago. The new solar chemical composition is supported by a high degree of internal consistency between available abundance indicators, and by agreement with values obtained in the solar neighborhood and from the most pristine meteorites.

A. Serenelli worked on interior models of the Sun. One main goal has been to understand the effect of the solar surface abundances newly determined by M. Asplund and collaborators. Results show that inconsistencies between solar model predictions and helioseismic determination of the solar structure are present when the most recent solar abundance determinations are adopted in solar models. A solution to this problem remains elusive unless ad-hoc modifications to the physical inputs in solar models are invoked. Additional work on solar modelling focused on episodes of accretion onto the young Sun and theis effects on the present-day solar structure. Results show that, by comparing model predictions with helioseismic determination of solar structure and measured solar neutrino fluxes, it is possible to constrain the accretion history onto the early Sun. The work on solar interior models has been done in collaboration with S. Basu (Yale University), A. Ferguson (Wichita State University), M. Asplund (MPA), W. Haxton (University of California Berkeley), W. Chaplin (University of Birmingham), Y. Elsworth (University of Birmingham) and R. New (Sheffield Hallam University).

W. Hayek, M. Asplund and R. Collet used the new radiative magneto- hydrodynamics (RMHD) code "BIFROST", in collaboration with by B. Gudiksen (Oslo), V. Hansteen (Oslo), M. Carlsson (Oslo), J. Leenaarts (Utrecht) and R. Trampedach (Boulder), for 3D time-dependent simulations of surface convection in the magnetically quiet Sun. The radiative transfer module, developed by W. Hayek, includes coherent scattering for computing radiative heating/cooling rates, for a more realistic treatment of the radiation field. They could show that continuum scattering processes do not have a significant effect on the solar photospheric temperature structure. Treating line-blanketing with coherent scattering, however, leads to cooler temperatures in the high photosphere and above. Neglecting coherent scattering in solar RMHD simulations still yields a good approximation for the temperature structure of the lower photosphere, which is important for abundance measurements with synthetic 3D spectral line formation.

M. Asplund, T. Pereira (ANU) and D. Kiselman (Stockholm) have obtained high spatial and spectral resolution observations of the solar atmosphere using the Swedish Solar Telescope on La Palma in order to test the new generation of 3D hydrodynamical solar model atmosphere and non-LTE spectral line formation calculations. In particular they focused on the atomic oxygen lines that are crucial for the recent dramatic reevaluation of the solar oxygen abundance. Both the spatially resolved and center-to-limb behaviour of the lines could be excellently reproduced with the new 3D modelling. In addition, a comparison with the continuum center-to-limb variation, spectral energy distribution, detailed line profiles and asymmetries and H line wings revealed very good agreement, significantly better than any of the tested 1D models. This further reinforces the view that the 3D modelling is highly realistic and a reliable tool to derive the solar chemical composition.

U. Anzer and P. Heinzel (Ondřejov Observatory, Czech Rep.) reconsidered the problem of the energy balance in solar prominences. They found that the dominant radiative losses come from singly ionised calcium (CaII). On the basis of detailed radiative transfer calculations the temperatures at which the losses due to calcium balance the gains from hydrogen were determined to be between 4300 K and 5200 K. U. Anzer, S. Gunár and P. Heinzel (Ondřejov Observatory) continued their investigation of Lyman line profiles in prominences. On the basis of a large sample of randomly generated multi-thread models they calculated the distributions of the total line intensities, the Lyman decrements, the line asymmetries and the central reversals. For the first three quantities a good agreement between the calculated and the observed distributions were found. The calculated central reversals, however, turned out to be much deeper than the observed ones, the reasons for which will hopefully be clarified with more realistic fine-structure models.

3.2 Stellar physics

The most recent solar abundances by Asplund (MPA) and co-workers reset the abundance scale of all stars. There are claims that this leads to difficulties in reproducing stellar cluster colour-magnitude-diagrams. A group of MPA scientists (Z. Magic, A. Serenelli, A. Weiss) together with B. Chaboyer (Dartmouth College) have been investigating this in greater detail. The conclusion for the open cluster M67, which has solar metallicity, is that both the old and new abundance scale allow for fits of good quality. The validity of the new solar abundances thus cannot be verified with such tests.

The new and extended grid of Asymptotic Giant Branch models with consistent treatment of carbon enhancement due to the third dredge-up by A. Kitsikis (MPA) have been published by A. Weiss (MPA) and J. Ferguson (Wichita Univ.). This large dataset is particularly valuable for population synthesis models, and is already used by M. Salaris (Liverpool) and L. Piovan (Univ. of Padova) in a project with A. Weiss to predict colours of Asymptotic Giant Branch with thick dust envelopes.

M. Cruz is using the same version of the Garching stellar evolution code to perform nucleosynthetic studies in zero or very low metallicity intermediate-mass stars. The code was further improved by the inclusion of an extended proton-capture nuclear network. She could already show that elements such as Al, Mg, Si are produced to the level of 10^{-10} and a study of these nuclei as seed for s-process is under way.

P. Jofré Pfeil is studying stellar populations of the Milky Way's halo, using turn-off temperatures as an age indicator. The SEGUE-part of the Sloan Digital Sky Survey contains more than 6000 such turnoff halo stars with low resolution spectra. In collaboration with A. Weiss and B. Panter (Edingburgh) she has developed a tool to automatically and rapidly estimate the basic atmosphere parameters (metallicity, effective temperature and surface gravity) for large numbers of stars from their spectrum. The effective temperature–metallicity diagram will allow an estimate of the age–metallicity relation.

V. Silva Aguirre, A. Serenelli and A. Weiss, together with J. Ballot (Toulouse), are developing stellar evolution models of solar-like and red-giant stars to compare the current theoretical framework with the most precise oscillation data ever, obtained by the KEPLER satellite mission. Special attention is given to mixing processes in the core of the stars to test the current theories of convection, semiconvection and overshooting.

In connection with the KEPLER project on asteroseismology A. Weiss started a stellar model calibration inititiative for red giants. This is a follow-up project of a similar activity for a workshop at the Lorentz Center in Leiden, during which the first comparison of red giants models from different stellar evolution codes was done, as well as a comparison of theoretical surface temperatures with cluster giant branches. The aim is to be able to provide reliable red giant models, as they are crucial for determinig ages and compositions of old stellar systems.

M. Bergemann, working together with Martin Asplund, developed atomic models to perform non-LTE spectral line formation for several Fe-peak and rare-earth elements, Co, Cr, Ti, and Ba. With these models, she performed abundance analysis of cobalt and chromium for the Sun and metal-poor Galactic stars and showed that entirely different trends of [Co/Fe] and [Cr/Fe] with [Fe/H] result when non-LTE effects on abundances are taken into account. Co abundances are systematically higher than that of Fe in metal-poor stars, whereas the trend of [Cr/Fe] is solar at all metallicities. These trends, combined with the recently discovered flat [Mn/Fe] ratios in metal-poor stars, can not be reproduced by models of Galactic chemical evolution with standard prescriptions for explosive nucleosynthesis yields. For titanium, non-LTE corrections to abundances from -0.05 to 0.15 dex are found. Ti is often used to measure a total α-element enhancement in a star, hence the non-LTE result suggests either upward or downward revision of $[\alpha/\mathrm{Fe}]$ in the halo and thick disk objects, depending on the ionization stage of Ti used in abundance calculations. The new sophisticated model of Ba is being used in collaboration with I. Ramirez and P. Baumann in calculations of Ba abundances in stars of the thick and thin disks to test whether [Ba/Fe] ratio can be used to discriminate between two stellar disk populations.

M. Asplund has together with K. Lind (ESO) and P. Barklem (Uppsala) investigated the detailed spectral line formation of lithium in late-type stars. In particular the team included in their analysis new atomic calculations of collisional cross-sections, which quantitatively change the results compared with previous studies. Departures from LTE are significant and are driven by the competing effects of ultraviolet over-ionization and photon losses in the 670.8 nm resonance lines. The non-LTE abundance corrections are pronounced especially for high Li abundances.

L. Casagrande, I. Ramírez, J. Meléndez (CAUP), M. Asplund and M. Bessell (ANU) have been working on the absolute calibration of the effective temperature scale via the infrared flux method. Thanks to solar twins and HST spectrophotometry, for the first time the uncertainty on the zero point of the temperature scale has been reduced to few tens of Kelvin, breaking the typical 100 K impasse which has plagued previous works in the field. Such accuracy is crucial to determine absolute stellar abundances, which is a central topic in so many areas of modern astrophysics.

L. Casagrande, I. Ramírez and M. Asplund have together with J. Meléndez (CAUP) applied the new temperature scale to study the primordial Li Spite plateau. They have found evidence for a mass dependent lithium depletion in old, metal-poor stars. This result can be explained from stellar models including diffusion and turbulence with a depletion pattern which would naturally bring the measured lithium abundances into agreement with Standard Big Bang nucleosynthesis.

Reliable effective temperatures are also needed for testing stellar models in the theoretical Hertzsprung-Russell diagram, thus bypassing the uncertainties related to synthetic color-temperature transformations. L. Casagrande, L. Portinari (Turku), and C. Flynn (Turku) have studied the broadening of field stars in the low Main Sequence and highlighted the possible connection between shortcomings in stellar models and the overwhelmingly large helium abundances inferred from Globular Clusters with multiple Main Sequences. A downward revision of the helium content in a subpopulation of those clusters would facilitate their interpretation in terms of stellar nucleosynthesis and chemical evolution models.

Towards the end of their lives, stars with masses between roughly 10 and 25 $M_\odot$ become red supergiants (RSG), which are the largest and brightest stars known. These stars have effective temperature ($T_{\rm eff}$) ranging from 3400 to 4100 K, luminosities of 20000 to 300000 $L_\odot$, and radii up to 1500 $R_\odot$. There are a number of open issues related to these stars: (i) they shed large amounts of mass back to the interstellar medium, but their mass-loss mechanism is unidentified; (ii) their chemical composition is largely unknown due to difficulties in analyzing their spectra with broad, asymmetric lines with variations suspected to stem from a convection pattern consisting of large granules and (super)-sonic velocities.

A. Chiavassa has together with B. Plez and E. Josselin (both Montpellier) and B. Freytag (Lyon) investigated the possibility for detecting and characterizing granulation (i.e., contrast, size) on red supergiants using three-dimensional simulations of stellar convection. They demonstrated that such simulations provide an excellent fit to existing interferometric observations of the prototypical supergiant Betelgeuse. This confirms the existence of large convective cells on the surface of red supergiants.

An international team lead by A. Chiavassa and involving observers (S. Lacour and X. Haubois, Paris; F. Millour and T. Driebe, Bonn; M. Wittkowski, ESO; E. Thiébeaut, Lyon) and theoreticians (B. Plez and E. Josselin, Montpellier; B. Freytag, Lyon; and M. Scholz, Heidelberg) unveiled for the first time the photosphere of the very cool late-type star VX Sgr using interferometric observations with the VLTI/AMBER and performing image reconstruction for different wavelength bin. The study of this star is particularly important because its classification is rather uncertain. VX Sgr shows high luminosity typical of red supergiants but also very low temperature and large variability typical of Mira stars. VX Sgr is also a candidate for the predicted but not yet discovered, super-AGB stars. Using 3D hydrodynamical stellar convection simulations, the team could assess that the atmosphere of VX Sgr resembles more Mira/AGB stars than red supergiants. In particular, they found molecular (water) layers that are typical for Mira stars.

R. Collet, M. Asplund, W. Hayek, Å. Nordlund (Copenhagen) and R. Trampedach (Canberra) have carried out high-resolution simulations of convection at the surface of metal-poor red giant stars using a parallel 3D radiative hydrodynamical code, with realistic input physics and non-grey radiative transfer. A local adaptive mesh was implemented in the radiative transfer calculations to adequately resolve steep vertical temperature gradients in the atmospheres of these stars as well as their corrugated optical surfaces. In particular, the code has been used to produce a realistic surface convection simulation of the template metal-poor star HD122563 whose chemical composition is generally regarded as a point of reference in abundance analyses of giant stars at low metallicity. R. Collet and collaborators have computed synthetic line profiles using the HD122563 simulation as a 3D model stellar atmosphere and compared them with the results of calculations based on a classical 1D hydrostatic model atmosphere of the star. They have investigated the systematic differences between 3D and 1D abundance analyses of HD122563 and found that, due to the cooler upper photospheric temperature stratification of the 3D model, with the assumption of local thermodynamic equilibrium the oxygen and iron abundances are lower by a factor 3-10 in the 3D analysis than in the 1D one.

In the framework of 3D stellar surface convection simulations, R. Collet M. Asplund, W. Hayek, and R. Trampedach (Canberra) have implemented and tested an improved version of the multigroup method to effectively include line-blanketing in the radiative transfer calculations. The new scheme has been tested in particular with simulations of convection at the solar surface where it has led to a major improvement in terms of predicted temperature stratification as viewed from a comparison of observed and computed center-to-limb intensity variations in the Sun. For metal-poor dwarfs and turnoff stars the new scheme largely confirms the cool temperature stratification in the upper atmospheric layers predicted by previous 3D simulations. Similar calculations are currently underway for metal-poor red giant stars.

Improvements on stellar parameter determination and chemical abundance studies of OB-type stars have become more efficient after the calculation of new grids of synthetic non-LTE spectra based on the latest model atoms by M. F. Nieva in collaboration with N. Przybilla (Bamberg). Most of the analysis has been automatized allowing to analyze larger samples of stars at the same high precision than previously. The first application concentrated on a sample of ~ 25 stars in the solar neighbourhood that confirms the high homogeneity previously found by the team. M. F. Nieva, N. Przybilla (Bamberg) and S. Simon-Diaz (IAC) have also studied early B-type stars in the Orion association. They have demonstrated that the stars show a high degree of chemical homogeneity and no correlation with age within the association subgroups in contrast to previous investigations.

M. F. Nieva together with A. Irrgang, U. Heber and N. Przybilla (all Bamberg) have investigated runaway stars in the Milky Way. Comparison of a normal B-star in the solar neighbourhood with a runaway star of similar parameters allow to study the chemical peculiarity of the runaway and together with kinematic analyses it puts constraints for its origin mechanism. She has also analysed a late O-type star that was a target for the CoRot satellite together with C. Aerts (Leuven). This has provided constraints on the previously relatively poorly understood interior structure of such stars.

M. F. Nieva, N. Przybilla (Bamberg) and A. Seifahrt (Göttingen) have made a detailed study of the previously unexplored near-IR part of the spectrum of OB-stars based on high-resolution CRIRES spectra and detailed non-LTE spectral synthesis. Most observed H, He and metal lines have been reproduced and the quantitative analysis agrees with the one in the optical. This opens up this wavelength region for future analyses, which will be crucial for studies of for example massive stars in star-forming regions or near the Galactic center where the obscuration is high. It also provides useful quantitative information for telluric line removal of other kind of object at lower resolution.

A. Serenelli has worked on modelling of low-mass helium core white dwarf stars. In collaboration with R. Strickler (Santa Cruz), A. Cool (San Francisco), J. Anderson (STScI, H. Cohn and P. Lugger (both Indiana), he has shown that the helium-core white dwarfs in the globular cluster NGC 6397 have a radial distribution that supports a formation scenario where these white dwarfs were formed in binary systems through mass transfer/loss episodes of the white dwarf progenitor onto a more massive companion.

M. Asplund, I. Ramírez, J. Meléndez (Porto), B. Gustafsson (Uppsala) and D. Yong (Canberra) have determined very precisely the chemical composition of a number of stars very similar to the Sun using high-quality observations obtained with the Magellan, McDonald and Keck telescopes. They have found statistically significant correlations between the elemental abundances and condensation temperature which suggest that the Sun is slightly deficient in refractory elements. This result has been attributed to the formation of terrestrial planets in the solar system because the refractory elements have been locked-up there. In this respect the Sun is unusual but not unique: $\sim 20\%$ of stars resemble the Sun chemically and are thus prime candidates for hosting terrestrial planets. This opens up the truly enthralling prospect of identifying stars harbouring Earth-like planets purely by a detailed investigation of the stellar chemical compositions.

Together with C. Allende Prieto (London), L. Koesterke (Texas), and D.L. Lambert (Texas), I. Ramírez and M. Asplund have compared detailed spectral line profiles predicted using a three-dimensional hydrodynamic model atmosphere for a K-type dwarf star with very high resolution observations. Very good agreement was found between model and observations which validated the 3D model atmosphere, in particular for use in the derivation of stellar parameters and chemical compositions of K-dwarfs.

J. Cuadra, C. Baruteau and D. Lin (both at Santa Cruz) are studying numerically the evolution of binary stars embedded in a gaseous disc. Fragmentation of a massive accretion disc is the likely origin of the young stars observed in the inner parsec of the Galaxy, and some of the stars are expected to form as binaries. The left-over gas affects the young binaries, hardening their orbits while making them migrate towards the central black hole. The balance between these two processes will determine the observable stellar population and dynamics.

Compact binaries, i.e. binary systems in which at least one of the two components is a compact star (white dwarf, neutron star, black hole), are of considerable astrophysical interest. One of the ongoing activities in the theory of stellar structure and evolution concerns the formation and evolution of such binaries. As an ongoing service to the community working on compact binaries H. Ritter has continued compiling the data for the regular updates of the "Catalogue of Cataclysmic Binaries, Low–Mass X–Ray Binaries and Related Objects" which is available only on-line since 2003. In collaboration with U. Kolb (Open University), two new releases of this catalogue (the latest as of 1 July 2009) have been issued (with the next release due 1 January 2010).

3.3 Supernovae

The modeling of both, core-collapse and thermonuclear supernovae continued to be a field of very active research at MPA also in 2009.

N. Hammer, H-.Th. Janka and E. Müller performed the first 3D simulations of the large-scale mixing that takes place in the shock-heated stellar layers ejected in the explosion of a massive star. The blast is initiated and powered by neutrino-energy deposition behind the stalled shock by means of choosing sufficiently high neutrino luminosities from the contracting, nascent neutron star, whose high-density core is excised and replaced by a retreating inner grid boundary. The outgoing supernova shock is followed beyond its breakout from the stellar surface about two hours after the core collapse. Violent convective overturn in the post-shock layer causes the explosion to start with significant large-scale asphericity, which acts as a trigger of the growth of Rayleigh-Taylor instabilities at the composition interfaces of the exploding star. Deep inward mixing of H is found as well as fast-moving, metal-rich clumps penetrating with high velocities far into the H-envelope of the star as observed, for example, in the case of Supernova 1987A. The metal core of the progenitor is partially turned over with Fe-dominated fingers overtaking O-rich bullets and both Fe and O moving well ahead of the material from the C-layer. Comparing with corresponding 2D (axially symmetric) calculations, they found the growth of the Rayleigh-Taylor fingers to be faster, the deceleration of the dense metal-carrying clumps in the He and H-layers to be reduced, the asymptotic clump velocities in the H-shell to be higher, and the outward radial mixing of heavy elements and inward mixing of H to be more efficient in 3D than in 2D. They present a simple argument that explains these results as a consequence of the different action of drag forces on moving objects in the two geometries.

B. Müller in his PhD work, supervised by H.-Th. Janka, developed a new one- and two-dimensional general relativistic code for simulating stellar core collapse and supernova explosions including three flavor, energy-dependent neutrino transport. The code was constructed by a merge of the CO-CONUT hydrodynamics solver, provided by H. Dimmelmeier (Univ. Thessaloniki), and the VERTEX ray-by-ray two-moment transport solver with variable Eddington factor closure of M. Rampp and H.-Th. Janka. The code was extensively tested in 1D and 2D and is now applied for different questions of stellar core collapse.

The neutrino emission from the onset of stellar core collapse to the late stages of the cooling of the nascent neutron star was studied for oxygen-neon-magnesium core supernovae in a Diploma project by L. Hüdepohl, using the PROMETHEUS/VERTEX neutrino-hydro code with three-flavor energy-dependent neutrino transport. The project was supervised by A. Marek, B. Müller and H.-Th. Janka and conducted in collaboration with G. Raffelt (MPI for Physics, Munich). With a state-of-the-art description of neutrino-matter interactions, the hot proto-neutron star cools significantly faster than expected from previous models and the spectra of electron antineutrinos and heavy-lepton neutrinos are very similar and only slightly harder than those of electron neutrinos. This leads to a proton excess in the neutrino-driven wind also at late times and thus excludes these ejecta from ONeMg core supernovae as r-process site.

S. Wanajo, H. -T. Janka, and B. Müller explored nucleosynthesis in electron-capture supernovae of AGB stars. The nucleosynthesis calculations were applied to the thermodynamic trajectories of the self-consistent explosion model of a $9 M_\odot$ star (an oxygen-neon-magnesium core) with a state-of-the-art 1D hydrodynamic simulation. Our result shows that, with a reasonable variation of the electron-to-baryon ratio of the ejecta, this type of supernovae can be the major source of ^{64}Zn (the dominant isotope of Zn) and ^{92}Mo, whose astrophysical origins are currently unknown. This is the first result in the series of our nucleosynthesis studies with the self-consistently exploding models of a $9 M_\odot$ star, and the next one with the 2D-hydro version is on going.

Previous studies of type IIP (core-collapse) supernovae have inferred that progenitor masses recovered from hydrodynamic models are higher than 15 $M_\odot$. To verify the progenitor mass of this supernova category, V. Utrobin and N. Chugai (guests at MPA) attempt a parameter determination of the well-observed luminous type IIP supernova 2004et. They modeled the bolometric light curve and the photospheric velocities of SN 2004et by means of hydrodynamic simulations in an extended parameter space. From hydrodynamic simulations and observational data, they infer a presupernova radius of $1500 \pm 140 R_\odot$, an ejecta mass of $24.5 \pm 1 M_\odot$, an explosion energy of $(2.3 \pm 0.3) \times 10^{51}$ erg, and a radioactive ^{56}Ni mass of $0.068 \pm 0.009 M_\odot$. The estimated progenitor mass on the main sequence is in the range of $25 - 29 M_\odot$. In addition, we find clear signatures of the explosion asymmetry in the nebular spectra of SN 2004et. The measured progenitor mass of SN 2004et is significantly higher than the progenitor mass suggested by the pre-explosion images. They speculated that the mass inferred from hydrodynamic modeling is overestimated and crucial missing factors are multi-dimensional effects.

F. Meyer has shown that the pattern of alternating mass distribution around the circumference of the inner ring in SN 1987A, now illuminated by the impact of the arriving SN ejecta and understood as a result of Rayleigh-Taylor instability in the formation process of the inner ring, by their radial orientation point to the presence of a shear flow between polar and equatorial expansion velocity in the original red giant wind. This seems to support models for the stellar wind formation in the literature.

S. Hachinger, in collaboration with D. Sauer (Stockholm) used his newly-written NLTE excitation/ionisation solver to synthesize spectra of supernovae Ib/c with Helium lines. Helium lines are the feature distinguishing SNe Ib from SNe Ic, but as yet it has been unclear how much Helium physically must be contained in the objects to produce the lines. With the aim of exploring the differences of SNe Ib to SNe Ic, and connecting to progenitor studies of SNe Ib/c, S. Hachinger plans to analyze more objects and infer Helium abundances in SNe Ib as well as upper limits to Helium abundances in SNe Ic.

P. Mazzali and collaborators looked at various aspects of core-collapse SNe. In particular, they continued to investigate GRB-SNe and events that are possibly similar. In two papers in collaboration with K. Nomoto and the University of Tokyo group, they examined the late-phase spectra of the XRF-SN 2008D: spectroscopic and polarimetric evidence both suggest that the explosion of 08D was rather aspherical. This seems to be in good agreement with the former conclusion that the XRF in 08D was not so much shock breakout but rather the emergence of a choked jet on the surface of a WR star.

In a paper that appeared in Nature (Gal-Yam et al.) P. Mazzali and collaborators studied a very luminous SN, and found that it must have ejected at least 60 solar masses of material. This qualified SN2007bi as the first bona fide "Pair Instability" SN, an explosion of a very massive star driven by a collapse that is initiated by the destruction of electrons as they produce e^+e- pair in their very dense cores.

P. Mazzali and collaborators also discovered and described possibly the least massive core-collapse SN known to date. In a paper that also appeared in Nature, Valenti et al. described SN2008ha, a very faint SN which ejected much less than 1 $M_\odot$. This was possibly the result of another mode of explosion which has been theoretically predicted but has not yet been observed: the accretion-induced collapse of an O-Ne-Mg white dwarf.

In a series of two papers (Hamuy et al. on the observations, Mazzali et al. on the models) P. Mazzali described the first known Type IIb hypernova. This event was similar to the classical SN 1993J, but was much more massive and energetic. They could show that explosion energy does not depend on complete stripping of the core, but that it is much more likely to be related to progenitor mass.

In 2009 P. Mazzali joined the Palomar Transient Factory (PTF) consortium, first on an individual, invitational basis, and then on a full basis. It is expected that the survey will be the work-horse for the discovery of new transient events at cadences from hours to weeks, and that it will uncover areas of science that have not been investigated so far.

Global (SPH and AMR) simulations suggest that Kelvin-Helmholtz instabilities of the shear flows in the contact layer of two merging neutron stars may amplify a weak seed field to a very large field strength. To check the validity of these claims by an independent numerical approach, M. Obergaulinger, E. Müller and M.A. Aloy (University of Valencia, Spain) performed high-resolution simulations of representative model systems of such shear flows. In a comprehensive parameter study, they determined the saturation of the field growth in two and three dimensions as a function of the shear velocity, the initial field, and the grid resolution. They found that the field can be amplified at most to a strength corresponding to local equipartition with the kinetic energy, limiting the field strength achievable to $\sim 10^{16}$ G.

Investigations of all aspects of Type Ia supernovae, including their role as cosmic distance indicators, were in the focus of W. Hillebrandt's division. The explosion mechanism of Type Ia supernovae is explored in the Emmy Noether research group "Comprehensive Modeling of Type Ia Supernova Explosions" led by F. Röpke. Different scenarios were studied in multidimensional hydrodynamic simulations. In particular, the work focused on Chandrasekhar-mass models, sub-Chandrasekhar mass models and mergers of two white dwarfs. The explosion stage was simulated up to a stage where the results could be mapped into the radiation transfer simulations of S. Sim and M. Kromer. The derived observables are used to compare the models with observations of Type Ia supernovae and to validate them. Pure deflagration in Chandrasekhar-mass white dwarfs can probably account for a sub-class of Type Ia supernovae while delayed detonations remain a candidate for explaining normal to bright events.

In his diploma work, P. Edelmann (supervised by F. Röpke) investigates the propagation of thermonuclear flames in white dwarf matter on microscopic scales with one-dimensional hydrodynamic simulations. C. Auer investigated techniques to accurately implement level-set method in hydrodynamic simulations in his diploma project (supervised by F. Röpke). The level-set method is used to track thermonuclear flames in Type Ia supernova explosion simulations. In his PhD thesis F. Ciaraldi-Schoolmann studies the properties of high turbulent velocity fluctuations in the deflagration to detonation transition (DDT) scenario in Type Ia supernova simulations. Based on an analysis of F. Röpke in 2007, these properties are analyzed by computing probability density functions of the velocity fluctuations and fitting them with an appropriate fit function. If the cumulative probability of finding high enough fluctuations in sufficient large patches of the burning front exceeds a certain threshold, the DDT is triggered. At the moment this criteria is tested with different resolutions and ignition scenarios.

Within his PhD project jointly supervised by F. Röpke and W. Hillebrandt, M. Fink continued investigating the sub-Chandrasekhar supernova scenario. Progenitor systems with parameters physically motivated from AM Canum Venaticorum binaries with a helium WD donor and a C/O WD accretor were used. Minimum-mass helium-shell detonations in these systems were found to robustly trigger a secondary core detonation. Nucleosynthesis was calculated using an improved treatment for nuclear burning calibrated to a large nuclear network in hydrodynamic simulations and successive post-processing. The nucleosynthetic yields of the helium detonation were found to be different from previously published values. This may leave an imprint on the observables of the explosion. As a second project, simulations of delayed detonations in rapidly rotating WDs were carried out. To this end, rotating initial models were calculated and the gravity solver and the fictitious force terms in the supernova code were modified.

R. Pakmor, M. Kromer, F. K. Röpke, S. Sim, A. Ruiter and W. Hillebrandt used a series of simulations to study the complete evolution of a binary system of two merging white dwarfs. Using the SPH code GADGET2 they could show that a violent merger of two equal-mass white dwarfs reaches the conditions to ignite a detonation. Thus they showed for the first time, that the merger of two white dwarfs can lead to a thermonuclear explosion. They followed the detonation on a grid code, and the detailed nucleosynthesis via tracer particles. Using these they were able to compute synthetic lightcurves and spectra of this explosion. Comparing spectra and lightcurves to observations, they found excellent agreement with observed Type Ia Supernovae of the subclass of 1991bg-like events. The results were published in Nature.

Although there is a nearly universal agreement that SNeIa are associated with the thermonuclear disruption of a CO white dwarf upon reaching the Chandrasekhar mass limit, the exact nature of their progenitors is still unknown. A white dwarf may accrete matter from a non-degenerate companion star in a binary system, gradually increasing its mass until the nuclear runaway starts. Alternatively, the detonation may be triggered by a coalescence of two white dwarfs in a compact binary. While no significant X-ray radiation is expected in the merger scenario until shortly before the supernova, accreting white dwarf becomes a sources of copious X-rays for about 10^7 years before the explosion. This offers a means to determine which scenario dominates. M.Gilfanov and A.Bogdan have shown that X-ray flux from a sample of seven early-type galaxies detected by Chandra is factor of $\sim 30 - 50$ times less than predicted in the accretion scenario. Therefore no more than ~ 5 per cent of SNe Ia in early type galaxies can be produced by accreting white dwarfs, unless explosions of sub-Chandrasekhar white dwarfs make a significant contribution to the supernova rate.

There are also other indications that not all Type Ia supernovae are explosions of white dwarfs (WDs) approaching the Chandrasekhar-mass ($M_{\rm Ch}$) stability limit of $\sim 1.4\ M_\odot$. However, a recently discovered subclass seems to deviate from this scheme. Its members are by a factor ~ 2 more luminous than ordinary Type Ia SNe, have slowly evolving light curves and low ejecta velocities, inconsistent with expectations from the $M_{\rm Ch}$ scenario. This is why strongly rotating super-$M_{\rm Ch}$ WDs or massive WD mergers have been proposed as possible origins of these events. With the aim of pinning down the nature of these overluminous SNe Ia, S. Taubenberger and collaborators have collected an extensive optical and near-IR data set of SN 2009dc, the best ever obtained for such an object. SN 2009dc has a peak luminosity that requires more than 1.2 $M_\odot$ of radioactive ^{56}Ni. The unusually low ejecta velocities inferred from spectral lines indicate a low kinetic energy to ejecta mass ratio, supporting the idea of a super-$M_{\rm Ch}$ explosion. Left-over carbon, revealed by unprecedentedly strong C II lines in early spectra, indicates low densities and incomplete burning in the outer layers.

Exploring possible explosion channels for SN 2009dc has turned into a collaborative effort within the MPA SN Ia group, guided by W. Hillebrandt and P. Mazzali. S. Hachinger has applied the method of abundance tomography to the densely sampled early-time spectra of SN 2009dc in order to constrain the chemical stratification of the ejecta and the density profile of the explosion. M. Fink has run hydrodynamic explosion simulations of heavily rotating super-$M_{\rm Ch}$ WDs, and R. Pakmor has studied the feasibility of WD mergers to explain SNe like 2009dc.

P. Mazzali also continued his study of supposedly super-Chandrasekhar SNe Ia. In collaboration with K. Nomoto and the Tokyo University group they observed and analysed SN2006gz in the nebular phase. The lack of emission lines of Fe in the spectra is difficult to reconcile with any type of SN Ia explosion.

S. Hachinger (in collaboration with P. Mazzali, S. Taubenberger R. Pakmor and W. Hillebrandt) continued the analysis of the subluminous Type Ia supernova 2005bl. An abundance tomography was performed, and repeated with different density profiles (MNRAS, 399, 1238). Thus, not only abundances but the density profile could be inferred. They found that the explosion ejected less mass at high velocities than usual SNe Ia, and that nucleosynthesis in the object was largely incomplete, with intermediate-mass elements (Si, O, ...) as main products. To produce these nucleosynthesis yields, one needs a detonation at low densities. Finally, the properties of the object they found were well reproduced in the white-dwarf merger simulations of R. Pakmor.

P. Mazzali continued the investigation of the properties of various types of Supernovae through the analysis of observational data. For SNe Ia, a second paper on the presence of variable Na I lines in the spectra at early times, which may be indicative of the presence of CSM near the site of the explosion, and therefore possibly linked to the mass donor in the progenitor binary system, was published (Simon at al.).

The decay of ^{57}Co (the daughter nucleus of the short-lived ^{57}Ni), with a half-life of 272 days, has been thought to give a negligible contribution to late-time SN light curves. Decaying to 100% via electron capture, ^{57}Co does not emit positrons which could interact with the SN ejecta and heat them. However, I. Seitenzahl, S. Taubenberger and S. Sim have shown that due to the nuclear structure of the daughter ^{57}Fe, with a particularly low-lying exited state, a significant amount of energy in the ^{57}Co decay is released in the form of internal-conversion and Auger electrons, which likely deposit their energy in the ejecta rather than escape. This effect has apparently been neglected in previous studies. Taking it into account, a better agreement between observed bolometric SN light curves and those predicted on the basis of explosion models and nucleosynthesis calculations can be achieved between 600 and 1800 days after the explosion.

Finally, the MPA group began to use SNe Ia luminosity distances for cosmology. S. Benitez finished her diploma project (supervised by F. Röpke and W. Hillebrandt) on a model-independent reconstruction of the cosmic expansion rate $H(z)$ from Type Ia supernova data. The only assumption that enters into her analysis is the geometry of the Universe, i.e., the Robertson-Walker metric. Her work can be used to constrain Dark Energy models. First results, based on the most complete data set available to date, show that the standard ΛCDM cosmology fits the data well. On the other hand, certain non-standard models can be ruled out already.

3.4 Black holes and compact objects

It is well known that in addition to a handful of bright X-ray sources (usually compact binary systems) in the Galaxy there is an unresolved X-ray glow at energies above a few kiloelectronvolts extended along the Galactic plane. This glow was discovered some 25 years ago and was dubbed Galactic X-ray Ridge. E. Churazov, R. Sunyaev in collaboration with Revnivtsev (Excellence Cluster Universe, IKI), S. Sazonov (IKI), W. Forman (CfA), A. Vikhlinin (CfA) used a megasecond-long Chandra observation to reveal the nature of this glow. The emission has a spectrum characteristic of a $\sim 10^8$ K optically thin thermal plasma, with a prominent iron emission line at 6.7 keV. The gravitational well of the Galactic disk, however, is far too shallow to confine such a hot interstellar medium; instead, it would flow away at a velocity of a few thousand kilometres per second, exceeding the speed of sound in the gas. To replenish the energy losses requires a source of 10^{43} erg s^{-1}, exceeding by orders of magnitude all plausible energy sources in the Milky Way. An alternative is that the hot plasma is bound to a multitude of faint sources, which is supported by the recently observed similarities in the X-ray and near-infrared surface brightness distributions (the latter traces the Galactic stellar distribution). The scenario was strongly supported by Chandra observations: at energies of ∼6-7keV, more than 80 per cent of the seemingly diffuse X-ray emission is resolved into discrete sources, probably accreting white dwarfs and coronally active stars.

The jets that are observed to originate in active galactic nuclei, Gamma-ray bursts and protostars are believed to be produced by rapidly rotating obsjects like accretion disks or stars containing strong magnetic fields. The nature and origin of these strong fields is uncertain. Best for producing jets are large scale ordered fields, but in many cases it is more plausible that a smaller scale field, with mixture of field line directions is present in the central object. As part of his thesis project R. Moll has investigated the conditions for jet production by such mixed fields, with 3-D MHD simulations. The results show that efficient jet production is still possible, but provided that a strong *differential* rotation in the source. Jets produced this way can penetrate through a dense envelope surrounding the source. The results apply to Gamma-ray bursts and jets produced by protostellar disks.

A standard optically-thick accretion disc at the core of AGN is expected to produce the large optical/UV luminosity observed in these systems but it does not account for their X-ray emission. The X-rays in radio quiet AGN are assumed to be produced by Compton up-scattering of UV photons by a 'corona' of hot electrons but the relation between this structure and the accretion disc is unclear. To address this question P. Arévalo, E. Churazov, P. Lira (Universidad de Chile) P. Uttley, E. Breedt and I. M. McHardy (Southampton) studied the Seyfert Galaxy NGC 3783. Its variability in the optical bands is significantly correlated with the X-rays, indicating that the source regions are physically connected. The delay of the optical fluctuations points to reprocessing of X-rays in a part of the optically thick accretion disk. This disk then must flare out at a radius similar to that of the broad line region. The study also finds that small amplitude optical variability can be produced by reprocessing, but that the long time-scale, large amplitude fluctuations observed in the optical are intrinsic to the accretion disk. This behaviour adds to similar results recently obtained for at least three other AGN.

M. Herzog and F. Röpke conducted multidimensional hydrodynamical simulations of phase transitions in neutron stars. They started by simulating the “burning” of a neutron star to a strange star. This process is similar to the thermonuclear burning of a white dwarf in a supernova Ia, therefore the same code can be used. The first steps involved investigating if the conditions for a combustion are fulfilled and modifying the code for the new setup.

E.B. Abdikamalov (SISSA, Italy), C.D. Ott (Caltech), L. Rezzolla (AEI Golm), L. Dessart (Laboratoire d'Astrophysique, Marseille), and H. Dimmelmeier (Univ. Thessaloniki) in collaboration with A. Marek and H.-Th. Janka investigated the gravitational-wave signals from the accretion-induced collapse of rotating white dwarfs to neutron stars by 2D general relativistic simulations with an approximative treatment of the neutrino losses. The results suggest that due to stronger deleptonization during the collapse, the wave form is of “Type III” and thus distinctively different from the signals expected from the core collapse of rotating massive stars.

A. Bauswein during his PhD work, supervised by H.-Th. Janka and R. Oechslin, explored the differences between binary mergers of two neutron stars or two strange-matter stars. Strange matter is a hypothetical absolute energetic ground state of matter and could make the constitution of compact supernova remnants instead of nucleonic matter. The relativistic merger simulations showed that characteristic differences of the gravitational-wave emission will allow for an identification of the nature of the merging objects by measurements with upcoming interferometric detectors, if the strange stars are more compact than neutron stars.

M. Ruffert (Univ. Edinburgh) as a sabbatical visitor to MPA in collaboration with H.-Th. Janka has performed Newtonian hydrodynamical simulations of polytropic neutron stars with black holes. The latter were decribed by a pseudo-relativistic gravitational potential that captures the existence of an innermost stable circular orbit. The Newtonian simulations exhibit similar trends as general relativistic calculations, although with significant quantitative differences. A clear separating line between mass-shedding and gravitational capturing limits as suggested by analytical arguments is absent.

R. Krivonos, S. Tsygankov, E. Churazov, R. Sunyaev and M. Revnivtsev (Excellence Cluster Universe, IKI) developed new analysis algorithms which led to a substantial improvement of sensitivity of the IBIS soft gamma-ray imager aboard ESA's INTEGRAL observatory. Using these algorithms a 7-year ultra deep survey of Galactic Plane in the hard X-ray (17-60 keV) band has been analyzed. This new survey allowed them to significantly extend the study of the faint end of galactic X-ray binaries population with luminosities $\sim 4\ 10^{34}\ erg\ s^{-1}$ (at the distance of the Galactic Center). Follow-up observations with the XRT telescope on triggered an extensive optical follow-up program to refine the positions, measure the spectra, and establish the nature of unidentified INTEGRAL sources. This program was done in collaboration with I. Bikmaev (Kazan State University) and R. Burenin (IKI, Moscow) using the RT 1.5-meter telescope in Turkey. Most of the sources show clear signs of low energy absorption, indicating that with INTEGRAL's sensitivity at high photon energy a population of highly obscured Galactic objects starts to show up. The sample of extragalactic sources detected in the survey has doubled compared to previous INTEGRAL survey conducted by high energy group at MPA. The completeness of the AGN sample is sufficient to obtain a statistically clean sample of extragalactic objects, which is crucial for such studies as the energy output of supermassive black holes and the clustering of Active Galactic Nuclei in the local Universe.

X-ray pulsars are unique laboratories to study matter under extreme conditions of very strong magnetic fields and gravity. Using the data from several X-ray observatories M. Revnivtsev (Excellence Cluster Universe; IKI), E. Churazov, K. Postnov (Sternberg Institute, Moscow) and S. Tsygankov have found a distinct break in the Power Density Spectra of flux variability of accreting magnetized neutron stars and white dwarfs. The break in the PDS is a natural manifestation of the transition from the accretion disk to magnetospheric flow at the frequency characteristic for the inner edge of the accretion disk. The proximity of the PDS break frequency to the neutron star spin frequency in corotating pulsars strongly suggests that the typical variability time scale in accretion disks is close to the Keplerian one. In transient accreting X-ray pulsars characterized by large variations of the mass accretion rate during outbursts, the PDS break frequency follows the variations of the X-ray flux, reflecting the change of the magnetosphere size with the accretion rate.

S. Tsygankov and A. Lutovinov (IKI, Moscow) have studied spectral properties of X-ray pulsars emission during most powerful outbursts. They have shown that the energy of the cyclotron absorption line is not constant, but is linearly increasing when the source luminosity is decreasing. Such a behavior is fully consistent with theoretically predicted variations of the height of the radiation-dominated shock above the neutron star surface. In addition, the hypothesis of hysteretic behaviour of the observed radiation during the brightening and fading phases of the outburst can be ruled out.

Z. Zhongli, M. Gilfanov and R. Voss (MPE) did a systematic survey for faint low mass X-ray binaries in globular clusters (GC-LMXBs). In seven nearby galaxies (M31, Centaurus A, M81, Maffei 1, NGC 3379, NGC 4697, NGC 4278) and the Milky Way 188 GC-LMXBs were used to construct a combined luminosity function with much better statistics than previous study. Compared with the luminosity function of field LMXBs, a deficiency of the number of GC-LMXBs was confirmed at the low luminosity end (from a few times 10^{36} erg s^{-1} to $\sim 10^{35}$ erg s^{-1}). This shows that not all field LMXBs have the same formation history as GC-LMXBs.

Z. Zhang, M. Gilfanov and R. Voss (Excellence Cluster) in collaboration with scientists from CfA, Virginia and Michigan Universities undertook a systematic survey of nearby galaxies observed by Chandra to study dynamical formation of low-mass X-ray binaries in globular clusters. They found statistically significant difference between the luminosity distribution of globular cluster and that of field sources with the relative underabundance of faint sources in the globular cluster population. This may disprove the hypothesis that the entire LMXB population in early type galaxies is created dynamically in globular clusters. A plausible explanation for this difference in XLFs is the enhanced fraction of helium accreting systems in globular clusters, which are created in collisions between red giants and neutron stars. Due to the four times higher ionization temperature of He, such systems are subject to accretion disk instability at ≈ 20 times higher mass accretion rate, and therefore are not observed at low luminosities.

P. Cerdá-Durán, in ongoing work with I. Cordero-Carrión (University of Valencia, Spain) and J.M. Ibañez (University of Valencia, Spain) have applied the Meudon formalism of the Einstein equations (FCF) to extract waveforms from rotating neutron stars. This is an intermediate step towards the developing of a full general relativistic code.

M. Gabler, P. Cerdá-Durán, E. Müller, J.A. Font (Universidad de Valencia) and N. Stergioulas (Aristotle University of Thessaloniki) investigated the torsional oscillations of the elastic crust of a highly magnetized neutron star. They extended the 2D, ideal-MHD code of P. Cerdá-Durán "MCoCoA" to include the effects of the crust. Two different approaches have been applied: a linear evolution of the crust and a method using a Riemann solver. The second approach have been shown to be superior with respect to damping. As a first result the purely shear oscillations of the crust are recovered satisfactory.

M. Gabler, U. Sperhake (California Institute of Technology, Pasadena) and N. Andersson (University of Southampton) studied radial non-linear oscillations in compact stars. A numerical scheme specially tailored for such a study is based on formulating the time evolution in terms of deviations from a stationary equilibrium confguration. Using this technique, they investigate over a wide range of amplitudes non-linear effects in the evolution of radial oscillations of neutron stars.

T. Mädler was working on the characteristic initial value formulation of General Relativity with the long term aim to simulate the stellar collapse of an iron core to a Neutron star in Bondi-Sachs coordinates with twisting axisymmetry. In collaboration with B. Schmidt he established the regularity conditions for the vertex of a single light cone and calculated the corresponding Einstein equations with a perfect fluid source in an affine null coordinate system by means of a Taylor expansion in the neighborhood of the origin on a central geodesic.

3.5 Accretion

Classical Novae (CN) are nuclear explosions occuring upon accumulation of a certain amount of hydrogen-rich material on the surface of a white dwarf which is collecting mass from a (binary-) companion star. The frequency of these events in a galaxy depends on the rate at which matter accretes onto the white dwarf, hence it can be related to their luminosity. The energy of accretion is radiated in the optical, ultraviolet or X-ray bands, depending on the type of the binary system. In magnetic systems (polars and intermediate polars) and dwarf novae in quiescence it is emitted predominantly in the X-ray band. Á. Bogdán and M. Gilfanov computed the X-ray luminosity of these systems in M31 based on CN rate determined from optical observations and compared with Chandra observations of this galaxy. They obtained an upper limit of ~ 5 per cent for the contribution of magnetic systems to the CN rate, and demonstrated that dwarf novae accrete at least 90 per cent of the material during outbursts, and only small fraction during quiescent periods.

The stars at the centers of accretion disks are sometimes strongly *magnetic*. If the rotation rate of such a star is fast, the accreting gas can be flung out by teh rotating m,agnetic field instead of accreting on the star; this case is called a 'propellering'. In a project for her PhD thesis, C. D'Angelo has found, however, that there exists a second form of accretion in this case (suggested already by Sunyaev and Shakura in 1977). Instead of propellering, the gas can accumulate in the inner parts of the disk and accrete through the magnetic field onto the star in a cyclic process of alternating accreting and non-accreting ('quiescent') states. This process is likely to play an important role in disks around protostars and in X-ray binary disks.

X-ray spectra of galactic black hole binaries allow to study the innermost regions of accreting black holes. Recent observations seem to indicate a thermal component in the innermost regions close to the central object, that is an inner disk. The existence of cool matter below an advection-dominated flow can be understood as resulting from re-condensation of gas from the hot flow to an inner disk. E. Meyer-Hofmeister, F. Meyer, B.F. Liu (National Astronomical Observatories, CAS, Kunming, China) have found that the transition from hard to soft spectral state in low-mass X-ray binaries can to be affected by irradiation of the corona by such an inner disk. GX 339-4 is an example for this in teraction.

P. Montero, in collaboration with M. Shibata (Kyoto University) and J.A. Font (University of Valencia), have used the Nada code to carry out the first general relativistic numerical simulations in axisymmetry of a system formed by a black hole surrounded by a self-gravitating torus, aiming to assess the influence of the torus self-gravity on the onset of the runaway instability. They considered several models with varying torus-to-black hole mass ratio and angular momentum distribution orbiting in equilibrium around a non-rotating black hole. The tori were perturbed to induce the mass transfer towards the black hole. These numerical simulations showed that all models exhibit a persistent phase of axisymmetric oscillations around their equilibria for several dynamical timescales without the appearance of the runaway instability, indicating that the self-gravity of the torus does not play a critical role favoring the onset of the instability.

3.6 Milky Way

Ages and metallicities of stars in the Solar neighbourhood are fundamental observational constraints on models of Galactic disk evolution. L. Casagrande have used the InfraRed Flux Method for nearly all stars is the Geneva-Copenhagen Survey (GCS) and determined improved effective temperatures and luminosities. The new grid of MARCS model atmospheres and spectral synthesis has been used to asses the effect of the new temperatures on the metallicities of the GCS and found major impact. L. Casagrande, I. Ramírez, M. Asplund and R. Schönrich are currently redetermining fundamental stellar parameters, ages and metallicities of the GCS in a fully consistent way. Such a wealth of homogeneous and well calibrated data will have major consequences in improving our understanding on the formation and evolution of the Galaxy, using the new chemical evolution model of R. Schönrich which includes radial migration in the disk.

M. Asplund has together with K. Lind, F. Primas (both ESO), C. Charbonnel (Geneva) and F. Grundahl (Aarhus) made a large-scale study of the globular cluster NGC 6397. Using FLAMES and GIRAFFE spectra from VLT, they analysed the Li abundances for > 450 stars on the main sequence, turn-off stars, subgiants and red giants to elucidate self-enrichment of globular clusters, mixing processes in stars and the primordial lithium abundance. They found strong evidence for extra Li depletion at the red giant branch bump not predicted by standard stellar evolution models but also evidence for a varying Li abundances between the turn-off and subgiant phase. The latter could signal additional mixing processes below the convection zone, possibly caused by atomic diffusion tempered by turbulence. The present Li abundances in turn-off metal-poor stars may thus not properly reflect the original Li content the stars where born with, which could explain the factor of 3-5 discrepancy between the observed Li abundance in low-metallicity stars (the so-called Spite plateau) and the value predicted by Big Bang nucleosynthesis.

L. Sbordone, and a team of collaborators mostly from Paris Observatory analyzed a large sample of extremely metal-poor halo dwarf/turn-off stars to determine their lithium abundances. The Li abundance in old, moderately cool (6000-6700K) turn-off stars is a crucial observable, potentially bearing informations on the primordial nucleosynthesis immediately following the Big Bang, as well as on the mixing processes taking place in and near the stellar convection zone. Since many decades, a plateau (the "Spite plateau") has been detected in the Li abundance of metal-poor ([Fe/H]<-1) dwarf and turn-off stars, which appear to be remarkably independent of metallicity. The interpretation that such Li abundance corresponds to the primordial Li production is nevertheless at odds with the WMAP measurements of the cosmic microwave background, which suggest a significantly higher primordial Li abundance. The team assembled the largest sample of extremely metal-poor ([Fe/H]<-3) stars ever studied, and employed state-of-the-art techniques (such as 3D hydrodynamic atmosphere modeling and NLTE line formation) to determine accurate stellar parameters and precise Li abundances. The study detects a progressive disruption of the Spite plateau at very low metallicities, with more metal-poor stars showing varying degrees of depletion with respect to the plateau level. This phenomenon is possibly related to metallicity-dependent atmospheric Li depletion processes, taking place after the stars formed.

R. Schönrich and J. Binney (Oxford) examined the consequences of including radial mixing in a model of the chemical and kinematic evolution of a Galactic disc. Fitting this model to the metallicity distribution they found that it reproduces all known correlations between metallicity and velocities of stars in the Solar neighbourhood. Although the model has continuous star formation, monotonic declining from a unique peak early in its history, and not even assumes any break in kinematics, it produces a thick disc matching all observed qualities (vertical two-exponential profile, distinct chemistry from local stellar populations, kinematic properties like higher asymmetric drift) thus challenging all known evidence for a turbulent origin of the Milky Way thick disc and providing an alternative approach to forming thick discs in general.

Based on this model R. Schönrich, J. Binney (Oxford) and W. Dehnen (Leicester) re-examined the local standard of rest, or respectively the solar motion against the local circular velocity. They show that the classical analysis for the azimuthal (rotational) velocity component via the Strömberg relation between velocity dispersion and asymmetric drift of a population is invalid, since it necessitates a binning of the used samples in colour, which is correlated with metallicity and by this with the radial distribution of stars. This gives rise to a treacherous Strömberg relation, which is expected to underestimate the solar rotational motion by roughly $7\,\mathrm{km\,s^{-1}}$. They further show that the Schönrich & Binney model produces correct velocity distributions, which by comparison with the measured distributions require $V_\odot \sim 12\,\mathrm{km\,s^{-1}}$, supporting the expected underestimate with the Strömberg method.

M. Asplund, I. Ramírez, J. Meléndez (Porto), A. Alves-Brito (Swinburne) and D. Yong (Canberra) have investigated the poorly understood Galactic bulge by means of an abundance analysis of 25 red giants for a large number of elements. For comparison, similar giants in the solar neighborhood from the thin and thick disks as well as the halo were analysed in an identical fashion. They found no chemical distinction between the bulge and the local thick disk in contrast to other groups relying on literature values for nearby disk dwarf stars. The findings suggest that the bulge and local thick disk stars experienced similar formation timescales, star formation rates and initial mass functions. The identical α-enhancements of thick disk and bulge stars may reflect a rapid chemical evolution taking place before the bulge and thick disk structures we see today were formed, or it may reflect Galactic orbital migration of inner disk/bulge stars resulting in stars in the solar neighborhood with thick-disk kinematics, as predicted by the Galactic chemical evolution model of R. Schönrich. The similarity between the thick disk and the bulge was also confirmed through the analysis of microlensed bulge dwarf stars by M. Asplund, T. Bensby (ESO), S. Feltzing (Lund), J. Johnson (Ohio) and collaborators. During the microlensing event, even such faint stars as dwarfs in the bulge are brightened sufficiently to be accessible with large telescopes like VLT, Magellan and Keck, which the team employed. They find excellent agreement between the two stellar populations in terms of their chemical compositions.

3.7 Galaxy structure and evolution

Global properties and scaling relations
F. Shankar and M. Bernardi (UPENN) found that the sizes and velocity dispersions of more luminous SDSS early-type galaxies vary by less than 15%, whatever their age, a challenge for current galaxy formation models. A closer check revealed that the lowering in the dispersion is caused by older galaxies departing from the scaling relations characterizing lower mass galaxies. Such features might find an explanation in models where more massive galaxies undergo more minor mergers than less mas sive galaxies at late times, thus causing a break in the homology. In terms of the Fundamental Plane of early-type galaxies, the data indic ate that all galaxies show a significant and similar increase in the dynamical-to-stellar mass ratio with increasing mass, independent of t heir age.

M. Bernardi (UPENN), F. Shankar, S. Mei (Paris Diderot Univ.), F. Marulli (Univ. of Bologna), and R. K. Sheth (UPENN) provided fits to the distribution of galaxy luminosity, size, velocity dispersion and stellar mass as a function of concentration index and morphological type in the SDSS. The total local stellar mass density to be in good agreement with expectations based on integrating the star formation history. They also find that the stellar mass density further increases at large masses assuming different initial mass functions for ellipticals and spiral galaxies, as suggested by recent chemical evolution models, and results in a better agreement with the dynamical mass function.

Gas Properties
Jian Fu (SHAO/MPA exchange student) has been working with Q. Guo and G.Kauffmann to develop new semi-analytic models that follow the conversion of atomic gas into molecular gas as disk galaxies form in a LCDM cosmology. The models follow the build-up of disks over time as they grow from the inside out through the accretion of new gas, and they also incorporate new recipes for star formation that are motivated by the recent results from the THINGS/SINGS, which have provided a more accurate characterization of the relationship between star formation and different cold gas phases. The goal of the project is to make a series of predictions for scaling relations between HI, H2 and stellar masses and surface densities that can be tested by future surveys, such as the GALEX Arecibo Sloan Survey (GASS), and its sister survey COLD GASS (CO Legacy Dataset for GASS), now being carried out by MPA scientists. The models can also be used to predict the location on the scaling relations of galaxies that have recently had a significant accretion episode, compared to those that have been accreting at a more modest rate. Future work will extend these models out to higher redshifts.

D. Schiminovich (Columbia), B. Catinella, G. Kauffmann and other collaborators at various institutions are carrying out the GALEX Arecibo SDSS Survey (GASS), an ambitious program designed to measure the neutral hydrogen content of ~ 1000 nearby, massive galaxies, uniformly selected from the SDSS spectroscopic and GALEX imaging surveys. The survey started in March 2008 and is on-going. The analysis of the first Data Release ($\sim 20\%$ of the final sample) has produced several interesting results. A large fraction ($\sim 60\%$) of the galaxies are detected in Hi. Their gas content (i.e., the ratio between Hi and stellar masses) decreases strongly with stellar mass, stellar surface mass density and NUV-r colour, but is only weakly correlated with galaxy bulge-to-disk ratio. The fraction of galaxies with significant (more than a few percent) neutral hydrogen content is found to decrease sharply above a characteristic stellar surface mass density of $10^{8.5}$ $M_\odot$ kpc^{-2}, where galaxies transition from disk-dominated, late-type to bulge-dominated, early-type objects. The fraction of gas-rich galaxies decreases much more smoothly with stellar mass.

One of the key goals of the GASS survey is to identify and quantify the incidence of galaxies that are transitioning between the blue, star-forming cloud and the red sequence of passively-evolving galaxies. Likely transition candidates can be identified as outliers from the mean scaling relations between gas fraction and other galaxy properties. GASS has already identified a few interesting examples of transition objects, including a “red and dead”, early-type galaxy with unusually high gas content, which might be in the process of reaccreting a disk. More information (including the complete list of collaborators) can be found on the GASS web site:
(*http://www.mpa-garching.mpg.de/GASS*).

Jing Wang, R. Overzier, B. Catinella and G. Kauffmann have been studying how the ultraviolet and optical photometric properties of galaxies are correlated with their HI gas content using data from the ALFALFA (Arecibo Legacy Fast ALFA) Survey and GASS. HI rich galaxies were found to have significantly bluer and more actively star-forming outer disks than galaxies of the same mass with ”normal” HI gas content. In addition HI rich galaxies were significantly more asymmetric and had clumpier blue light distributions. The most HI rich galaxies did not often contain bars or rings; the incidence of these signatures of dynamical instabilities increased with decreasing M(HI)/M_*. The results indicate that the outer disks of many spiral galaxies are still undergoing active growth through gas accretion at the present day.

G. Kauffmann, C. Li and T. Heckman (JHU) have been using complete photometric samples from the data release 7 of the Sloan Digital Sky Survey to study how much gas is accreting onto isolated central galaxies (i.e. galaxies that are not in groups or clusters) in the form of HI gas in satellites that are located within a distance of a few hundred kiloparsecs from the primary. Empirical relations that allow HI content of a galaxy to be predicted from a combination of colour and surafce brightness are used to derive the average gas mass in satellites as a function of projected radius for central galaxies of different stellar masses and star formation rates. Merging raters calibrateds from the Millennium Run then allow one to estimate the rate at which this gas accretes onto the central galaxy. The derived gas accretion rates fall below the the observed star formation rates by more than a factor of 30.

Despite the success of the cold dark matter (CDM) model to describe the large structure of the Universe, some potential problems remain at smaller scales. For instance, this model predicts a significantly larger number of substructures inside galactic-sized haloes than the number of observed satellites in the Milky Way. The discrepancy is usually explained by invoking physical models where there is a strong suppression of star formation in low-mass subhaloes. An alternative solution is offered by models where the dark matter particles have masses of a few keV. These, warm dark matter (WDM) models predict considerably less low-mass systems than CDM models. For similar reasons, an overabundance of low-mass isolated systems can lead to potential problems for the CDM model. J. Zavala, Y. P. Jing (SHAO, Shanghai), A. Faltenbacher, G. Yepes (UAM, Madrid), Y. Hoffman (RIP, Jerusalem), S. Gottlöber (AIP, Potsdam) and B. Catinella explored this possibility by running a couple of CDM and WDM constrained simulations, which, by using observational data, were designed to reproduce the gross features of the nearby Universe. The group obtained predictions on the abundance of isolated galaxies and compared them with preliminary data from the HI survey ALFALFA. It was found that this abundance as a function of maximum circular velocity, the so-called velocity function, flattens for low velocities. A result that clearly contrasts with the CDM simulation that predicts a steep velocity function, overpredicting the number of low-mass galaxies by as much as a factor of 10. The CDM model can be reconciled with observations only through a severe suppression of gas in the less massive haloes, well below conventional models. On the contrary, the WDM simulation agrees with observations remarkably well. This analysis promises exciting prospects for future studies once the ALFALFA survey is complete.

Galaxy Properties as a function of Environment

D. Christlein, in collaboration with E. Gawiser (Rutgers), D. Marchesi ni (Tufts) and N. Padilla (PUC Chile), has concluded his work on the field galaxy luminosity function from the MUSYC-ECDFS field, using the new ”Photo metric Maximum Likelihood” algorithm. Constraining the field LF without the use of spectroscopic or photometric redshifts to M_r 3D-14, they find a st eep upturn of the faint end slope to alpha 3D-1.6 at intermediate magnitude s. Such an upturn was speculated about, but could not be measured directly due to surface brightness limitations, by Blanton et al. (2005) on the basi s of SDSS data. This population closes part of the gap between the faint en d slope of the LF and the slope of the halo mass function in CDM theory, an d may constitute a sensitive probe of environmental influences in dwarf gal axies. To this end, D. Christlein, S. Mieske (ESO), L. Infante (PUC Chile), D. Harsono (Leiden) and R. De Propris (CTIO) have applied the PML method t o a sample of galaxy clusters around z 3D0.3, and have found the LF to be f lat to M_r 3D-14, although the early type LF is indeed steeper than in the field. This suggests that the growth of dwarf galaxies is suppressed in the se overdense regions even before they attain the luminosity distribution ob served in the field.

In collaboration with D. Zaritsky (Steward) and J. Bland-Hawthorn (Syd ney), D. Christlein has concluded a study of the surface brightness profile s of Hα emission in the outer disks of galaxies. Rather than being t runcated abruptly at a star-formation threshold, the Hα emission in this sample of late-type disk galaxies is described by a downbending broken -exponential profile with a characteristic break radius at $0.7R_{25}$, equ ivalent to the Freeman Type II profiles often seen in the stellar continuum . The high significance and regularly of the outer-disk profile indicates t hat the Hα break is a real phenomenon, rather than just a stochastic effect due to small numbers of observed HII regions. The outer disk Hα emission declines more rapidly than the stellar continuum.

S. Weinmann, G. Kauffmann, A. von der Linden (KIPAC Stanford) and Gabriella De Lucia (MPIA; INAF Trieste) have investigated how current semi-analytical models of galaxy evolution have to be changed in order to reproduce the relation between galaxy properties and their environment. They have found that this can be achieved with a simple model in which the diffuse gas halo of satellites is stripped at the same rate as the surrounding subhalo loses mass due to tidal effects. In low mass haloes, the diffuse gas reservoir is composed primarily of gas that has been expelled from the galaxy by supernovae driven winds. Unlike assumed in standard models, they find that this gas must remain available as a future reservoir for star formation, even in satellite galaxies.

Y. Guo (UMass), Dan McIntosh (U. of Kansas), H.J. Mo (UMass), N. Katz (UMass), F. van den Bosch (MPIA Heidelberg), M. Weinberg (UMass), S. Weinmann, A. Pasquali (MPIA Heidelberg) and X. Yang (Shanghai Observatory) have investigated the structural properties of central and satellite galaxies in groups and clusters. They find that morphological changes likely mainly occur for central galaxies, and do not seem to affect satellite galaxies.

T. Lisker (ZAH Heidelberg), J. Janz (ZAH Heidelberg), G. Hensler (U. of Vienna), K. Suk (Chungnam National University), S.C Rey (Chungnam National University), S. Weinmann, C. Mastropietro (LERMA), O. Hielscher (ZAH Heidelberg), S. Paudel (ZAH Heidelberg) and R. Kotulla (U. of Hertfordshire) have reported on the discovery of two different populations of dwarf elliptical galaxies in the Virgo cluster, which are distinct both in orbital and structural properties. The origin of this dichotomy is unclear and may be related with different histories regarding the accretion to the cluster.

Y. Wang (SHAO), X. Yang (SHAO), F. van den Bosch (MPIA Heidelberg), N. Katz (UMass), A. Pasquali (MPIA Heidelberg), D. McIntosh (U. of Kansas) and S. Weinmann have reported on the discovery of a population of isolated red dwarf galaxies. The origin of these galaxies is puzzling, as it seems unlikely that they are affected by environmental effects like gas stripping.

Satellite galaxies

Together with E. D'Onghia, L. Hernquist and D. Keres (all three at Harvard-CfA), V. Springel studied the depletion of dark matter substructures in Milky Way sized halos by the baryonic disk. When dark matter subhalos cross the dense disk, they experience a net heating that can eventually lead to a complete disruption of the subhalo. In the study, the effect has been first examined in cosmological simulations where a disk potential was slowly grown over time. Using the high-resolution Aquarius simulations, the orbits of substructures were then tracked and used to establish the frequency and the parameters of disk crossings. Based on analytic estimates of the cumulative heating effect, the study shows that the relatively small number of satellites seen within ~ 30 kpc of the Milky Way center can be substantially depleted by a factor of ~ 2 at $10^9\,\mathrm{M}_\odot$ and ~ 3 at $10^7\,\mathrm{M}_\odot$ through disk heating.

L. Sbordone, G. Giuffrida (INAF-ASDC), S. Zaggia (INAF-OAPD), G. Marconi (ESO), P. Bonifacio (Obs. Paris), C. Izzo (ESO), T. Szeifert (ESO) and R. Buonanno (Rome 2 University) are producing the first "wide angle" survey of the Sagittarius dwarf Spheroidal galaxy (Sgr dSph). Sgr dSPh is the most striking case of ongoing merging process involving the Milky Way: our Galaxy is tidally disrupting Sgr dSph as it moves along a quasi-polar, short period orbit, releasing a massive stellar stream in the Halo. The remaining Sgr dSph main body is extended over about 20 degrees in the sky, due to its proximity to the Sun, so that most studies concentrated so far on small fields close to the galaxy core. Such studies have shown a remarkable age and metallicity spread in Sgr dSph, with stars going from [Fe/H] 3D-2.5 up to [Fe/H] 3D0, peaking around [Fe/H] 3D-0.5. A number of chemical peculiarity have been found in the little sample of stars analyzed with high resolution spectroscopy. The aim of this new study is to pro be Sgr dSph over most of its extension, looking for photometrical or spectroscopical evidences of gradients in the age or composition of the Sgr dSph populations, and to assess its kinematics through radial velocity measurements. Seven fields have been imaged with VIMOS across Sgr dSph minor and major axis, which allowed to produce deep color magnitude diagrams as well as low-precisaion radial velocities (Through VIMOS MOS mode) useful to determine target membership. A FLAMES/UVES high resolution follow up has been performed. The photometric study is currently accepted by A & A making public the full photometric catalog of more than 300000 sources, while the chemical analysis ($\sim$ 250 FLAMES-GIRAFFE and $\sim$ 50 FLAMES-UVES stars) is underway. Preliminary results indicate a sharp radial gradient in the galaxy metallicity, which appears to drop to an average of [Fe/H]~ -1 towards its outskirts. This gradient is however not apparent in the photometry, most likely due to age-metallicity degeneracy.

3.8 Galaxies and their AGN

S. Bonoli, F. Shankar, S. White and V. Springel, in collaboration with S. Wyithe (University of Melbourne) used the Millennium Simulation to analyze the possibility that recently-merged haloes are more strongly clustered than other haloes with the same properties. This effect, known as "merger bias", could in principle help to understand the very strong clustering observed for high-redshift quasars. However, they found that, for a wide range of redshift and halo mass, the effect is not statistically significant. These results suggest that objects that are believed to be of merger-driven nature, such as bright quasars, do not cluster significantly differently from other objects of the same characteristic mass.

D. Sijacki (Cambridge), V. Springel and M. Haehnelt (Cambridge) carried out high-resolution hydrodynamical simulations of clusters of galaxies including a treatment for black hole (BH) growth and its associated feedback processes. Their study focused on powerful high-redshift quasars and the question whether the recoil expected from the gravitational wave emission in black hole mergers can seriously hamper the growth of supermassive black holes. In order to explore the full range of expected recoils and radiative efficiencies, models with spinning BHs were considered as well. It was found that whereas black hole kicks can expel a substantial fraction of low-mass BHs, they do not significantly affect the build-up of the supermassive BHs. A clear signal of a 'downsizing' of the BH accretion rate for the population of BHs down to $z = 2$ was identified in the simulations, and the properties of the simulated supermassive BHs were found to be consistent with observations of $z = 6$ quasars in terms of the estimated BH masses and bolometric luminosities, the amount of star formation occurring within the host halo, and the presence of highly enriched gas in the innermost regions of the host galaxy.

F. Xiang, E. Churazov, E. Rudometkin (IKI), W. Forman (CfA), H.Boehringer (MPE) by means of numerical simulations evaluated the impact of gas shock heating by a central active galactic nuclei (AGN) in M87 on the radial distribution of heavy elements. The propagation of a shock creates an inverted entropy profile, and the subsequent rearrangement of the gaseous atmosphere transports metal-rich gas from the central region to larger radii. For the parameters of the relatively weak shock, recently found in M87, the abundance profile is not strongly affected by the redistribution of the shock heated gas (except for the very central region). At the same time, the energetics of the source is fully sufficient to broaden the metal distribution to match the observations, strongly suggesting that mechanisms other than direct shock heating must operate in cluster cores. The absence of a very strong abundance peak at the very centre of M87 suggests that the central AGN produces frequent (every few 10 Myr) and relatively weak outbursts, rather than rarer (every few 100 Myr) and an order of magnitude more powerful events.

Correlation properties of the Cosmic X-ray background (CXB) contain information about spatial distribution of galaxies and AGN, which in turn trace the large-scale structure of the Universe. X-ray spectra of galaxies, groups and clusters of galaxies contain a number of bright and narrow emission lines in the soft X-ray band, AGN spectra have narrow iron line at 6.4 keV. I.Prokopenko (IKI Moscow), M.Gilfanov and R.Sunyaev computed angular power spectra of CXB and demonstrated that observations in narrow energy channels probe large scale structure in a thin slice which red-shift is defined by the ratio of the line energy to the observed energy, thus opening prospects for X-ray tomography of the Universe

J. Cuadra and S. Nayakshin (Leicester) are studying the effect of a 'kicked' black hole on a large-scale galactic disc. A displaced massive black hole can keep accreting and radiating for a long time after the merger that originated it. From an off-centre position, the black hole's feedback has a much larger influence on the galactic disc, in some cases managing to unbind most of the gas. If this process is ubiquitous in galaxy formation, it could explain the origin of the $M_{\rm BH}$–σ correlation.

Using a sample of 14,000 radio-loud AGN (RLAGN) with photometric redshifts between $0.4 < z < 0.8$, E. Donoso, G. Kauffmann, Cheng Li, P. Best (Royal Observatory Edinburgh, UK) and T. Heckman (Johns Hopkins University) studied the clustering of powerful radio galaxies. By analyzing the cross-correlation between RLAGN and a reference samples of luminous red galaxies in the same redshift range, they have quantified how the clustering of RLAGN depends on host galaxy mass and on radio luminosity. The main resultd is that RLAGN are clustered more strongly on all scales than control samples of radio-quiet galaxies with the same stellar masses and redshifts, but the differences are largest on scales less than $\sim 1\ Mpc\ h^{-1}$. In addition, the clustering amplitude of the RLAGN varies significantly with radio luminosity on scales less than 1 Mpc h^{-1}. This proves that the gaseous environment of a galaxy on the scale of its dark matter halo, plays a key role in determining not only the probability that a galaxy is radio-loud AGN, but also the total luminosity of the radio jet. They have also compared the clustering of radio galaxies with that of radio-loud quasars in the same redshift range. Unified models predict that both types of active nuclei should cluster in the same way. The data show that most RLAGN are clustered more strongly than radio-loud QSOs, even when the AGN and QSO samples are matched in both black hole mass and radio luminosity. Only the most extreme RLAGN and RLQSOs in our sample, with radio luminosities in excess of $\sim 10^{26}$ W Hz^{-1}, have similar clustering properties. The majority of the strongly evolving RLAGN population at redshifts $\sim$0.5 are found in different environments to the quasars, and hence must be triggered by a different physical mechanism. In addition, Donoso, Li and Kauffmann have successfully applied halo occupation models to semianalytic models of galaxy formation (SAMs). This allows to directly test the feedback effect of RLAGN as implemented in SAMs, and estimate the heating output of radio galaxies in dark matter haloes of different mass and in different cosmic epochs.

P. Kuchar and T. Enßlin have reanalysed the Faraday rotation map of the Hydra A galaxy with an improved method to measure the magnetic power spectrum in the Hydra A cluster cool core. A Kolmogorov-like power spectrum was found, observed to range at least from 0.3 kpc to 15 kpc. Henrik Junklewitz and Torsten Enßlin have investigated the statistics of radio observables like intensity, polarisation and Faraday rotation of turbulent magnetic fields illuminated by synchrotron emission of relativistic electrons. They discovered that information about the magnetic helicity is encoded in suitable cross correlation functions of such observables. A. Waelkens, A. Schekochihin (London), and T. Enßlin also showed that also the power spectrum of magnetic tension forces is encoded in such polarization data.

R. Krivonos and M. Revnivtsev (Excellence Cluster Universe, IKI) studied the spatial density variations of nearby (D<70 Mpc) hard X-ray emitting AGNs by measuring so called bias factor, i.e. ratio of fractional X-ray AGN density fluctuations to the fractional matter density fluctuations. Authors used the most straightforward way to measure the AGNs bias factor by directly correlating the matter density variations with that of the AGNs volume density. The measured X-ray AGN bias factor is consistent with unity, which means that matter density fluctuations at scale of 70 Mpc and zero redshift are linearly translated into fluctuations of the X-ray AGN volume density. Apparently, hard X-ray emitting AGNs are unbiased tracers of the galaxy population in the nearby Universe. The measured AGN bias factor implies that SMBH activity is independent from density of galaxies on spatial scales 70 Mpc.

R. Overzier, Q. Guo, G. Kauffmann, G. De Lucia, R. Bouwens (Santa Cruz) and G. Lemson (MPE) have compared the environment of luminous z=6 quasars as observed by the Hubble Space Telescope with a large catalog of mock galaxies in a range of environments at z=6 extracted from the Millennium Run simulations. The new study shows that the limited depth and area of the current observations may explain the lack of structures detected. Alternatively, the quasars could be powered by supermassive black holes in galaxy hosts or dark matter halos that are otherwise fairly average and are thus not expected to be associated with enhancements in their local galaxy density.

F. Shankar, in collaboration with D. H. Weinberg (OSU), and Y. Shen (Princeton), adopted quasar clustering measurements and continuity equation model results, to provide firm constraints on the duty cycle and scatter of the quasar luminosity-halo mass relation at $z \sim 1.5$.

Y. Shen (Princeton), F. Shankar, and J. Hennawi (MPIA) used halo occupation distribution models and matching with very recent quasar clustering at small and large scales at $z > 3$, constrained the fraction of satellite quasars to be significant and in the range $0.3 - 0.5$.

F. Shankar, J. Moreno (Haverford), D. H. Weinberg (OSU), R. K. Sheth (UPENN), Cheng Li, M. Crocce (Univ. Barcelona), R. Angulo, and F. Marulli (Univ. of Bologna), re-visited basic models of quasars triggered in major merger events comparing with a variety of different datasets, finding a series of interesting new results: evidence for fast black hole accretion and very limited post-peak, low Eddington activity at $z > 3$, high clustering for low-luminosity, low-z quasars, and evidence for evolution on the black hole mass-host stellar mass relation.

F. Shankar, G. R. Sivakoff (Univ. of Virginia), X. Dai (Michigan), and M. Vestergaard (Copenhagen) using SDSS and FIRST data were able to infer that optical and radio quasar undergo a significantly different accretion history, concluding that radio quasars cannot be a mere random subsample of the optical ones. Together with J. Bird (OSU), the same Authors extended their study to compact and extended radio sources, finding that environment must play a significant role in determining the morphology of radio sources.

F. Shankar and L. Ferrarese (Univ. of Victoria) improved on previous studies by carefully reanalyzing, on an object-by-object basis, the local relations between black hole mass and bulge luminosity or galaxy velocity dispersion, and finally providing a more secure measurement of the local black hole mass function.

S. A. Sim continued to work on the application of Monte Carlo radiative transfer simulations for the study of spectroscopic features associated with highly ionized outflows from active galactic nuclei (AGN). Together with Long (STScI), L. Miller (Univ. of Oxford), T. J. Turner (NASA/GSFC) and J. N. Reeves (Univ. of Keele), he extended previous work to account for a wider range of ionization conditions in outflows and incorporated an improved treatment of the necessary atomic physics in their radiative transfer code. They also made detailed comparison of their synthetic spectra with the 2 − 10 keV spectrum of the bright quasar PG1211+143 and found excellent agreement for models of an outflow with wide opening angle and mass-loss rate comparable to the Eddington accretion rate of the source. J. von Groote and S. A. Sim are now extending this analysis to the low energy parts of the X-ray spectrum of PG1211+143 and to the study of other bright AGN.

3.9 Reionisation and the intergalactic medium

The epoch of cosmic reionization is one of the most interesting times during galaxy formation. Reionization is not only important for the evolution of the temperature and pressure of the intergalactic medium (IGM), but may also have a strong impact on the formation of small galaxies. At the same time, future observational probes with new radio telescopes, e.g. LOFAR, promise to deliver rich information about this epoch, which will inform theoretical models for the source populations and help us to better understand galaxy formation. In order to study the cosmic reionization in detail, M. Petkova and V. Springel have developed a novel numerical implementation of radiative transfer in the cosmological smoothed particle hydrodynamics (SPH) simulation code GADGET-3. They have used their code to self-consistently simulate the process of reionization and its thermal feedback together with the build-up of galaxies, thereby yielding a comprehensive model for the transition from a neutral to an ionized Universe. Their results show that the simulated universe can be reionized by redshifts $z \sim 6-9$ through the UV radiation from star-forming galaxies, provided that a sufficiently high escape fraction of ionizing photons into the IGM is assumed. Matching both the one-point flux probability distribution and the flux power spectrum of the Lyman-α forest at $z = 3$ is found to put strong constraints on the viable escape fraction and photoheating rates. Also, the results show that feedback from reionisation decreases the gas and stellar contents of low mass dark matter halos.

Together with L. Tornatore, S. Borgani and M. Viel from Trieste, V. Springel analysed the impact of feedback on the low-redshift intergalactic medium (IGM) based on high-resolution hydrodynamical simulations that included a detailed chemical enrichment model. Their work focused on the effects strong galactic outflows driven by supernova explosions and active galactic nuclei have on the thermo- and chemo-dynamical properties of the IGM. At $z = 0$ the fraction of baryons in the warm hot IGM was found to be about 50% in the runs with black hole feedback, larger than the 40% obtained in the runs with wind feedback. The relative abundances of C/O and O/Fe evolve quite differently at high redshifts for the different feedback models that were studied, but their values are nevertheless similar at $z = 0$. The sensitivity of WHIM properties on the implemented feedback scheme could be important both for discriminating between different feedback physics and for detecting the WHIM with future far-UV and X-ray telescopes.

Resonant scattering in bright X-ray emission lines is a powerful tool for diagnostics of hot plasma in elliptical galaxies, groups of galaxies and clusters. I.Zhuravleva, E.Churazov, R.Sunyaev, K.Dolag and W.Forman (CfA) have studied the impact of gas motions on the polarization of bright X-ray emission lines from the hot intercluster medium. The changes in the polarization signal are in particular sensitive to the gas motions perpendicular to the line of sight. Using Monte Carlo radiative transfer code they calculated the expected polarization degree for several patterns of gas motions, including a slow inflow expected in a simple cooling flow model and a fast outflow in an expanding spherical shock wave. In both cases, the effect of non-zero gas velocities is found to be minor. The polarization signal was also calculated for a set of clusters, taken from large-scale structure simulations. Due to the asymmetry in the radiation field – most of the line photons are coming from the central dense part of the cluster – the polarization for the brightest X-ray lines from galaxy clusters can reach values as high as 30% at the cluster outskirts. The presence of bulk and turbulent motions decreases the polarization signal down to $\sim 10\%$. Future X-ray polarimeters could use the polarization signal from clusters to evaluate the presence of the bulk motions and micro-turbulence in the gas, although such observation are challenging unless the energy resolution of the instrument is good.

Further exploiting the effect of resonant scattering N.Werner (KIPAC), I.Zhuravleva, E.Churazov, A.Simionescu (KIPAC), S.W.Allen (KIPAC), W.Forman (CfA), C.Jones (CfA) and J.S. Kaastra (SRON) put constraints on turbulent pressure in the X-ray halos of giant elliptical galaxies from resonant scattering. They obtained high resolution spectra of bright nearby elliptical galaxies, using the grating spectrometers on the XMM-Newton satellite. In particular the data for NGC 4636 allow the effect of resonant scattering were studied in detail and to proved that the Fe XVII line at 15.01 is suppressed only in the dense core and not in the surrounding regions. Using deprojected density and temperature profiles for this galaxy obtained with the Chandra satellite, they modeled the radial intensity profiles of the strongest resonance lines, accounting for the effect of resonant scattering, for different values of the characteristic turbulent velocity. Comparing the model to the data, it was found that the isotropic turbulent velocities on spatial scales smaller than ≈ 1 kpc are less that 100 km/s and the turbulent pressure support in the galaxy core is smaller that 5 per cent of the thermal pressure at the 90 per sent confidence level.

3.10 Formation of galaxies and clusters

Cecilia Scannapieco has continued to study galaxy formation using a modified version of the GADGET SPH code which treats the hot and cold phases of the interstellar medium separately, both for hydrodynamics and for feedback. Together with S. White, V. Springel and P. Tissera (Buenos Aires), she resimulated eight halos from the Aquarius Project, each representing an object of similar mass to the Milky Way's halo, but including a representation of the baryonic physics – gas cooling, star formation, feedback from supernovae and chemical enrichment. The resulting galaxies had disk and bulge components similar to those of real galaxies in all but one case (which made a pure bulge) but in no case did the disk account for more than a quarter of the total stellar mass. It appears that significant changes must be made to the treatments of star formation and feedback if typical halos are to make galaxies similar to those they must contain if the real Universe follows the ΛCDM model. In a separate project these same authors compared these simulations to the original Aquarius dark matter only simulations, in order to study how the formation of the stellar galaxies affect the dark matter structure of the halos. They found that no adiabatic contraction model was able to represent the effects properly. These appear to depend on the detailed assembly history of each object. In addition the formation of the galaxy breaks the simple relationships between phase-space density and radius which are found in simulated dark matter onl halos.

T. Sawala, C. Scannapieco and S. White performed cosmological, hydrodynamical simulations of the formation and evolution of isolated dwarf galaxies. It was found that supernova feedback and the cosmic UV background are both important factors in the evolution of galaxies with a halo masses of about 10^9 solar masses. The resulting objects match several of the observed properties of the Local Group dwarf spheroidal galaxies, including stellar masses, ages, metallicities, abundance ratios and the absence of interstellar gas. The observed common mass scale, implying extreme mass-to-light-ratios at the lowest luminosity end, and the observed luminosity-metallicity relation, are also reproduced. They are explained by self-regulated star formation, which depends strongly on the halo mass of the objects.

As part of her PhD thesis, Qi Guo worked with the Millennium and Millennium-II simulations to create a semi-analytic galaxy formation model which gives a consistent result on the two simulations, despite the difference of a factor of 125 in their mass resolution, and which is consistent with the observed properties (size, luminosity, colour, morphology..) and clustering of galaxies ranging from the dwarf spheroidal satellites of the Milky Way to the cD galaxies at the centres of the most massive clusters. Together with S. White she used an early version of these models to compare with the various observed galaxy populations at redshifts of 2 and 3, and to study the likely present-day descendants of these objects. She found the model to describe the abundance, colours and clustering of the high redshift populations quite well, but to underpredict the star formation rates usually assigned to them. Their descendents are predicted to span a wide range of masses and environments in the nearby Universe. In a different project, together with S. White, C. Li and M. Boylan-Kolchin, Qi Guo used the observed stellar mass function derived by Li and White and the overwhelming halo/subhalo statistics provided by the MS and MS-II simulations to explore the consequences of assuming that the stellar mass of the galaxy at the centre of a dark matter halo or subhalo is a monotonically increasing function of the maximum mass ever attained by that q(sub)halo. In agreement with previous work (though with much better statistics) these authors were able to show that the relation between halo mass and galaxy mass shows a very pronounced characteristic scale at a steller mass just below that of the Milky Way, that this relation is in good agreement with inferences from gravitational lensing and satellite galaxy dynamics, and that the relation implies that galaxy formation was typically much less efficient than in most published simulations of the process.

M. Boylan-Kolchin, V. Springel, S. D. M. White, and A. Jenkins (Durham, UK) have used the recently-completed Millennium-II Simulation to make one of the first statistical studies of the properties of Milky Way-mass dark matter halos. Such an undertaking was previously impossible due to the competing demands of large simulation volume with high mass resolution. They showed that, contrary to results of previous work, the subhalo occupation distribution does not obey Poisson statistics but rather is dominated by intrinsic scatter of approximately 18the most massive subhalos. The existence of satellites as massive as the Magellanic Clouds is much more likely if the Milky Way's dark matter halo is massive ($\sim 2.5 \times 10^{12}\,M_\odot$) rather than at the low end of current estimates ($\sim 10^{12}\,M_\odot$). Furthermore, it was found that the probability of disk disruption is sensitive to the mass ratio for satellites that is relevant for disk disruption, as 1:30 mergers are inevitable while 1:10 mergers only occur in half of halos since $z = 2$.

C. Li and S. White have explored the distribution of stellar mass in the low-redshift Universe using a complete and uniform sample of almost half a million galaxies from the Sloan Digital Sky Survey. Galaxy abundances are well determined over almost four orders of magnitude in stellar mass, and are reasonably but not perfectly fit by a Schechter function with characteristic stellar mass $m_* = 6.7 \times 10^{10} M_\odot$ and with faint-end slope $\alpha = -1.155$. For a standard cosmology and a standard stellar Initial Mass Function, only 3.5% of the baryons in the low-redshift Universe are locked up in stars. The projected autocorrelation function of stellar mass is robustly and precisely determined for $r_p < 30h^{-1}$Mpc. Over the range $10h^{-1}$kpc $< r_p < 10h^{-1}$Mpc it is extremely well represented by a power law. The corresponding three-dimensional autocorrelation function is $\xi^*(r) = (r/6.1h^{-1}\mathrm{Mpc})^{-1.84}$. Relative to the dark matter, the bias of the stellar mass distribution is approximately constant on large scales, but varies by a factor of five for $r_p < 1h^{-1}$Mpc. This behaviour is approximately but not perfectly reproduced by current models for galaxy formation in the concordance ΛCDM cosmology. Detailed comparison suggests that a fluctuation amplitude $\sigma_8 \sim 0.8$ is preferred to the somewhat larger value adopted in the Millennium Simulation models with which we compare our data. This comparison also suggests that observations of stellar mass autocorrelations as a function of redshift might provide a powerful test for the nature of Dark Energy.

C. Li and S. White have used the SDSS DR7 data to estimate projected autocorrelation functions $w_p(r_p)$ for the light of galaxies in the five SDSS photometric bands. Comparison with the analogous stellar mass autocorrelation, estimated in a companion paper, shows that stellar luminosity is less strongly clustered than stellar mass in all bands and on all scales. Over the full nonlinear range $10h^{-1}$kpc$< r_p < 10h^{-1}$Mpc our autocorrelation estimates are extremely well represented by power laws. The parameters of the corresponding spatial functions $\xi(r) = (r/r_0)^\gamma$ vary systematically from $r_0 = 4.5h^{-1}$Mpc and $\gamma = -1.74$ for the bluest band (the u band) to $r_0 = 5.8h^{-1}Mpc$ and $\gamma = -1.83$ for the reddest one (the z band).

These may be compared with $r_0 = 6.1h^{-1}$Mpc and $\gamma = -1.84$ for the stellar mass. Ratios of $w_p(r_p)$ between two given wavebands are proportional to the mean colour of correlated stars at projected distance r_p from a randomly chosen star. The ratio of the stellar mass and luminosity autocorrelations measures an analogous mean stellar mass-to-light ratio (M_*/L). All colours get redder and all mass-to-light ratios get larger with decreasing r_p, with the amplitude of the effects decreasing strongly to redder passbands. Even for the u-band the effects are quite modest, with maximum shifts of about 0.1 in $u - g$ and about 25% in M_*/L_u. These trends provide a precise characterisation of the well-known dependence of stellar populations on environment.

E. Neistein and S. M. Weinmann developed a new approach for modeling the formation and evolution of galaxies. Galaxies are assumed to grow inside dark-matter haloes, as is done by standard semi-analytical models. However, the processes that shape the evolution of galaxies are assumed to depend only on the host halo mass and redshift. This approach is flexible, fast, and transparent, and it has enough degrees of freedom in order for the modeled galaxies to reproduce accurately the observed population of galaxies. The current work introduces five different models of galaxy formation, where each assumes very different scenario and physical ingredients. Using these models the level of degeneracy in theories of galaxy formation is explored, and observational data which may help to constrain the models are suggested.

R. Overzier and T. Heckman (JHU) have studied a sample of nearby ($z < 0.3$), UV-selected galaxies that appear to be the best local analogs of the UV-bright Lyman Break Galaxies (LBGs) that are common at high redshift ($z > 3$). The local analogs are similar to LBGs in terms of their stellar mass, star formation rate, attenuation, metallicity, size, morphology and gas properties. The LBG analogs are powered by intense, compact starburst regions that are much larger and more massive than typical star-forming regions in local galaxies, and appear to have been triggered by mergers and interactions. A small subset was found to contain highly peculiar nuclei of small size (∼100 pc) and high stellar mass ($\sim 10^9\ M_\odot$). These nuclei are most consistent with being the progenitors of the nuclear "cusps" seen in low mass early-type galaxies. These very young galaxy bulges are incapable of triggering a powerful active nucleus as they are still in a supernova-dominated outflow phase. Using the same sample, R. Overzier and T. Heckman (JHU) have shown that most of the local LBG analogs would not be identified as undergoing a merger when artificially redshifted to $z = 2 - 4$, thus suggesting that the merger rates at high z based on observations of LBGs are likely to be underestimated. This is an important finding, as some recent models have suggested that galaxy mergers play only a minor role in galaxy evolution at high redshift.

E. Puchwein, V. Springel, and D. Sijacki (Institute of Astronomy, Cambridge, UK) analyzed high-resolution cosmological hydrodynamical simulations of galaxy clusters to study the formation of cluster galaxy populations and the origin of intracluster light. It was found that the fraction of intracluster stars in the simulations exceeds the values typically inferred from observations. This result is robust with respect to numerical resolution and integration accuracy. Including feedback from active galactic nuclei (AGN) in the simualtions strongly improves the agreement between central and satellite galaxy masses and observational constraints, while it does not significantly change the relative fraction of intracluster stars.

M. Wadepuhl and V. Springel simulated the influence of different physical effects on the formation of Milky Way sized galaxies and their population of satellite galaxies. Their results show that the expected number of observable satellite galaxies depends sensitively on the details of the included baryonic physics, and that a simple epoch of reionization at $z = 6$ appears insufficient to explain the properties of the observed Milky Way satellites. This suggests that a more sophisticated modeling of physical feedback processes is required. Interestingly, the simulations show that additional pressure from cosmic rays leads to a more realistic population of simulated satellite galaxies.

The origin of cosmological magnetic fields within the large scale structure of the universe is still one of the remaining, open questions in our understanding of diffuse medium filling the space between galaxies and the large scale structures. Whereas the strength and structure of such magnetic field within galaxy clusters can be already probed by radio observations in various ways, the magnetic field strength and configuration withing lower density environments like filaments are extremely difficult to detect directly. K. Dolag, together with M. Kachelriess (NTNU, Trondheim), S. Ostapchenko (NTNU, Trondheim) and R. Tomas (ITP, Hamburg) demonstrated, that high-energy photons from blazars can be used to constrain the presence of week magnetic fields in filaments and intervening structures. Such photons interact within tens of kpc with the extragalactic photon background, initiating electromagnetic pair cascades. The charged component of such cascades is deflected by the magnetic fields filling the large scale structures, leading to halos even around initially point-like sources. Employing magnetic fields predicted by structure formation simulations, it was demonstrated that observations of blazar halos would provide valuable information on the magnetic field within the large scale structure along the line of sight and may be already detectable by current imaging air Cherenkov telescopes.

Using cosmological, magneto-hydro-dynamical simulations, J. Donnert and K. Dolag (together with their collaborators G. Brunetti and R. Cassano (IRA, Bologna)) compared the predictions of giant radio halos based on hadronic models for the origin of radiating, relativistic electrons in galaxy clusters with observations. In the case of the Coma cluster it was demonstrated that such class of models will require an extremely large amount of cosmic ray protons in the outskirts of the cluster to match the radio observations at large distances from the center. It was also for the first time self consistently demonstrated that the Sunyaev-Zeldovich effect caused by the ICM of the Coma cluster can not be accounted for the spectral shape seen in the radio observations. The analysis was also extended to a sample of 16 large clusters from the simulation. It was shown that the hadronic model systematically under predicts the size of observed radio halos and can not reproduce the bi-modality in radio luminosity of large clusters, given the obtained magnetic field evolution during mergers from the cosmological simulations. Therefore new predictions of the Gamma-Ray flux from these models were presented, which expect an independent test of hadronic models by the Fermi Gamma-ray observatory in the near future.

Using a large set of cosmological cluster simulations, K.Dolag and colaborators (S. Borgani (Dip. Astro. Trieste) and G. Murante (INAF, Pino Torinese)) present a detailed analysis of halo substructures in hydrodynamical simulations of galaxy clusters, focusing in particular on the influence both of radiative and non-radiative gas physics and of non-standard physics such as thermal conduction and feedback by galactic outflows. We find that diffuse hot gas is efficiently stripped from sub-halos when they enter the highly pressurized cluster atmosphere. The fraction of mass contributed by gas in sub-halos is found to increase with the cluster-centric distance. Interestingly, this trend extends well beyond the virial radii, thus showing that galaxies feel the environment of the pressurized cluster gas over fairly large distances. It was also demonstrated, that the compact stellar cores (i.e. galaxies) are generally more resistant against tidal disruption than pure dark matter sub-halos. Still, the fraction of star-dominated substructures within the simulated clusters is only 10 per cent. In an continuation of this work the possibility of distinguishing the central galaxy from the diffuse stellar component within clusters was investigated. It was demonstrated that, after subtracting all member galaxies, the velocity distribution of the remaining stellar population build up from from two dynamically, well-distinct stellar components within simulated galaxy clusters. These differences in the dynamics can be used to separate the star particles into a cD and a diffuse stellar component. Applied to a cosmological, hydrodynamical simulation it was found that these two components have clearly distinguished spatial and velocity distributions as well as different star formation histories. It was also demonstrated, that the fraction of stars within such diffuse stellar component does not depend on the virial mass of the galaxy cluster and is much more sensitive to the formation history of the cluster. This is in line with previous findings that the diffuse stellar component originates from the late stages of merger events of galaxies with the cD. Therefore clusters which have had enough time to liberate stars since the last major infall show a larger diffuse stellar component. Interestingly we found in the simulations, that the mass ratio between the second brightest cluster galaxy and the cD galaxy can be used as a proxy for the time till the last major merger. S.E. Nuza and K. Dolag (together with A. Saro (Dip. Astro. Trieste)) for the first time applied population synthesis models to the stellar population of sub-halos (i.e. galaxies) formed in a large scale, cosmological, hydrodynamical simulation, including also the modeling of dust attenuation based on the distribution of to the ambient ISM. Therefore, for the first time, we were able to study simultaneously the clustering, colour and luminosity properties of galaxies formed in cosmological, hydrodynamical simulations. The color and luminosity properties of the galaxies strongly indicate the need to include further feedback processes within the cosmological simulations in order to suppress star-formation in massive halos at low redshift. Late type and faint galaxies show a remarkable agreement with observations and applying a simple recipe to emulate the required feedback they found that also clustering properties of early type galaxies show a good agreement with observations.

F. Shankar, in collaboration with F. Marulli (Univ. of Bologna), M. Bernardi (UPENN), X. Dai (Michigan), J. B. Hyde (UPENN), and R. K. Sheth (UPENN), have worked with a sample of 45,700 early-type galaxies extracted from SDSS, finding that the shape, normalization, and dispersion around the mean size-stellar mass relation is the same for young and old systems, provided the stellar mass is greater than $3\times10^{10}M_{\odot}$. This is difficult to reproduce in pure passive evolution models, which generically predict older galaxies to be much more compact than younger ones of the same stellar mass. However, they find that this aspect of the measurements is well reproduced by hierarchical models of galaxy formation. Whereas the models predict more compact galaxies at high redshifts, subsequent minor, dry mergers increase the sizes of the more massive objects, resulting in a flat size-age relation at the present time. F. Shankar, in collaboration with F. Marulli (Univ. of Bologna), M. Bernardi (UPENN), X. Dai (Michigan), S. Khochfar (MPE), and M. Boylan-Kolchin, also find that hierarchical models are capable of reproducing the overall shape of the local size function, although the same models still fail in properly matching the trend and scatter of the size-stellar mass relation of local early-type galaxies.

3.11 Cosmic Microwave Background

M. Frommert, T. Enßlin and F. Kitaura have derived a new method for detecting the integrated Sachs Wolfe effect in the cosmic microwave background via its cross-correlation with the large-scale structure (LSS). This method differs from that usually used in two fundamental ways: the LSS distribution and a part of the primordial temperature fluctuations are kept fixed, rather than averaged over different realisations as done in the standard method. For an ideal scenario, the overall enhancement of the detection significance as compared to the standard method amounts to 23%.

M. Frommert and T. Enßlin have used the part of the WMAP polarization map which is uncorrelated with the temperature map as a statistically independent probe of the so-called *axis of evil*. The latter is an unusual alignment between the preferred directions of the quadrupole and the octopole in the temperature map. Looking for the axis in the uncorrelated polarization map helps to assess whether it is due to chance fluctuations in the temperature or to a preferred direction intrinsic to the geometry of the primordial Universe. They find that the axis of the quadrupole of the uncorrelated polarization map aligns with the *axis of evil*, whereas the axis of the octopole does not. However, due to the high noise-level in the WMAP polarization map, the uncertainty in the result is so high that no evidence for or against a preferred direction intrinsic to the primordial Universe is obtained. Nevertheless, this technique applied to *Planck* data will serve as a powerful means to understand the origin of the *axis of evil* and other CMB anomalies.

M. Frommert, D. Pflueger (Informatik, TUM), T. Riller, M. Reinecke, H.-J. Bungartz (Informatik, TUM), and T. Enßlin have developed and implemented a new method to speed up cosmological parameter estimation. This method uses a sparse-grids based interpolation of the log-likelihood, which is orders of magnitude faster to compute than the original likelihood. This is a competitive alternative to other approaches for accelerating parameter sampling.

A number of public outreach activities accompanied the Planck Surveyor launch on May 14th and operation since mid August. A movie explaining Planck, basics of the CMB and presenting the MPA Planck group was made and published on YouToube. An exhibit showing interactively the dependence of the CMB sky on steerable cosmological parameter was build by Thomas Riller and Mona Frommert for the new Cosmology section of the Deutsche Museum. An Internet comic "Riding Early Waves", which explains the basic CMB physics, was produced by Jojo and T. Enßlin.

M. Bottino, A.J. Banday (CESR Toulouse) and D. Maino (University of Milan) have carried out an analysis of the diffuse Galactic foreground contribution (due to synchrotron, free-free and dust emission) present in the WMAP 5-year data as determined by the method of Independent Component Analysis, and implemented in the *fastica* algorithm. The aim of the analysis is both to build an understanding of the nature of the foregrounds (both spectral and morphological), and to experiment with the applicability and performance of the component separation algorithm. Particular emphasis has been placed on the study of the free-free spectrum, in an attempt to confirm the presence of a spectral feature as claimed by Dobler et al. (2008) and explained in terms of spinning dust emission in the warm ionised medium. The existence of this feature is supported only if a CMB estimate is subtracted before attampting any template fitting. This is important in order to avoid cross-talk between the CMB and foreground emission - the so called "cosmic covariance" of Chiang et al (2009). More recently, the analysis has been extended to full-sky data: a good estimate of the CMB has been recovered, even though the foreground components are very strongly mixed. We are currently attempting to improve the CMB reconstruction still further by applying the method to separate regions of the sky which we have inferred have different spectral properties to each other.

F. Elsner and B. Wandelt (University of Illinois) developed a new approach to search for non-Gaussian signatures in Cosmic Microwave Background radiation data. They used Bayesian methods to improve state-of-the-art frequentist estimators in terms of accuracy. This technique will help to test inflationary models experimentally.

C. Hernández-Monteagudo, in collaboration with S. Ho (Lawrence Berkeley Lab.), has investigated the signature of the peculiar motion of the missing baryo ns in the CMB. This signature is embedded in the intrinsic CMB temperature anisotropies, and could only be picked up through cross correlation analyses o f CMB maps with peculiar velocity templates. These templates can be built either from estimations of the kinetic Sunyaev-Zel'dovich effect in galaxy clus ters above $2{\times}10^{14}$ $M_{\odot}$, or from deep and wide galaxy survey. In collaboration with R.E.Smith (Univ.Zürich) and U.Seljak (Univ.Züric h, UC Berkeley), C. Hernández-Monteagudo has studied the effect of non-linear evolution on the cross-correlation analyses of the Integrated Sachs-Wolfe effect (ISW) with Large Scale Structure surveys (LSS). It was shown that non-linear evolution has little effect on the large angular scales where most of the ISW − LSS cross-correlation arises, and that linear theory can be applied to good accuracy (better than 5%). These results were used by C.Hernán dez-Monteagudo to conduct a cross-correlation test between WMAP CMB data and the NVSS radio galaxy catalog. In this study, he showed that the large scale clustering of NVSS galaxies does not conform theoretical expectations, nor does the large angle cross-correlation of those galaxies with the CMB temperature anisotropies. Either the galaxies in this radio survey are not probing the large scale potential wells in the redshift range $z \in [0.3, 1.2]$, or there exists a serious mismatch between the theoretically expected ISW component and the one present in WMAP data. In collaboration w ith R. A. Sunyaev (MPA), C.Hernández-Monteagudo has also studied the possibility of detecting the ISW by looking at the so-called *blurring term* in the direction of galaxy clusters, which accounts for the fraction of CMB photons that are scattered away from the line of sight when encountering a cloud of electrons. C.Hernández-Monteagudo has continued his activities within the ISW project inside Working Group 5 of the *Planck* collaboration . He has also pursued his work in the *Atacama Cosmology Telescope* collaboration, with particular emphasis on the modelling of the Infrared Source population. Finally, he has finished a collaboration with G.Rossi (Korea Inst.for Advanced Study), R.Sheth (Univ.Pennsylvania) and C.Park (Korea Inst.for Advanced Study) on the peak clustering in WMAP data and its connection to non-Gaussian signals.

R.A. Sunyaev and J. Chluba (CITA) refined and extended their detailed studies in connection with cosmological recombination. Using both numerical and analytical approaches they were able to show that two-photon corrections lead to important modifications to the Lyman-alpha escape probability of hydrogen at redshift $z \sim 1100$, demonstrating that in particular the 3d-1s two-photon channel plays an important role. Furthermore, they investigated the effects of partial frequency redistribution caused by line-scattering off moving neutral atoms and scattering of free electrons. They showed that all these processes affect the *ionization history* of the Universe and consequently the shape and position of the *last scattering surface* at a level which will be very important to the analysis of upcoming CMB data from the Planck Surveyor. In addition, they studied the feedback of helium photons during cosmological recombination, showing that the total number of helium-related quanta in the *cosmological recombination spectrum* is increased by 40%-70%, reaching at total of $\sim 12 - 14$ photons per helium nucleus. They payed particular attention to the effects of ionizing photons from HeII-recombination ($z \sim 6000$), since these are reprocessed by both neutral helium and hydrogen. The feedback processes could render it slightly easier to determine the primordial abundance of helium in future measurement of the cosmological recombination spectrum. However, the ionization history of the Universe is not affected much by this process.

3.12 Dark matter and dark energy

Mark Vogelsberger and Simon White studied the structure of dark matter halos on very small scales. By implementing an integration of the geodesic deviation equation in tandem with the integration of the equations of motion within Volker Springel's GADGET-3 code, they were able to follow the evolution of the fine-grained distribution function of the dark matter in the neighbourhood of every particle in N-body simulations of structure formation from general cosmological initial conditions. This allows the density of the individual stream surrounding each particle to be followed, and, in particular, all caustic crossings of the particle to be identified. White and Vogelsberger also developed a treatment of the annihilation radiation emitted at generic caustic crossings which allows an accurate evaluation of the contribution of fine-grained structure to the total annihilation luminosity; earlier work had suggested that caustics might contribute a substantial, even dominant contribution to this luminosity. Vogelsberger and White implemented these capabilities into a fully three-dimensional simulation of the one-dimensional similarity solution for halo formation first presented by Bertschinger. This similarity solution turned out to be violently dynamically unstable to nonradial perturbations, turning into an extremely elongated and stably growing bar-like system. This structure has a substantially more complex fine-grained structure than the previously studied (unstable) similarity solution. In particular, it turned out that stream densities are substantially lower and caustics are weaker, with the result that annihilation at caustics has no significant effect on the annihilation radiation from the inner halo.

Using extended Press-Schechter theory R. Angulo and S. White investigated the formation and assembly history of haloes assuming that the dark matter consist of neutralinos. They found that the first-generation haloes of most particles do not have a mass similar to the free-streaming mass of neutralinos nor do they form at high redshift. This suggest that they will be efficiently disrupted during halo assembly. On a complementary line of research, E. Jennins (Durham), C. Baugh (Durham), R. Angulo and S. Pascoli (Durham) studied the nonlinear growth of cosmic structures in different dark energy models, using large volume N-body simulations. The found quintessence models that are different from ΛCDM both today and at high redshifts ($z \sim 1000$) and which feature late ($z < 2$), rapid transitions in the equation of state, can have identical baryonic acoustic oscillation (BAO) peak positions to those in ΛCDM. They also found that these models have higher abundances of dark matter haloes at $z > 0$ compared to ΛCDM and so measurements of the mass function should allow us to distinguish these quintessence models from a cosmological constant.

Jens Jasche, in collaboration with Francisco Kitaura, Benjamin Wandelt and Torsten Enßlin, developed the new Bayesian computer algorithm ARES (Algorithm for REconstruction and Sampling) for the analysis of galaxy surveys. ARES is a high performance full Bayesian LSS analysis algorithm particularly aiming at joint inferences of the cosmological power-spectrum and the according three dimensional density field. It accurately resolves artificial mode coupling as introduced by survey geometry or selection effects permitting precision estimates of the baryon acoustic oscillations or the large scale turn over in the cosmological power-spectrum. In addition, ARES provides the full non-Gaussian power-spectrum posterior and thus provides uncertainty information for the estimated quantities. This also allows for calculation of higher-order correlations, cosmological parameter estimation and model comparison. Aside from power-spectra, ARES also provides full three dimensional density fields allowing for analyses of the relation between galaxy properties and their large scale environment. ARES, therefore, is a scientifically valuable method for LSS inferences, particularly suited for precision cosmological power-spectrum estimation.

J. Jasche developed the new Bayesian computer algorithm HADES (HAmiltonian Density Estimation and Sampling) for non-linear, non-Gaussian three dimensional LSS inference. It performs density field inferences deep into the non-linear regime and also provides the according non-Gaussian uncertainty information. HADES is the first non-Gaussian and non-linear three dimensional full Bayesian LSS inference algorithm. It provides samples from the lognormal-Poissonian distribution by efficiently exploring high dimensional spaces (usually consisting of 10^6 or more parameters) via an efficient sampling algorithm (see Figure 3.1). In this fashion, HADES yields a full characterization of the three dimensional large scale structure from galaxy observations.

J. Jasche, in collaboration with F. Kitaura, Ch. Li and T. Enßlin, performed a non-linear non-Gaussian large scale structure analysis by applying

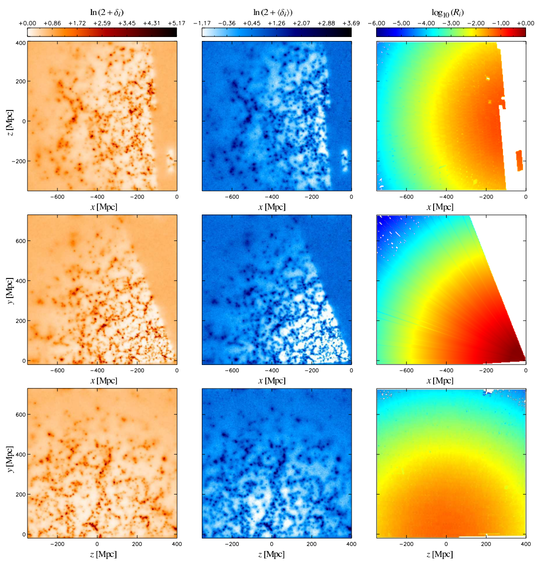

Figure 3.1: Three different slices from different sides through the ensemble mean density (left panels), ensemble variance (middle panels) and the three dimensional response operator consisting of survey geometry and radial selection function (right panels). Especially the variance plots demonstrate, that the method accounted for the full Poissonian noise structure introduced by the galaxy sample. One can also see the correlation between high density regions and high variance regions, as expected for Poissonian noise.

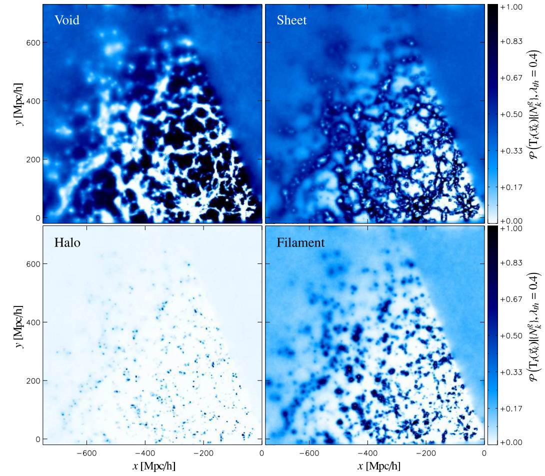

Figure 3.2: Slices through the cosmic web posterior for the threshold values ($\lambda_{th} = 0.4$) for the four different web types (void, sheet, filament and halo). It is interesting to note, that sliced sheets look filamentary, while filaments piercing the slice appear as dots.

the newly developed HADES algorithm to the latest Sloan Digital Sky Survey data release 7 galaxy sample. The procedure yielded about three terabytes of valuable scientific information in the form of 40.000 full three dimensional density samples, which encode all non-Gaussian uncertainties. The analysis results depict the filamentary structure of the cosmic web in unprecedented accuracy. The full statistical characterization of the LSS permits accurate non-Gaussian error propagation to any finally inferred quantity. In particular, a cosmic web type classification yielded the web type posterior, which encodes the uncertainty of finding a specific web type (halo, filament, sheet or void) at a given position in the observed volume (See Figure 3.2). In addition, many physical quantities, such as the gravitational potential, large scale cosmic flows and the tidal-shear tensor can be estimated for subsequent analyses.

R.B. Metcalf has studied how the gravitational lensing of 21 cm radiation from pre-galactic HI can be used to measure cosmological parameters such as the density of matter , Ω, and evolution of dark energy. It was found that by combining such data with future weak lensing data using galaxies as sources unprecedented constraints on dark energy and the masses of neutrinos could be obtained. The evolution of dark energy at redshifts above z =1 could be probed. Other observations, such as type Ia supernovae surveys, are not capable of measuring dark energy at such high redshifts. This technique would also significantly reduce the degeneracy between neutrino masses and dark energy parameters. Perhaps most significantly, lensing of pre-galactic 21 cm radiation could be used to image the distribution of dark matter with a resolution of several arcminutes using a telescope like the proposed Square Kilometer Array (SKA).

Supersymmetric extensions of the standard model of particle physics offer attractive candidates to be the major component of dark matter. One of them is the neutralino, whose properties make them fit remarkably well within the cold dark matter model of structure formation. Interestingly, their intrinsic properties make their detection feasible through non-gravitational effects. One particularly exciting prospect for their detection lies in observing the $\gamma-$ray radiation created in pair annihilation of neutralinos. If this radiation is large enough, they could be detected by satellites such as FERMI, which has been mapping the $\gamma-$ray sky since mid 2008. Outside our Galactic halo, these $\gamma-$rays would be produced abundantly by dark matter annihilating in all the haloes and subhaloes within our past light-cone, contributing to the so-called extragalactic $\gamma-$ray background (EGB) radiation. J. Zavala, V. Springel and M. Boylan-Kolchin explored this possibility by using the Millennium-II simulation of structure formation to generate, for the first time, all-sky maps of the contribution of dark matter annihilation to the EGB radiation. It was found that in the most optimistic scenario considered, the energy spectrum of the isotropic component of the radiation lies approximately one order of magnitude below the values of the EGB measured by the telescope EGRET in the energy range $1-20$ GeV, where an apparent excess of $\gamma-$rays had led to speculations of a possible origin in dark matter annihilation. The analysis of the anisotropic component of the EGB yielded specific predictions for the shape of the angular power spectrum which can potentially be used to discriminate against other $\gamma-$ray sources. We also found that this shape depends on the energy of the observations. Interestingly, these differences can be exploited to construct "color" maps that enhance the signal of nearby dark matter structures. If strong spectral features in the rest-frame emission spectrum of the annihilation radiation are present, this could be especially powerful, perhaps even allowing tomographic observations of dark matter structures. The annihilation of neutralinos into positrons and electrons can also contribute to the solution of the excess of these particles in cosmic rays reported by a number of experiments such as PAMELA and FERMI. However, the annihilation rates need to be typically "boosted" by a factor of a 1000 or higher over the values obtained using standard assumptions. A possibility to obtain such high boosts is to consider the effect of an attractive force acting between the dark matter particles prior to the annihilation (usually modeled by a Yukawa-type potential). This is the so-called Sommerfeld-enhancement and in recent years has motivated a plethora of studies. J. Zavala, M. Vogelsberger and S. White studied the effect of Sommerfeld-enhanced annihilation in the early Universe. Firstly, an analysis was made on its impact in the present-day dark matter abundance and found that previous works that assumed no effect need to be revised to re-normalize the cross sections (by as much as an order of magnitude) to the proper values implied by the observed relic density. This normalization is important because it sets the level over which boosts factors have been typically computed. Secondly, the amount of energy deposited in these type of models into the radiation-plasma in the redshift range $5\times10^4 < z < 2\times10^6$ was calculated. Energy injection at this epoch would create a distortion in the Cosmic Microwave Background energy spectrum. The COBE/FIRAS experiment has put constraints on this Bose-Einstein $\mu-$type distortion. It was found that for some parameter combinations, the energy injection by annihilation would be higher than current observational bounds. This is a relevant result, because these combinations give the higher boosts and are typically invoked to solve the cosmic ray anomalies.

E. Puchwein and S. Hilbert (Argelander-Institut für Astronomie, Bonn, Germany) use ray-tracing through the Millennium simulation to study how secondary matter structures along the line-of-sight and the stellar mass in galaxies affect strong gravitational lensing by galaxy clusters. They find that additional structures along the line-of-sight increase the strong-lensing optical depth by $\sim 10-25\%$, while strong-lensing cross-sections of individual clusters are frequently boosted by as much as $\sim 50\%$. The enhancement is mainly due to structures that are not correlated with the lens. Cluster galaxies increase the strong-lensing optical depth by up to a factor of 2, while interloping galaxies are not significant. They conclude that these effects need to be taken into account for predictions of the giant arc abundance, but they are not large enough to fully account for the reported discrepancy between predicted and observed abundances. They also find that the radial distribution of tangential arcs is very broad and extends out to several Einstein radii. Thus, individual arcs are not well suited for constraining them.

3.13 Numerical methods

V. Springel completed the new cosmological moving-mesh code AREPO. It uses a novel discretization scheme to calculate hydrodynamical flows which can largely eliminate some of the most important weaknesses of the Lagrangian smoothed particle hydrodynamics (SPH) technique and of standard Eulerian hydrodynamics on a static mesh. The new approach is based on a moving unstructured mesh that is defined as the Voronoi tessellation of a set of discrete points. The fluid equations are solved with an unsplit finite-volume Godunov scheme. The new method is fully Galilei-invariant and offers second-order accuracy. It achieves comparable accuracy for treating shocks as Eulerian schemes, but provides a much improved treatment of contact discontinuities. The new scheme adjusts its spatial resolution to the local clustering of the flow automatically and continuously, and hence retains a principle advantage of SPH for simulations of cosmological structure growth.

S. Hess and V. Springel developed a novel Lagrangian particle hydrodynamics method. It is the density estimate is carried out with the help of an auxiliary mesh constructed as the Voronoi tesselation of the simulation particles. This Voronoi-based approach improves, in particular, the ability of the scheme to represent sharp contact discontinuities. Hess & Springel find that this eliminates spurious surface tension effects present in the traditional smoothed particle hydrodynamics (SPH) technique which play a role in suppressing certain fluid instabilities. Furthermore, the newly developed 'Voronoi Particle Hydrodynamics' produces better results than SPH especially in shocks and turbulent regimes of ordinary hydrodynamic flows.

R. Angulo and S. White demonstrated that the output of a cosmological N-body simulation can, to remarkable accuracy, be scaled to represent the growth of large-scale structure in a cosmology with parameters similar to but different from those originally assumed. This scaling reproduces the mass and halo power spectra, in both real and redshift-space, to better than 1% on large scales ($k < 0.1hMpc^{-1}$). A halo-by-halo comparison shows that centre-of-mass positions and velocities are reproduced to better than $100h^{-1}$kpc and 10%, respectively. Halo masses, concentrations and spins are also reproduced at about the 10% level, although with small biases. Halo assembly histories are accurately reproduced, leading to central galaxy magnitudes with errors of about 0.25 magnitudes and a bias of about 0.1 magnitudes for a representative semi-analytic model. This algorithm will enable a systematic exploration of the coupling between cosmological parameter estimates and uncertainties in galaxy formation in future large-scale structure surveys.

T. Enßlin and M. Frommert have investigate the signal processing problem of reconstructing a Gaussian random field with unknown power spectrum. A novel algorithm with higher fidelity than existing approaches using the maximum a posteriori approximation could be derived using a parameter uncertainty renormalisation flow analysis of information field theory. Cornelius Weig and Torsten Enßlin have developed a novel algorithm to reconstruct the cosmic matter distribution from galaxy measurements with position uncertainty due to measurement errors and redshift distortions.

A. Wongwathanarat, in a PhD project supervised by E. Müller, implemented an axis-free two-patch overset grid technique in spherical coordinates (Yin-Yang grid; based on the work of Kageyama & Sato, 2004) into the explicit Eulerian hydrodynamics code PROMETHEUS. The Yin-Yang grid eases the severe restriction of the time step size due to the CFL condition when using explicit time discretization. Moreover, the Yin-Yang grid does not introduce numerical artifacts that are often encountered near the coordinate symmetry axis when using a computational grid in spherical polar coordinates. The code successfully passed several hydrodynamical tests including the Sod shock tube test, the Taylor-Sedov explosion test, and tests involving self-gravitating flows (non-rotating and rotating polytropes). To handle self-gravity, the code includes a three dimensional Poisson solver using an expansion into spherical harmonics (Müller & Steinmetz, 1995).

Within his PhD project supervised by F. Roepke, F. Miczek has continued developing a new hydrodynamic simulation code for low Mach number flows. In order to be applicable to convective processes in stars, the code was extended by new features including an improved spatial discretization, an interface for general equations of state, gravity and diffusive radiative transfer. Moreover, a flexible framework for the solution of the non-linear algebraic equations, resulting from the implicit time stepping alorithm was developed. As a first astrophysical application, shear instabilities in stars are considered.

T. Mädler, in a PhD project supervised by E. Müller, was working on the characteristic initial value formulation of General Relativity with the long term aim to simulate stellar core collapse in Bondi-Sachs coordinates with twisting axisymmetry. In collaboration with B. Schmidt (Munich, Germany) he established the regularity conditions for the vertex of a single light cone and calculated the corresponding Einstein equations with a perfect fluid source in an affine null coordinate system by means of a Taylor expansion in the neighborhood of the origin on a central geodesic. He is currently implementing the Einstein fluid equations in a numerical code.

P. Cerdá-Durán presented a new method to estimate the numerical viscosity in simulations of astrophysical objects, which is based on the damping of fluid oscillations. He calibrated the method by adding an explicit bulk viscosity and considering different numerical schemes. He applied the method to general relativistic hydrodynamic flows using spherical polar coordinates, and found that in simulations of radial oscillations of neutron stars the main source of numerical viscosity is the surface of the star. The method should be useful when trying to determine the resolution requirements and limitations of numerical simulations in various astrophysical scenarios.

P. Cerdá-Durán has developed a new numerical technique, *mesh coarsening*, which allows to drastically decrease time-step in multidimensional hydrodynamics simulations in spherical coordinates using explicit methods. This new technique will allow to perform three-dimensional simulations of the core-collapse with relatively small computational cost.

Numerous physical problems require a detailed understanding of the radiative transfer of photons into different environments, ranging from intergalactic and interstellar medium to stellar or planetary atmospheres. The full solution of the seven dimensional radiative transfer equation is still beyond our computational capabilities. For this reason, an increasing effort has been devoted to the development of radiative transfer codes. An ongoing effort is done by A. Maselli (Florence) and B. Ciardi to develop the radiative transfer code CRASH. Lately, the implementation of scattering of Ly-alpha photons (M. Pierleoni, A. Maselli, B. Ciardi) has been added, while papers to summarize the implementation of x-ray physics (D. Schleicher [Leiden], A. Maselli, B. Ciardi) and a parallel version of the code (A. Partl [Potsdam], A. Maselli, B. Ciardi) are being written.

L. Sbordone is finalyzing the development of MyGIsFOS, an automatic code aimed at determining atmospheric parameters and detailed chemical abundan ces from stellar high-resolution spectra. MyGIsFOS works by replicating a "manual" chemical analysis, measuring individual lines for different elements against a pre-calculated grid of synthetic spectra, and it is thus best suited to handle intermediate-high resolution spectra such as the ones produced e.g. by FLAMES-GIRAFFE or UVES, with the aim of retrieving chemical abundances for a large number of elements. MyGIsFOS is being currently employed on a sample UVES spectra of extremely metal poor dwarf stars, as well as on the aforementioned spectra of the Sgr dSph wide angle survey.

Longtime numerical simulations of solar surface convection have been done with the Antares code for the 3D case by F. Zaussinger and F. Kupka. A simulation covering almost nine hours of solar time has been calculated to obtain a better understanding of p-mode excitation and damping and to investigate statistical properties of the flow. These simulations have also been used to compare the ANTARES code with previously existing simulation codes differing in their numerical schemes, assumptions on boundary conditions, and radiative transfer methods implemented into them.

High resolution simulations of A-stars in 2D for the case of a solar helium abundance and for the case of no helium being present have been analyzed in detail. Large shock fronts were found to cover a significant fraction of the photospheric layers. For the helium free case a much thinner convection zone showing a reversal in the direction of the kinetic energy flux (compared to the solar case) was found. The role and consequences of insufficient resolution and the nature of the severe time step limitations due to efficient radiative transfer near the stellar surface were analyzed and discussed. The new simulations with grid refinement were found to be just at the limit of resolving the radiative cooling taking place at the stellar surface. The cooling leads to a numerically stiff term in the dynamical equation for the energy which calls for an improved time integration scheme.

Further developments in the interdisciplinary project"Double- diffusive convection in ocean and in stars" were done by F. Zaussinger. Semiconvective mixing processes are of general importance in stellar evolution. To gain deeper insight into semiconvection zones of massive stars a specially adapted version of the Antares simulation code was developed. High resolution simulations in 2D have now been performed, which could challenge existing numerical simulations. A detailed parameter study with varying Prandtl- and Lewis number is currently in progress. The goal of this study is to improve estimates for the diffusion efficiency parameter of semiconvection in various stellar regimes. This project is a collaboration between the MPA, the University of Vienna and the Alfred-Wegener Institute (Bremerhaven). Therefore H. Grimm-Strele and N. Happenhofer (both University of Vienna) were invited in September.

4 Publications and Invited Talks

4.1 Publications in Journals

4.1.1 Publications that appeared in 2009 (220)

Abazajian, K.N. J.K. Adelman-McCarthy et al.(S. White): The Seventh Data Release of the Sloan Digital Sky Survey. Astrophys. J. Suppl. **182**, 543–558 (2009).

Agnoletto, I. et al. (incl. P. Mazzali and S. Taubenberger): SN 2006gy: Was it really extraordinary? Astrophys. J. **691**, 1348–1359 (2009).

Altavilla, G., P. Ruiz-Lapuente et al. (incl. W. Hillebrandt): Type Ia SNe along redshift: The R(Si II) ratio and the expansion velocities in intermediate-z supernovae. Astrophys. J. **695**, 135–148 (2009).

Althaus, L. G., J.A. Panei, M.M. Miller Bertolami et al.: New evolutionary sequences for hot h-deficient white dwarfs on the basis of a full account of progenitor evolution. Astrophys. J. **704**, 1605–1615 (2009).

Ameglio, S., S. Borgani et al. (E. Dolag): Reconstructing mass profiles of simulated galaxy clusters by combining Sunyaev–Zeldovich and X-ray images. Mon. Not. R. Astron. Soc. **394**, 479–490 (2009).

Anzer, U.: Global prominence oscillations. Astron. Astrophys. **497**, 521–524 (2009).

Arevalo, P., P. Uttley et al. (incl. E. Churazov): Correlation and time delays of the X-ray and optical emission of the Seyfert galaxy NGC 3783. Mon. Not. R. Astron. Soc. **397**, 2004–2014 (2009).

Ashdown, M.A., C. Baccigalupi et al. (incl. M. Reinecke): Making maps from Planck LFI 30 GHz data with asymmetric beams and cooler noise. Astron. Astrophys. **493**, 753–783 (2009).

Asplund, M., N. Grevesse, A. Sauval and S. Pat: The Chemical Composition of the Sun. Ann. Review of Astron. Astrophys. **47**, 481–522 (2009).

Bai, L., G. Rieke et al. (incl. D. Christlein): The infrared luminosity functions of rich clusters. Astrophys. J. **693**, 1840–1850 (2009).

Barazza, F.D. et al. (incl. G. De Lucia and S.D.M. White): Frequency and properties of bars in cluster and field galaxies at intermediate redshifts. Astron. Astrophys. **497**, 713–728 (2009).

Bardelli, S., E. Zucca et al. (incl. S. Charlot): The VVDS-VLA deep field - IV. Radio-optical properties. Astron. Astrophys. **495**, 431–446 (2009).

Basu, S., W. Chaplin et al. (incl. A. Serenelli): Fresh insights on the structure of the solar core. Astrophys. J. **699**, 1403–1417 (2009).

Battaglia, N., C. Pfrommer et al. (incl. T. Enßlin): Exploring the magnetized cosmic web through low-frequency radio emission. Mon. Not. R. Astron. Soc. **393**, 1073–1089 (2009).

Basu-Zych, A.R., T. Goncalves, R. Overzier et al.: An OSIRIS study of the gas kinematics in a sample of UV-selected galaxies: evidence of ”hot and bothered” starbursts in the local universe. Astrophys. J. **699**, L118–L124 (2009).

Basu-Zych, A.R., D. Schiminovich et al. (incl. R. Overzier): Studying large- and small-scale environments of ultraviolet luminous galaxies Astrophys. J. **699**, 1307–1320 (2009).

Bauswein A., T.-H. Janka, R. Oechslin et al.: Mass ejection by strange star mergers and observational implications. Phys. Rev. Lett. **103**, 011101 (2009).

Bernardi, G., A.G. de Bruyn et al. (incl. B. Ciardi): Foregrounds for observations of the cosmological 21 cm line - I. First Westerbork measurements of galactic emission at 150 MHz in a low latitude field. Astron. Astrophys. **500**, 965–979 (2009).

Börner, G.: Cosmology and fundamental physics. Gen. Rel. and Grav. **41**, 2169–2177 (2009).

Bolton, J. and G. Becker: Resolving the high redshift Ly-α forest in smoothed particle hydrodynamics simulations. Mon. Not. R. Astron. Soc. Lett. **398**, L26–L30 (2009).

Bolton, J.S., S. Oh Peng and S. Furlanetto: The evolution of the Ly-alpha forest effective optical depth following He ii reionization. Mon. Not. R. Astron. Soc. **396**, 2405–2418 (2009).

Bolton, J.S., S. Oh Peng and S. Furlanetto: Photoheating and the fate of hard photons during the reionization of He ii by quasars. Mon. Not. R. Astron. Soc. **395**, 736–752 (2009).

Bonoli, S. and U.L. Pen: Halo stochasticity in global clustering analysis. Mon. Not. R. Astron. Soc. **396**, 1610–1618 (2009).

Bonoli, S. F. Marulli, V. Springel, S.D.M. White et al: Modelling the cosmological co-evolution of supermassive black holes and galaxies – II. The clustering of quasars and their dark environment. Mon. Not. R. Astron. Soc. **396**, 423–438 (2009).

Botticella, M.T, A. Pastorello et al. (incl. S. Taubenberger): SN 2008S: an electron-capture SN from a super-AGB progenitor? Mon. Not. R. Astron. Soc. **398**, 1041–1068 (2009).

Boylan-Kolchin, M., V. Springel, S. White et al.: Resolving cosmic structure formation with the Millennium-II simulation. Mon. Not. R. Astron. Soc. **398**, 1150–1164 (2009).

Brunetti, G., R. Cassano, K. Dolag and G. Setti: On the evolution of giant radio halos and their connection with cluster mergers. Astron. Astrophys. **507**, 661–669 (2009).

Budavari, T., V. Wild, A. Szalay et al.: Reliable eigenspectra for new generation surveys. Mon. Not. R. Astron. Soc. **394**, 1496–1502 (2009).

Budavari, T., S. Heinis et al. (incl. G. Kauffmann): GALEX-SDSS catalogs for statistical studies. Astrophys. J. **694**, 1281–1292 (2009).

Bufano, F., S. Immler, et al. (incl. P. Mazzali): Ultraviolet spectroscopy of supernovae: the first two years of Swift observations. Astrophys. J. **700**, 1456–1472 (2009).

Burenin, R.A., I.F. Bikmaev et al. (incl. R. Sunyaev): Optical identification of the hard X-ray source IGR J18257-0707. Astron. Lett. **35**, 71–74 (2009).

Campisi, M.A., C. Vignali, M. Brusa et al.: On the nature of red galaxies: the Chandra perspective. Astron. Astrophys. **501**, 485–494 (2009).

Carbone, C., C. Baccigalupi et al. (incl. V. Springel): Lensed CMB temperature and polarization maps from the Millennium Simulation. Mon. Not. R. Astron. Soc. **396**, 668–679 (2009).

Cerda-Duran, P., N. Stergioulas, and J. A. Font: Alfven QPOs in magnetars in the anelastic approximation. Mon. Not. R. Astron. Soc. **398**, 1607–1620 (2009).

Chen, Y.M., V. Wild, G. Kauffmann et al.: Constraints on the star formation histories of galaxies from z $\sim$ 1 to 0. Mon. Not. R. Astron. Soc. **393**, 406–418 (2009).

Chiavassa, A., B. Plez, E. Josselin and B. Freytag: Radiative hydrodynamics simulations of red supergiant stars. I. interpretation of interferometric observations Astron. Astrophys. **506**, 1351–1365 (2009).

Chluba, J. and R. Sunyaev: Time-dependent corrections to the Ly α escape probability during cosmologicalrecombination. Astron. Astrophys. **496**, 619–635 (2009).

Chluba, J. and R. Sunyaev: Cosmological hydrogen recombination: influence of resonance and electron scattering. Astron. Astrophys. **503**, 345–355 (2009).

Chluba, J. and R. Sunyaev: Pre-recombinational energy release and narrow features in the CMB spectrum. Astron. Astrophys. **501**, 29–47 (2009).

Christlein, D., E. Gawiser, D. Marchesini and N. Padilla: Introducing the photometric maximum likelihood method: galaxy luminosity functions at z<1.2 in MUSYC-ECDFS. Mon. Not. R. Astron. Soc. **400**, 429–450 (2009).

Ciaraldi-Schoolmann, F. et al. (incl. F. Röpke and W. Hillebrandt): Turbulence in a three-dimensional deflagration model for type Ia supernovae - I. Scaling properties. Astrophys. J. **696**, 1491–1497 (2009).

Cimatti, A., M. Robberto et al. (incl. G. Kauffmann and S. White): SPACE: the spectroscopic all-sky cosmic explorer. Experimental Astronomy **23**, 39– (2009).

Collet, R., M. Asplund and P. Nissen: The Barium isotopic abundance in the metal-poor star HD140283. Publ. Astron. Soc. of Australia **26**, 330–334 (2009).

Cordero-Carrion, I., P. Cerda-Duran, H. Dimmelmeier et al.: Improved constrained scheme for the Einstein equations: An approach to the uniqueness issue. Phys. Rev. D **79**, 024017 (2009).

Croston, J. H. et al. (incl. M. Gilfanov): High-energy particle acceleration at the radio-lobe shock of Centaurus A. Monthly Notices of the. Mon. Not. R. Astron. Soc. **395**, 1999–2012 (2009).

Cruz-Alvez, M., S. Rossi and T.C. Beers: Searching for s-process-enhanced metal-poor stars. Publ. Astron. Soc. of Australia **26**, 335–338 (2009).

Cunnama, D., A. Faltenbacher, C. Cress and S. Paamoor: The velocity-shape alignment of clusters and the kinetic Sunyaev–Zeldovich effect. Mon. Not. R. Astron. Soc. Lett. **397**, L41–L45 (2009).

Das, P., O. Gerhard, L. Coccato, E. Churazov et al. The orbital structure of the massive elliptical galaxy NGC 5846. Astronomische Nachrichten **329**, 940-943 (2009).

De Ravel, L., O. Le Fevre et al. (incl. S. Charlot): The VIMOS VLT deep survey - evolution of the major merger rate since z $\sim$ 1 from spectroscopically confirmed galaxy pairs. Astron. Astrophys. **498**, 379–397 (2009).

De Rossi, E.M, P. Tissera, G. De Lucia and G. Kauffmann: Milky Way type galaxies in a ΛCDM cosmology Mon. Not. R. Astron. Soc. **395**, 210–217 (2009).

De Silva, G.M., B.K. Gibson, J. Lattanzio and M. Asplund: O and Na abundance patterns in open clusters of the galactic disk. Astron. Astrophys. Lett. **500**, L25–L28 (2009).

Dekel, A., Y. Birnboim et al. (incl. E. Neistein): Cold streams in early massive hot haloes as the main mode of galaxy formation. Nature **457**, 451–454 (2009).

Dolag, K., M. Kachelriess, S. Ostapchenko and R. Tomas: Blazar halos as probe for extragalactic magnetic fields and maximal acceleration energy. Astrophys. J. **703**, 1078–1085 (2009).

Dolag, K. and F. Stasyszyn: An MHD gadget for cosmological simulations. Mon. Not. R. Astron. Soc. **398**, 1678–1697 (2009).

Dolag, K., S. Borgani, G. Murante and V. Springel: Substructures in hydrodynamical cluster simulations. Mon. Not. R. Astron. Soc. **393**, 497–514 (2009).

Dolag, K., M. Kachelrieß and D.V. Semikoz: UHECR observations and lensing in the magnetic field of the Virgo cluster. J. of Cosmology and Astrop. Phys. **1**, 1–11 (2009).

Domingo, V., I. Ermolli et al.: (incl. H. Spruit): Solar surface magnetism and irradiance on time scales from days to the 11-year Cyc. Space Science Rev. **145**, 337–380 (2009).

Donnert, J., K. Dolag, H. Lesch and E. Müller: Cluster magnetic fields from galactic outflows. Mon. Not. R. Astron. Soc. **392**, 1008–1021 (2009).

Donoso, E., P. Best and G. Kauffmann: Evolution of the radio-loud galaxy population. Mon. Not. R. Astron. Soc. **392**, 617–629 (2009).

Elsner, F. and B. Wandelt: Improved Simulation of Non-Gaussian Temperature and Polarization Cosmic Microwave Background. Maps. Astrophys. J. Suppl. **184**, 264–270 (2009).

Enßlin, T. A., M. Frommert and F.S. Kitaura: Information field theory for cosmological perturbation reconstruction and nonlinear signal analysis: Phys. Rev. D **80**, 105005 (2009).

Fabbian, D., M. Asplund, P. Barklem et al.: Neutral oxygen spectral line formation revisited with new collisional data: large departures from LTE at low metallicity. Astron. Astrophys. **500**, 1221–1238 (2009).

Fabbian, D., P. Nissen, M. Asplund, et al.: The C/O ratio at low metallicity: constraints on early chemical evolution from observations of galactic halo stars. Astron. Astrophys. **500**, 1143–1155 (2009).

Faltenbacher, A., Ch. Li, S.D.M. White et al.: Alignment between galaxies and large-scale structure. Res. in Astron. and Astrophys. **9**, 41–58 (2009).

Faure, C., J.-P. Kneib, S. Hilbert et al.: On the contribution of large-scale structure to strong gravitational lensing. Astrophys. J. **695**, 1233–1243 (2009).

Fendt, W.A., J. Chluba, J.A. Rubino-Martin and B. Wandelt: RICO: a new approach for fast and accurate representation of the cosmological recombination history. Astrophys. J. Suppl. **181**, 627–638 (2009).

Fivet, V., P. Quinet et al. (incl. M. Asplund): Experimental and theoretical radiative decay rates for highly excited ruthenium atomic levels and the solar abundance of ruthenium. Mon. Not. R. Astron. Soc. **396**, 2124–2132 (2009).

Fontanot, F., G. De Lucia, P. Monaco et al.: The many manifestations of downsizing: hierarchical galaxy formation models confront observations. Mon. Not. R. Astron. Soc. **397**, 1776–1790 (2009).

Frommert, M. and T. Enßlin: Ironing out primordial temperature fluctuations with polarization: optimal detection of cosmic structure imprints. Mon. Not. R. Astron. Soc. **395**, 1837–1844 (2009).

Fryer, C.L, P. Brown, et al (incl. P. Mazzali): Spectra and Light Curves of Failed Supernovae. Astrophys. J. **707**, 193–207 (2009).

Gabler, M., U. Sperhake, and N. Andersson: Nonlinear radial oscillations of neutron stars. Phys. Rev. D **80**, 064012 (2009).

Gadotti, D.A.: Structural properties of pseudo-bulges, classical bulges and elliptical galaxies: a sloan digital sky survey perspective. Mon. Not. R. Astron. Soc. **393**, 1531–1552 (2009).

Gal-Yam, A., P. Mazzali, E.O. Ofek et al.: Supernova 2007bi as a pair-instability explosion. Nature **462**, 624–627 (2009).

Gerssen, J., D. Wilman, et al. (incl. V. Wild): Highly ionized gas on galaxy scales: mapping the interacting Seyfert galaxy LEDA 135736. Mon. Not. R. Astron. Soc. Lett. **393**, L45–L49 (2009).

Giannos, D., D. Uzdensky and M. Begelmann: Fast TeV variability in blazars: jets in a jet. Mon. Not. R. Astron. Soc. Lett. **395**, L29–L33 (2009).

Gonzalez-Hernandez, J., P. Ruiz-Lapuente, A. Fillipenko et al.: The chemical abundances of tycho G in supernova remnant 1572. Astrophys. J. **691**, 1–15 (2009).

Grossi, M. et al. (incl. K. Dolag and F. Iannuzzi): Large-scale non-Gaussian mass function and halo bias: tests on N-body simulations. Mon. Not. R. Astron. Soc. **398**, 321–332 (2009).

Grossi, M. and V. Springel: The impact of early dark energy on non-linear structure formation. Mon. Not. R. Astron. Soc. **394**, 1559–1574 (2009).

Guo, Qi and S.D.M. White: High-redshift galaxy populations and their descendants. Mon. Not. R. Astron. Soc. **396**, 39–52 (2009).

Guo, Y., D. McIntosh et al. (incl. S. Weinmann): Structural properties of central galaxies in groups and clusters. Mon. Not. R. Astron. Soc. **398**, 1129–1149 (2009).

Hachinger S., P. A. Mazzali, S. Taubenberger et al.: Spectral analysis of the 91bg-like Type Ia SN 2005bl: low luminosity, low velocities, incomplete burning: Mon. Not. R. Astron. Soc. **399**, 1238—1254 (2009).

Hamuy, M., J. Deng, P. Mazzali et al.: Supernova 2003bg: the first type IIb hypernova. Astrophys. J. **703**, 1612–1623 (2009).

Hansen, F.K., A.J. Banday, K.M. Gorski et al. Power asymmetry in cosmic microwave background fluctuations from full sky to sub-degree scales: Is the universe isotropic? Astrophys. J. **704**, 1448–1458 (2009)

Harker, G., S. Zaroubi et al. (incl. B. Ciardi): Non-parametric foreground subtraction for 21-cm epoch of reionization experiments. Mon. Not. R. Astron. Soc. **397**, 1138–1152 (2009).

Harker, G., S. Zaroubi et al. (incl. B. Ciardi): Detection and extraction of signals from the epoch of reionization using higher-order one-point statistics. Mon. Not. R. Astron. Soc. **393**, 1449–1458 (2009).

Hatch, N.A., R. Overzier, J. Kurk et al.: The growth and assembly of a massive galaxy at z $\sim$2. Mon. Not. R. Astron. Soc. **395**, 114–125 (2009).

Herbert-Fort, S., D. Zaritsky, et al. (incl. D. Christlein): Spatially correlated cluster populations in the outer disk of NGC 3184. Astrophys. J. **700**, 1977–1987 (2009).

Hernandez-Monteagudo, C. and S. Ho: On the peculiar momentum of baryons after reionization. Mon. Not. R. Astron. Soc. **398**, 790–806 (2009).

Hilbert, S., J. Hartlap, S. White and P. Schneider: Ray-tracing through the millennium simulation: born corrections and lens-lens coupling in cosmic shear and galaxy-galaxy lensing. Astron. Astrophys. **499**, 31–43 (2009).

Hoftuft, J., H.K. Eriksen, A.J. Banday et al.: Increasing evidence for hemispherical power asymmetry in the five-year WMAP data. Astrophys. J. **699**, 985–989 (2009).

Hou, Z., A.J. Banday and K. Gorski: The hot and cold spots in five-year WMAP data. Mon. Not. R. Astron. Soc. **396**, 1273–1286 (2009).

Hunter, D. J. et al. (incl. S. Taubenberger and P. Mazzali): Extensive optical and near-infrared observations of the nearby, narrow-lined type Ic SN 2007gr: days 5 to 415. Astron. Astrophys. **508**, 371–389 (2009).

Irwin, J.A., G.L. Hoffmann et al. (incl. B. Catinella): ΛCDM Satellites and H I companions–the Arecibo ALFA survey of NGC 2903 Astrophys. J. **692**, 1447–1463 (2009).

Jansson, R., G. Farrar, A. Waelkens and T. Enßlin: Constraining models of the large scale galactic magnetic field with WMAP5 polarization data and extragalactic rotation measure sources. J. of Cosmology and Astrop. Phys. **7**, 1–26 (2009).

Kasen, D., F. Röpke and S. Woosley: The diversity of type Ia supernovae from broken symmetries. Nature **460**, 869–872 (2009).

Kauffmann, G., and T. Heckman: Feast and Famine: regulation of black hole growth in low-redshift galaxies. Mon. Not. R. Astron. Soc. **397**, 135–147 (2009).

Kawabata, K.S., M. Tanaka, K. Maeda et al.: Extremely luminous supernova 2006gy at late phase: detection of optical emission from supernova. Astrophys. J. **697**, 747–757 (2009).

Kerzendorf, W., B. Schmidt, M. Asplund et al.: Subaru high-resolution spectroscopy of star G in the tycho supernova remnant. Astrophys. J. **701**, 1665–1672 (2009).

Kitaura, F.S., J. Jasche, Ch. Li, et al.: Cosmic cartography of the large-scale structure with Sloan Digital Sky Survey data release 6. Mon. Not. R. Astron. Soc., **400**, 183–203, (2009).

Knobel, C., S.J. Lilly et al. (incl. M. Kitzbichler): An optical group catalog to z = 1 from the z COSMOS 10 k sample. Astrophys. J. **697**, 1842–1860 (2009).

Kotarba, H. et al. (incl. K. Dolag and F. Stasyszyn): Magnetic field structure due to the global velocity field in spiral galaxies. Mon. Not. R. Astron. Soc. **397**, 733–747 (2009).

Kromer, M., and S. Sim: Time-dependent three-dimensional spectrum synthesis for type Ia supernovae. Mon. Not. R. Astron. Soc. **398**, 1809–1826 (2009).

Kupka, F., J. Ballot and H.J. Muthsam: Effects of resolution and helium abundance in A star surface convection simulations. Comm. in Asteroseismology **160**, 30–63 (2009).

Landstreet, J.D., F. Kupka, H. Ford et al.: Atmospheric velocity fields in tepid main sequence stars. Astron. Astrophys. **503**, 973–984 (2009).

Leloudas, G., M. Stritzinger et al. (incl. S. Taubenberger): The normal type Ia SN 2003hv out to very late phases. Astron. Astrophys. **505**, 265–279 (2009).

Li, Ch. and S.D.M. White: The distribution of stellar mass in the low-redshift universe. Mon. Not. R. Astron. Soc. **398**, 2177 –2187 (2009).

Li, Ch., D. Gadotti, S. Mao and G. Kauffmann: The clustering of barred galaxies in the local universe. Mon. Not. R. Astron. Soc. **397**, 726–732 (2009).

Li, Y.-S., A. Helmi, G. De Lucia and F. Stoehr: On the common mass scale of the milky way satellites. Mon. Not. R. Astron. Soc. Lett. **397**, L87–L91 (2009).

Li, L.X., R. Narayan and J. McClintock: Inferring the inclination of a black hole accretion disk from observations of its polarized continuum radiation. Astrophys. J. **692**, 847–865 (2009).

Lind, K., M. Asplund and P. Barklem: Departures from LTE for neutral Li in late-type stars. Astron. Astrophys. **503**, 541–544 (2009).

Lind, K., F. Primas et al. (incl. M. Asplund): Signatures of intrinsic Li depletion and Li-Na anti-correlation in the metal-poor globular cluster NGC 6397. Astron. Astrophys. **503**, 545–557 (2009).

Lisker T., Janz J., et al. (incl. S. Weinmann): The First Generation of Virgo Cluster Dwarf Elliptical Galaxies? Astrophys. J. Lett. **706**, L124–L128 (2009).

Ludlow, A.D., J. Navarro, V. Springel et al.: The unorthodox orbits of substructure halos. Astrophys. J. **692**, 931–941 (2009).

Lutovinov, A.A. and S. Tsygankov: Timing characteristics of the hard X-ray emission from bright X-ray pulsars based on INTEGRAL data. Astron. Lett. **35**, 433–456 (2009).

Maciejewski, M., S. Colombi, C. Allard et al.: Phase-space structures – I. A comparison of 6D density estimators. Mon. Not. R. Astron. Soc. Lett. **393**, 703–722 (2009).

Maciejewski, M., S. Colombi, V. Springel et al.: Phase-space structures – II. Hierarchical structure finder. Mon. Not. R. Astron. Soc. **396**, 1329–1348 (2009).

Maeda, K., K. Kawabata et al. (incl. P. Mazzali): Subaru and Keck observations of the peculiar type Ia supernova 2006GZ at late phases. Astrophys. J. **690**, 1745–1752 (2009).

Maio, U., B. Ciardi, N. Yoshida et al. (incl. K. Dolag): The onset of star formation in primordial haloes. Astron. Astrophys. **503**, 25–34 (2009).

Mandelbaum, R., Ch. Li, G. Kauffmann and S.D.M. White: Halo masses for optically selected and for radio-loud AGN from clustering and galaxy–galaxy lensing. Mon. Not. R. Astron. Soc. **393**, 377–392 (2009).

Marek, A. and H.-Th. Janka: Delayed neutrino-driven supernova explosions aided by the standing accretion-shock instability. Astrophys. J. **694**, 664–696 (2009).

Marek, A., H.-Th. Janka and E. Müller: Equation-of-state dependent features in shock-oscillation modulated neutrino and gravitational-wave signals from supernovae. Astron. Astrophys. **496**, 475–494 (2009).

Marulli, F., S. Bonoli, et al. (incl. V. Springel): The spatial distribution of X-ray selected AGN in the Chandra deep fields: a theoretical perspective. Mon. Not. R. Astron. Soc. **396**, 1404–1414 (2009).

Maselli, A., A. Ferrara and S. Gallerani: Interpreting the transmission windows of distant quasars. Mon. Not. R. Astron. Soc. **395**, 1925–1933 (2009).

Maselli, A., B. Ciardi and A. Kanekar: Crash2: coloured packets and other updates. Mon. Not. R. Astron. Soc. **393**, 171–178 (2009).

Mazzali, P., J. Deng, M. Hamuy, K. Nomoto: SN 2003bg: a broad-lined type IIb supernova with hydrogen Astrophys. J. **703**, 1624–1634 (2009).

Mei, S., B. Holden et al. (incl. R. Overzier): Evolution of the color-magnitude relation in galaxy clusters at z $\sim$ 1 from the ACS intermediate redshift cluster survey. Astrophys. J. **690**, 42–68 (2009).

Melendez, J., M. Asplund, B. Gustafsson and D. Yong. The peculiar solar composition and its possible relation to planet formation Astrophys. J. Lett. **704**, L66-L70 (2009).

Menanteau, F., J.P. Hughes et al. (incl. C. Hernandez-Monteagudo): Southern cosmology survey - I. Optical cluster detections and predictions for the southern common-area millimeter-wave experiments. Astrophys. J. Lett. **698** 1221–1231 (2009).

Metcalf, R. B. and S.D.M. White: Cosmological information in the gravitational lensing of pregalactic H I. Mon. Not. R. Astron. Soc. **394**, 704–714 (2009).

Meyer-Hofmeister, E., B.F. Liu and F. Meyer: The hard to soft spectral transition in LMXBs - affected by recondensation of gas in an inner disk. Astron. Astrophys. **508**, 329–337 (2009).

Mimica, P., D. Giannios, M. Aloy Deceleration of arbitrarily magnetized GRB ejecta: the complete evolution. Astron. Astrophys. **494**, 879–890 (2009).

Mocak, M., E. Müller, A. Weiss and K. Kifonidis: The core helium flash revisited - II. Two and three-dimensional hydrodynamic simulations. Astron. Astrophys. **501**, 659–677 (2009).

Moll, R.: Decay of the toroidal field in magnetically driven jets. Astron. Astrophys. **507**, 1203-1210 (2009).

Nadyozhin, D.K., A.V. Karamyan and E.K. Grasberg: Dependence of the acceleration of the outer edge of a stellar envelope on supernova explosion energy. Astron. Lett. **35**, 388–395 (2009).

Nordlund, A., R. Stein and M. Asplund: Solar surface convection. Liv. Rev. in Solar Phys. **6**, 1–116

Obergaulinger, M., P. Cerda-Duran, E. Müller and M. Aloy: Semi-global simulations of the magneto-rotational instability in core collapse supernovae. Astron. Astrophys. **498**, 241–271 (2009).

Obreschkow, D., D. Croton, G. De Lucia et al.: Simulation of the cosmic evolution of atomic and molecular hydrogen in galaxies. Astrophys. J. **698**, 1467–1484 (2009).

Okumura, T., Y.P. Jing and C. Li: Intrinsic ellipticity correlation of SDSS luminous red galaxies and misalignment with their host dark matter halos. Astrophys. J. **694**, 214–221 (2009).

Oliveira, I., B. Merlin et al. (incl. R. Overzier): Optical characterization of a new young stellar population in the Serpens molecular cloud. Astrophys. J. **691**, 672–686 (2009).

Panov, I.V. and H.-Th. Janka: On the dynamics of proto-neutron star winds and r-process nucleosynthesis. Astron. Astrophys. **494**, 829–844 (2009).

Pasetto, S. and C. Chiosi: Tidal effects on the spatial structure of the local group. Astron. Astrophys. **499**, 385–394 (2009).

Pastorello, A., S. Valenti et al. (incl. S. Taubenberger): SN 2005cs in M51 – II. Complete evolution in the optical and the near-infrared. Mon. Not. R. Astron. Soc. **394**, 2266–2282 (2009).

Pastorello, A., R.M. Crocket et al. (incl. S. Taubenberger): SN 1999ga: a low-luminosity linear type II supernova? Astron. Astrophys. **500**, 1013–1023 (2009).

Pedrosa, S., P. Tissera and C. Scannapieco: The impact of baryons on dark matter haloes. Mon. Not. R. Astron. Soc. Lett. **395**, L57–L61 (2009).

Pereira, T., D. Kiselman and M. Asplund: Oxygen lines in solar granulation. I. Testing 3D models against new observations with high spatial and spectral resolution. Astron. Astrophys. **507**, 417–432 (2009).

Pereira, T., M. Asplund and D. Kiselman: Oxygen lines in solar granulation. II. Centre-to-limb variation, NLTE line formation, blends, and the solar oxygen abundance. **508**, 1403–1416 (2009).

Perez-Montero, E., T. Contini et al. (incl. S. Charlot): Physical properties of galaxies and their evolution in the VIMOS VLT deep survey - II. Extending the mass-metallicity relation to the range zâĂL' approximate to 0.89–1.24. Astron. Astrophys. **495**, 73–81 (2009).

Petkova, M., and V. Springel: An implementation of radiative transfer in the cosmological simulation code gadget. Mon. Not. R. Astron. Soc. **396**, 1383–1403 (2009).

Pierleoni, M., A., Maselli and B. Ciardi: crash α: coupling continuum and line radiative transfer Mon. Not. R. Astron. Soc. **393**, 872–884 (2009).

Poggianti. B., A. Aragon-Salamanca, et al. (incl. S. White): The ESO Distant Cluster Sample: Galaxy Evolution and Environment out to z = 1. The Messenger **136**, 54–59 (2009).

Poggianti, B.M., A. Aragon-Salamanca, et al. (incl. S. White): The Environments of Starburst and Post-Starburst Galaxies at z = 0.4-0.8. Astrophys. J. **693**, 112–131 (2009).

Prokopenko, I. and M. Gilfanov: Normal galaxies in the all-sky survey by the e ROSITA X-ray telescope of the Spectrum-X-Gamma observatory. Astron. Lett. **35**, 294–304 (2009).

Puchwein, E. and S. Hilbert: Cluster strong lensing in the Millennium simulation: the effect of galaxies and structures along the line-of-sight. Mon. Not. R. Astron. Soc. **398**, 1298–1308 (2009).

Ramirez, I., P. Allende et al. (incl. M. Asplund): Granulation in K-type dwarf stars - II. Hydrodynamic simulations and 3D spectrum synthesis. Astron. Astrophys. **501**, 1087–1101 (2009).

Ramirez, I., J. Melendez and M. Asplund: Accurate abundance patterns of solar twins and analogs: Does the anomalous solar chemical compositio come from planet formation. Astron. Astrophys. **508**, L17–L20 (2009).

Reichard, T.A., T. Heckman et al. (incl. G. Kauffmann): The lopsidedness of present-day galaxies: connections to the formation of stars, the chemical evolution of galaxies, and the growth of black holes. Astrophys. J. **691**, 1005–1020 (2009).

Reisenegger, A. Stable magnetic equilibria and their evolution in the upper main sequence, white dwarfs, and neutron stars. Astron. Astrophys. **499**, 557–566 (2009).

Revaz, Y., P. Jablonka, T. Sawala et al.: The dynamical and chemical evolution of dwarf spheroidal galaxies. Astron. Astrophys. **501**, 189–206 (2009).

Revnivtsev, M., A. Kniazev, S. Sazonov et al.: Astron. Lett. **35**, 33–38 (2009).

Revnivtsev, M., E. Churazov, K. Postnov and S. Tsygankov: Quenching of the accretion disk strong aperiodic variability at the magnetospheric boundary. Astron. Astrophys. **507**, 1211-1215 (2009).

Revnivtsev, M., S. Sazonov, E. Churazov et al.: Discrete sources as the origin of the galactic X-ray ridge emission. Nature **458**, 1142–1144 (2009).

Rossi, G., R.K. Sheth, C. Park and C. Hernández-Monteagudo: Non-Gaussian distribution and clustering of hot and cold pixels in the five-year WMAP sky. Mon. Not. R. Astron. Soc. **399**, 304–316 (2009).

Rudnick, G., A. von der Linden et al. (incl. S. White): The rest-frame optical luminosity function of cluster galaxies at $z < 0.8$ and the assembly of the cluster red sequence. Astrophys. J. **700**, 1559–1588 (2009).

Ruszkowski, M. and V. Springel: The role of dry mergers for the formation and evolution of brightest cluster galaxies. Astrophys. J. **696**, 1094–1102 (2009).

Sako, T., J. Paldus, G. Diercksen: The energy level structure of low-dimensional multi-electron quantum dots. Adv. in Quantum Chem. **58**, 177–201 (2009).

Salaris, M., A. Serenelli, A. Weiss and M. Miller-Bertolami: Semi-empirical white dwarf initial-final mass relationships: a thorough analysis of systematic uncertainties due to stellar evolution models Astrophys. J. **692**, 1013–1032 (2009).

Sanchez-Blazquez, P., et al. (incl. G. De Lucia and S.D.M. White): Evolution of red-sequence cluster galaxies from redshift 0.8 to 0.4: ages, metallicities, and morphologies. Astron. Astrophys. **499**, 47–68 (2009).

Saro, A., et al. (incl. G. De Lucia and K. Dolag): Simulating the formation of a protocluster at z $\sim$ 2. Mon. Not. R. Astron. Soc. **392**, 795–800 (2009).

Scannapieco, C., S.D.M. White, V. Springel and P. Tissera: The formation and survival of discs in a ΛCDM universe. Mon. Not. R. Astron. Soc. **396**, 696–708 (2009).

Scodeggio, M., D. Vergani et al. (incl. S. Charlot): The Vimos VLT deep survey - stellar mass segregation and large-scale galaxy environment in the redshift range $0.2 < z < 1.4$. Astron. Astrophys. **501**, 21–27 (2009).

Scott, P., M. Asplund, N. Grevesse and J.A. Sauval: On the solar nickel and oxygen abundances. Astrophys. J. Lett. **691**, L119-L122 (2009).

Seitenzahl, I., C. Meakin, D. Lamb and J. Truran: Initiation of the detonation in the gravitationally confined detonation model of type Ia supernovae. Astrophys. J. **700**, 642–653 (2009).

Seitenzahl, I., C. Meakin, A. Kasey et al.: Spontaneous initiation of detonations in white dwarf environments: determination of critical sizes. Astrophys. J. **696**, 515–527 (2009).

Seitenzahl, I., S. Taubenberger and S. Sim: Late-time supernova light curves: the effect of internal conversion and Auger electrons. Mon. Not. Roy. Astron. Soc. **400**, 531–535 (2009).

Serenelli, A. M., S. Basu, J.W. Ferguson and M. Asplund: New Solar Composition: The Problem with Solar Models Revisited. Astrophys. J. Lett. **705**, L123–L127 (2009).

Shankar, F.: The demography of supermassive black holes: Growing monsters at the heart of galaxies. New Astron. Rev., **53**, 57–77 (2009).

Shankar, F. and M. Bernardi: The age dependence of the size–stellar mass relation and some implications. Mon. Not. R. Astron. Soc. Lett. **396**, L76–L80 (2009).

Shen, K.J. and L. Bildsten: The effect of composition on nova ignitions. Astrophys. J. **692**, 324–334 (2009).

Shioya, Y., Y. Taniguchi et al. (incl. M. Kitzbichler): Photometric properties of Lyα emitters at z $\approx$4.86 in the COSMOS 2 square degree field. Astrophys. J. **696**, 546–561 (2009).

Silverman, J.M., P. Mazzali, R. Chornock et al.: Optical spectroscopy of the somewhat peculiar type IIb supernova 2001ig. Astron. Soc. of the Pacific **121**, 689–698 (2009).

Simon, J., A. Gal-Yam et al. (incl. P. Mazzali): Variable sodium absorption in a low-extinction type Ia supernova. Astrophys. J. **702**, 1157–1170 (2009).

Smith, R. E., C. Hernández-Monteagudo and U. Seljak: Impact of scale dependent bias and nonlinear structure growth on the integrated Sachs-Wolfe effect: Angular power spectra. Phys. R. D. **80** 063528 (2009).

Stello, D., W. Chaplin et al. (incl. J. Ballot): Radius determination of solar-type stars using asteroseismology: what to expect from the Kepler mission. Astrophys. J. **700**, 1589–1602 (2009).

Strickler, R., A. Cool et al. (incl. A. Serenelli): Helium-core white dwarfs in the globular cluster NGC 6397. Astrophys. J. **699**, 40–55 (2009).

Stritzinger, M., P. Mazzali, M. Phillips et al.: The He-rich core-collapse supernova 2007Y: observations from X-ray to radio wavelengths. Astrophys. J. **696**, 713–728 (2009).

Sunyaev, R. and J. Chluba: Signals from the epoch of cosmological recombination - Karl Schwarzschild Award Lecture 2008. Astron. Nachrichten **330**, 657–674 (2009).

Takiwaki, T., K. Kotake and K. Sato: Special relativistic simulations of magnetically dominated jets in collapsing massive stars. Astrophys. J. **691**, 1360-1379 (2009).

Tanaka, M., N. Tominaga et al. (incl. P. Mazzali): Type Ib supernova 2008D associated with the luminous X-ray transient 080109: an energetic explosion of a massive helium star. Astrophys. J. **692**, 1131–1142 (2009).

Tanaka, M., M. Yamanaka, et al. (incl. P. Mazzali): Nebular phase observations of the type Ib supernova 2008D/X-ray transient 080109: side-viewed bipolar explosion. Astrophys. J. **700**, 1680–1685 (2009).

Tanaka, M., K.S. Kawabata, et al. (incl. P. Mazzali): Spectropolarimetry of the unique type Ib supernova 2005bf: larger asymmetry revealed by later-phase data. Astrophys. J. **699**, 1119–1124 (2009).

Taniguchi, Y., T. Murayama et al. (incl. M. Kitzbichler): Hubble space telescope/advanced camera for surveys morphology of Ly-alpha emitters at redshift 5.7 in the COSMOS field. Astrophys. J. **701**, 915–944 (2009).

Taubenberger, S. et al. (incl. S. Hachinger, W. Hillebrandt and P. Mazzali): Nebular emission-line profiles of type Ib/c supernovae – probing the ejecta asphericity. Mon. Not. R. Astron. Soc. **397**, 677–694 (2009).

Thomas, R.M., S. Zaroubi, B. Ciardi et al.: Fast large-scale reionization simulations. Mon. Not. R. Astron. Soc. **393**, 32–48 (2009).

Trundle, C. et al. (incl. S. Taubenberger): Possible evidence of asymmetry in SN 2007rt, a type IIn supernova. Astron. Astrophys. **504**, 945–958 (2009).

Utrobin, V.P. and N. Chugai: High mass of the type IIP supernova 2004et inferred from hydrodynamic modeling. Astron. Astrophys. **506**, 829–834 (2009).

Valenti, S. et al. (incl. P. Mazzali and S. Taubenberger): A low-energy core-collapse supernova without a hydrogen envelope. Nature **459**, 674–677 (2009).

van Weeren, R. J., H.J. Röttgering, et al. (incl. T. Enßlin): Radio observations of ZwCl 2341.1+0000: a double radio relic cluster: Astron. Astrophys. **506**, 1083–1094 (2009).

Viel, M., E. Branchini, K. Dolag, M. Grossi et al.: Primordial non-Gaussianities in the intergalactic medium. Mon. Not. R. Astron. Soc. **393**, 774–782 (2009).

Vogelsberger, M., A. Helmi, V. Springel et al.: Phase-space structure in the local dark matter distribution and its signature in direct detection experiments. Mon. Not. R. Astron. Soc. **395**, 797–811 (2009).

Voss, R., M. Gilfanov, G. Sivakoff et al.: Luminosity functions of LMXBs in Centaurus A: globular clusters versus the field. Astrophys. J. **701**, 471–480 (2009).

Waelkens, A.H., T. Jaffe et al. (incl. T. Enßlin): Simulating polarized galactic synchrotron emission at all frequencies - the Hammurabi code. Astron. Astrophys. **495**, 697–706 (2009).

Waelkens, A.H., A. Schekochihin and T. Enßlin: Probing magnetic turbulence by synchrotron polarimetry: statistics and structure of magnetic fields from Stokes correlators. Mon. Not. R. Astron. Soc. **398**, 1970–1988 (2009).

Wanajo, S., K. Nomoto, H.-T. Janka et al.: Nucleosynthesis in electron capture supernovae of asymptotic giant branch stars. Astrophys. J. **695**, 208–220 (2009).

Wang, Y., X. Yang et al. (incl. S. Weinmann): The nature of red dwarf galaxies. Astrophys. J. **697**, 247–257 (2009).

Wang, J., and S.D.M. White: Are mergers responsible for universal halo properties? Mon. Not. R. Astron. Soc. **396**, 709–717 (2009).

Weinmann, S., G. Kauffmann, F. van den Bosch et al.: Environmental effects on satellite galaxies: the link between concentration, size and colour profile. Mon. Not. R. Astron. Soc. **394**, 1213–1228 (2009).

Weiss, A. and J.W. Ferguson: New Asymptotic Giant Branch models for a range of metallicities: Astron. Astrophys. **508**, 1343–1358 (2009).

Werner, N., I. Zhuravleva, E. Churazov et al.: Constraints on turbulent pressure in the X-ray haloes of giant elliptical galaxies from resonant scattering. Mon. Not. R. Astron. Soc. **398**, 23–32 (2009).

White, S.D.M. and M. Vogelsberger: Dark matter caustics. Mon. Not. R. Astron. Soc. **392**, 281–286 (2009).

Wild, V., J. Walcher, P. Johannsson et al.: Post-starburst galaxies: more than just an interesting curiosity. Mon. Not. R. Astron. Soc. **395**, 144–159 (2009).

Wittenmeyer, R.A., M. Endl et al. (incl. I. Ramirez): HD 91669B: a new brown dwarf candidate from the McDonald observatory planet search. Astron. J. **137**, 3529–3532 (2009).

Woosley, S. E., A. R. Kerstein, V. Sankaran, and F. K. Röpke: Type Ia Supernovae: Calculations of Turbulent Flames Using the Linear Eddy Model: Astrophys. J. **704**, 255–273 (2009)

Xiang, F., E. Rudometkin, E. Churazov et al. Does heating by AGN shocks affect abundance profiles in galaxy clusters? Mon. Not. R. Astron. Soc. **398**, 575–582 (2009).

Xu, D. D. et al. (incl. V. Springel and S. White): Effects of dark matter substructures on gravitational lensing: results from the Aquarius simulations. Mon. Not. R. Astron. Soc. **398**, 1235–1253 (2009).

Yue, B., B. Ciardi, E. Scannapieco and X. Chen: The contribution of the IGM and minihaloes to the 21-cm signal of reionization. Mon. Not. R. Astron. Soc. **398**, 2122–2133 (2009).

Zavala, J., Y.P. Jing, A. Faltenbacher et al.: The velocity function in the local environment from ΛCDM and WDM constrained simulations. Astrophys. J. **700**, 1779–1793 (2009).

Zhang, W., C. Li, G. Kauffmann et al.: Estimating the H I gas fractions of galaxies in the local universe. Mon. Not. R. Astron. Soc. **397**, 1243–1253 (2009).

Zhang, X.-G., D. Dultzin, T.G. Wang and G. Kauffmann: Partly obscured accretion disc model to explain shifted broad Balmer emission lines of active galactic nuclei. Mon. Not. R. Astron. Soc. **397**, 1510–1520 (2009).

Zhao, D.H., Y.P. Jing, H.J. Mo and G. Börner: Accurate universal models for the mass accretion histories and concentrations of dark matter halos. Astrophys. J. **707**, 354–369 (2009).

Zhuravleva, V.V. and N. Shakura: Temporal behaviour of global perturbations in compressible axisymmetric flows with free boundaries. Astron. Nachrichten **330**, 84–91 (2009).

4.1.2 Publications accepted in 2009 (71)

Aleksic, J., C. Pfrommer et al. (incl. T. Enßlin): MAGIC Gamma-Ray Observation of the Perseus Galaxy Cluster' The MAGIC Collaboration. Astrophys. J.

Angulo, R.E. and S. D. M. White: The Birth and Growth of Neutralino Haloes. Mon. Not. Roy. Astron. Soc.

Baldi, A., W. Forman, et al. (incl. E. Churazov): The unusual X-ray morphology of NGC4636 revealed by deep Chandra observations: cavities and shocks created by past AGN outbursts. Astrophys. J.

Baldi, M. V. Pettorino, G. Robbers and V. Springel: N-body simulations of coupled dark energy cosmologies. Mon. Not. Roy. Astron. Soc.

Basu-Zych, A. R., T. Gonçalves, R. Overzier, et al.: An OSIRIS Study of the Gas Kinematics in a Sample of UV-Selected Galaxies: Evidence of 'Hot and Bothered' Starbursts in the Local Universe. Astrophys. J.

Basu-Zych, A. R., D. Schiminovich, S. Heinis, R. Overzier, et al.: Studying Large- and Small-Scale Environments of Ultraviolet Luminous Galaxies. Astrophys. J.

Bauswein, A., H.-Th. Janka, R. Oechslin et al.: Mass Ejection by Strange Star Mergers and Observational Implications. Phys. Rev. Lett.

Bergemann, M., J. Pickering and T. Gehren: NLTE analysis of Co I/Co II lines in spectra of cool stars with new laboratory hyperfine splitting constants. Mon. Not. R. Astron. Soc.

Bernardi, M., F. Shankar, S. Mei, et al.: Galaxy luminosities, stellar masses, sizes, velocity dispersions as a function of morphological type. Mon. Not. Roy. Astron. Soc.

Bogdan, A. and M. Gilfanov: Soft band X/K luminosity ratios for gas-poor early-type galaxies. Astron. Astrophys.

Bonoli, S., F. Shankar, S. White et al.: On the merger bias and the clustering of Quasars. Mon. Not. Roy. Astron. Soc.

Bottino, M., A.J. Banday and D. Maino: New insights into foreground analysis of the WMAP five-year data using FastICA. Mon. Not. Roy. Astron. Soc.

Catinella, B., D. Schiminovich, G. Kauffmann et al.: The GALEX Arecibo SDSS Survey. I. Gas Fraction Scaling Relations of Massive Galaxies and First Data Release. Mon. Not. Roy. Astron. Soc.

Chiavassa, A., S. Lacour, F. Millour et al.: VLTI/AMBER spectro-interferometric imaging of VX Sgr's inhomogenous outer atmosphere. Astron. Astrophys.

Chluba, J. and R.A. Sunyaev: Ly alpha escape during cosmological hydrogen recombination: the 3d-1s and 3s-1s two-photon processes. Astron. Astrophys.

Chluba, J. and R.A. Sunyaev: Cosmological recombination: feedback of helium photons and its effect on the recombination spectrum. Mon. Not. Roy. Astron. Soc.

Ciaraldi-Schoolmann, F., W. Schmidt et al. (incl. F. K. Röpke and W. Hillebrandt): Turbulence in a three-dimensional deflagration model for type Ia supernovae: II. Intermittency and the deflagration-to-detonation transition probability. Astrophys. J.

Ciardi B., R. Salvaterra and T. Di Matteo: Ly. versus X-ray heating in the high-z intergalactic medium. Mon. Not. Roy. Astron. Soc.

De Graf, C., T. Di Matteo and V. Springel: Faint-end Quasar Luminosity Functions from Cosmological Hydrodynamic Simulations. Mon. Not. Roy. Astron. Soc.

D'Onghia, E., V. Springel, L. Hernquist and D. Keres. Substructure depletion in the Milky Way halo by the disk. Astrophys. J.

Docenko, D. and R.A. Sunyaev: Fine-structure infrared lines from the Cassiopeia A knots. Astron. Astrophys.

Donnert, J., K. Dolag, G. Brunetti et al.: Radio Halos From Simulations And Hadronic Models I: The Coma cluster. Mon. Not. Roy. Astron. Soc.

Donoso E., Ch. Li, G. Kauffmann et al.: Clustering of Radio Galaxies and Quasars Mon. Not. Roy. Astron. Soc.

Fabjan, D., S. Borgani et al. (incl. K. Dolag): Simulating the effect of AGN feedback on the metal enrichment of galaxy clusters. Mon. Not. Roy. Astron. Soc.

Frommert, M. and T. A. Enßlin: The axis of evil - a polarization perspective Mon. Not. R. Astron. Soc.

Gao, L., T. Theuns et al. (incl. V. Springel and S. White): The earliest stars and their relics in the Milky Way: Mon. Not. Roy. Astron. Soc.

Gilfanov, M. and A. Bogdan: An upper limit on the contribution of accreting white dwarfs to the type Ia supernova rate. Nature.

Giuffrida, G., L. Sbodone, S. Zaggia et al. A wide angle survey of the Sagittarius dwarf Spheroidal galaxy. I: VIMOS photometry and radial velocities across Sgr dSph major and minor axis. Astron. Astrophys.

Gizon, L., A. C. Birch, and H. C. Spruit: Local Helioseismology: Three Dimensional Imaging of the Solar Interior. Ann. Rev. Astron. Astrophys.

Goodger, J. L. et al. (incl. M. Gilfanov): Long Term Monitoring of the Dynamics and Particle Acceleration of Knots in the Jet of Centaurus A. Astrophys. J.

Guo, Y., D.H. McIntosh et al. (incl. S. Weinmann): Structural Properties of central galaxies in groups and clusters. Mon. Not. Roy. Astron. Soc.

Hatch, N. A., R. Overzier, J. Kurk et al.: The growth and assembly of a massive galaxy at $z \sim 2$. Mon. Not. Roy. Astron. Soc.

Hayek, W., U. Wiesendahl, N. Christlieb et al.: The Hamburg/ESO R-process enhanced star survey (HERES). IV. Detailed abundance analysis and age dating of the strongly r-process enhanced stars CS 29491-069 and HE 1219-0312. Astron. Astrophys.

Hernandez-Monteagudo, C. and R. Sunyaev: Galaxy Clusters as mirrors of the distant Universe. Implications for the kSZ and ISW effects. Astron. Astrophys.

Hovest, W., J. Knoche and T. Enßlin: Workflows für das frühe Universum: Die ProC-Workflowengine. Informatik-Spektrum.

Hunter, D. et al. (incl. S. Taubenberger): Extensive optical and near-infrared observations of the nearby, narrow-lined type Ic SN 2007gr: days 5 to 415. Astron. Astrophys.

Jennings, E., C.M. Baugh, E.R. Angulo and S. Pascoli: Simulations of Quintessential Cold Dark Matter: beyond the cosmological constant. Mon. Not. Roy. Astron. Soc.

Kitaura, F.S., J. Jasche and B. Metcalf: Recovering the nonlinear density field from the galaxy distribution with a Poisson-Lognormal filter. Mon. Not. R. Astron. Soc.

Kraemer, W.P. and V. Špirko: Statistical Properties of Energies and Electric Dipole Moments of the Bound Vibrational States of the System HCO^+/COH^+. Chem. Phys.

Lisker T., J. Janz et al. (incl. S. Weinmann): The First Generation of Virgo Cluster Dwarf Elliptical Galaxies? Astrophys. J.

Marulli F., S. Bonoli et al. (incl. V. Springel): The spatial distribution of X-ray selected AGN in the Chandra deep fields: a theoretical perspective. Mon. Not. Roy. Astron. Soc.

Maurer, I., P.A. Mazzali et al. (incl. S. Taubenberger): Characteristic velocities of stripped-envelope core-collapse supernova cores. Mon. Not. R. Astron. Soc.

Melendez, J., I. Ramirez, L. Casagrande, M. Asplund et al.: The solar, exoplanet and cosmological lithium problems. Astrophysics and Space Science.

Meneghetti, M., E. Rasia et al. (incl. K. Dolag): Weighting simulated galaxy clusters using lensing and X-ray. Astron. Astrophys.

Metcalf, R.B.: Neutrino masses, dark energy and the gravitational lensing of pre-galactic HI. Mon. Not. R. Astron. Soc.

Moll, R.: Large jets from small-scale magnetic fields. Astron. Astrophys.

Muthsam, H.J., F. Kupka, B. Löw-Baselli, et al.: ANTARES – A Numerical Tool for Astrophysical RESearch with applications to solar granulation. New Astronomy.

Navarro, J. F., A. Ludlow, V. Springel et al.: The Diversity and Similarity of Simulated Cold Dark Matter Halos. Mon. Not. Roy. Astron. Soc.

Oliveira, I., B. Merin, et al. (incl. R. Overzier): Optical Characterization of A New Young Stellar Population in the Serpens Molecular Cloud. Astrophys. J.

Overzier, R. A., T. Heckman, C. Tremonti, et al.: Local Lyman Break Galaxy Analogs: The Impact of Massive Star-Forming Clumps on the Interstellar Medium and the Global Structure of Young, Forming Galaxies. Astrophys. J.

Overzier, R. A., X. Shu, W. Zheng, et al.: Stellar Masses of Lyman Break Galaxies, Lyα Emitters, and Radio Galaxies in Overdense Regions at $z = 4 - 6$. Astrophys. J.

Overzier, R. A., Q. Guo, G. Kauffmann et al.: ΛCDM predictions for galaxy protoclusters - I. The relation between galaxies, protoclusters and quasars at $z \sim 6$ Mon. Not. Roy. Astron. Soc.

Pakmor, R., M. Kromer, F.K. Roepke et al.: Sub-luminous type Ia supernovae from the mergers of equal-mass white dwarfs with $M\tilde{0}.9\ M_{\odot}$. Nature.

Pereira, T.M.D., M. Asplund, R. Trampedach and R. Collet: How realistic are solar model atmospheres? Astron. Astrophys.

Ryde, N., B. Gustafsson et al. (incl. M. Asplund): Chemical abundances for 11 bulge stars from high-resolution, near-IR spectra. Astron. Astrophys.

Sako, T., Paldus, J. and, G. H. F. Diercksen: The origin of Hund's multiplicity rule in quasi-two-dimensional two-electron quantum dots. Phys. Rev. A.

Sawala, T., C. Scannapieco, U. Maio and S. White: Formation of Isolated Dwarf Galaxies with Feedback. Mon. Not. R. Astron. Soc.

Sehgal, N., P. Bode et al. (incl. C. Hernandez-Moneagudo): Simulations of the Microwave Sky. Astrophys. J.

Serenelli, A.: New Results on Standard Solar Models. Astrophysics and Space Science.

Sbordone, L., P. Bonifacio, E. Caffau et al.: The Metal Poor End of the Spite Plateau.

Shankar, F., G. R. Sivakoff, M. Vestergaard and X. Dai: The relative growth of Optical and Radio Quasars in SDSS. Mon. Not. Roy. Astron. Soc.

Shankar, F., F. Marulli, M. Bernardi et al.: Sizes and ages of SDSS ellipticals: Comparison with hierarchical galaxy formation models. Mon. Not. Roy. Astron. Soc.

Springel, V.: E pur si muove: Galilean-invariant cosmological hydrodynamical simulations on a moving mesh. Mon. Not. Roy. Astron. Soc.

Taubenberger S., S. Valenti, et al. (incl. S. Hachinger): Nebular emission-line profiles of Type Ib/c supernovae - probing the ejecta asphericity: Mon. Not. R. Astron. Soc.

Tornatore, L., S. Borgani, M. Viel and V. Springel: The impact of feedback on the low redshift Intergalactic Medium. Mon. Not. Roy. Astron. Soc.

Tsygankov, S.S. and E.M. Churazov: Searching for outbursts in narrow 511 keV emission line from compact objects with INTE GRAL. Astron. Lett.

Tsygankov, S.S., A.A. Lutovinov and A.V. Serber: Completing the puzzle of the 2004-2005 outburst in V0332+53: the brightening phase included. Mon. Not. Roy. Astron. Soc.

Wang, J., R. Overzier, G. Kauffmann et al.: The UV-optical colours of brightest cluster galaxies in optically and X-ray selected clusters. Mon. Not. Roy. Astron. Soc.

Wang Y., Yang X. et al. (incl. S. Weinmann): The Nature of Red Dwarf Galaxies. Astrophys. J.

Zavala, J., V. Springel and M. Boylan-Kolchin: Extragalactic gamma-ray background radiation from dark matter annihilation: Mon. Not. Roy. Astron. Soc.

Zhuravleva, I.V., E. Churazov, S. Sazonov et al.: Polarization of X-ray lines from galaxy clusters and elliptical galaxies a way to measure tangential component of gas velocity. Mon. Not. R. Astron. Soc.

4.2 Publications in proceedings and monographs

4.2.1 Publications in proceedings appeared in 2009 (48)

Barbuy, B., B. Dias et al. (incl. M. Asplund): Metal-poor globular clusters of the galactic bulge In: Proceedings 12th IAU Regional Latin American Meeting of Astronomy "Revista mexicana de astronomia y astrofisica: serie de conferencias" UNAM, Mexico **35**, p. 150–151.

Barbuy, B., M. Zoccali et al. (incl. M. Asplund): Stellar abundances tracing the formation of the galactic bulge. In: Proc. The Galaxy Disk in Cosmological Context 254th Symposium of the International Astronomical Union. Cambridge Univ. Press, p. 153–158.

Campisi, M.A.: Host galaxies of long gamma-ray bursts. In: Proc. Gamma-Ray Bursts. 6th Huntsville Symposium on Gamma-Ray Bursts. American Institute of Physics, Melville, NY, USA p. 263–268.

Casagrande, L. : The effective temperature scale: resolving different versions. In: Proceeding of the IAU General Assembly Joint Discussion 10: 3D Views on Cool Stellar Atmospheres - Theory Meets Observation, Vol. **80**, 727–731.

Christlein, D. and J. Bland-Hawthorn: Measuring outer disk warps with optical spectroscopy. In: Proc. The Galaxy Disk in Cosmological Context 254th Symposium of the International Astronomical Union. Cambridge Univ. Press, p. 283–288.

Cora, S., L. Tornatore, P. Tozzi and K. Dolag: ICM metallicity evolution: effects of dynamical processes. In: Proceedings 12th IAU Regional Latin American Meeting of Astronomy "Revista mexicana de astronomia y astrofisica: serie de conferencias" UNAM, Mexico **35**, p. 209-210.

Cordero-Carrión, P. Cerdá-Durán, H. Dimmelmeier et al.: Improved constrained scheme for the Einstein equations: An approach to the uniqueness issue. In: Proceedings of the Spanish Relativity Meeting. AIP Conference proceedings, **1122**, p. 232–235.

De Lucia, G.: 'Ab initio' models of galaxy formation: successes and open problems. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 3–10.

De Lucia, G. and A. Helmi: The galaxy and its stellar halo - insights from a hybrid cosmological approach. In: Proc. The Galaxy Disk in Cosmological Context 254th Symposium of the International Astronomical Union. Cambridge Univ. Press, p. 423–428.

De Propris, R. and D. Christlein: A composite K-band luminosity function for cluster galaxies. In: Proceedings of the JENAM 2008 Symposium No. 6 Matter Cycles of Galaxies in Clusters", 2009 AN 330, 943–945.

De Rossi, E., G. De Lucia, P. Tissera and G. Kauffmann: Chemical evolution of milky way type galaxies in the millennium simulation. In: Proceedings 12th IAU Regional Latin American Meeting of Astronomy "Revista mexicana de astronomia y astrofisica: serie de conferencias" UNAM, Mexico **35**, p. 213–214.

Dolag, K., F. Stasyszyn, J. Donnert and R. Pakmor: Magnetic fields and cosmic rays in galaxy clusters and large scale structures. In: Proc. Cosmic Magnetic Fields: From Planets, to Stars and Galaxies. 259th Symposium of the International Astronomical Union. Cambridge University Press, p. 519–528.

Elias-Rosa, N., A. Pastorello et al (incl. P. Mazzali): Explosion of a massive, He-rich star at $z = 0.16$. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 448–451.

Enßlin, T. A., Clarke, T., Vogt, C., Waelkens, A., and Schekochihin, A. A.: Magnetic turbulence in clusters of galaxies: Revista Mexicana de Astronomia y Astrofisica Conference Series 36, 209–???

Font, J.A., P. Cerdá-Durán, E. Müller and L. Antón: Relativistic simulations of magneto-rotational core collapse In: Proceedings of the ASTRONUM-2008 conference. Astronomical Society of the Pacific. (N.V. Pogorelov, E. Audit, et al.eds.) p. 86.

Gadotti, D.A.: Barred galaxies: an observer's perspective. In: Proc. Chaos in Astronomy Series: Astrophysics and Space Science Proceedings, Springer Verlag Berlin, p. 159–172.

Guo, Q. and S. White: Disk sizes in a ΛCDM universe In: Proc. The Galaxy Disk in Cosmological Context.254th Symposium of the International Astronomical Union, Cambridge Univ. Press, p. 411–416.

Hachinger, S., P. Mazzali, et al. (incl. W. Hillebrandt): Spectral luminosity indicators in SNe Ia – The R(Si II) line strength ratio. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings Vol. 1111, American Institute of Physics, p. 573–576.

Hillebrandt, W. and F. Kupka: An introduction to turbulence. In: Proc. Interdisciplinary Aspects of Turbulence. Lecture Notes in Physics. Eds. W. Hillebrandt, F. Kupka, Springer Verlag, Berlin, Vol. **756**, p. 1–20.

Kotarba, H., H. Lesch et al. (incl. F. Stasyszyn): Structure of magnetic fields in spiral galaxies. In: Proc. Cosmic Magnetic Fields: From Planets, to Stars and Galaxies. 259th Symposium of the International Astronomical Union. Cambridge University Press, p. 551–552.

Kromer, M., S. Sim and W. Hillebrandt: 3D non-LTE spectrum synthesis for type Ia supernovae. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 277–280.

Kromer, M., S. Sim and W. Hillebrandt: 3D non-LTE time-dependent spectrum synthesis for type Ia supernovae International Conference on Recent Directions in Astrophysical Quantitative Spectroscopy and Radiation Hydrodynamics. AIP Conference Proceedings **1171**, Boulder, Colorado, USA, 207–214.

Kupka, F.: Turbulent Convection and Numerical Simulations in Solar and Stellar Astrophysics. In: Interdisciplinary Aspects of Turbulence. Lecture Notes in Physics. Eds. W. Hillebrandt, F. Kupka, Springer Verlag, Berlin (2009) Vol. **756**, 49-105, Kupka, F., Belkacem, K., Goupil, M.-J., Samadi, R.: Using p-mode excitation rates for probing convection in solar-like stars. In: Proceedings of the JENAM 2008 Symposium N^{o}4: Asteroseismology and Stellar Evolution. Eds. S. Schuh and G. Handler, Comm. in Asteroseimology **159**, 2009, 24–26.

Li C.: Interactions, Star Formation, and AGN Activity: In: The Starburst-AGN Connection: ASP Conference Series, 2009, San Francisco Vol. **408**, 347–351.

Miller Bertolami, M.M., L.G. Althaus, K. Unglaub and A. Weiss: Modeling He-rich subdwarfs through the hot-flasher scenario: Journal of Physics Conference Series, **172**, 1–4.

Monaco, P., F. Fontanot et al. (incl. G. De Lucia): Modeling multi-wavelength properties of high redshift galaxies. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 48–51.

Müller, B., A. Marek and H.-Th. Janka: The SuperN-project: status and outlook. In: Proc. High Performance Computing in Science and Engineering 08. 11th Results and Review Workshop on High Performance Computing in Science and Engineering, Springer Verlag Berlin, p. 13–28.

Nieva M.F., N. Przybilla, A. Seifahrt et al.: Quantitative near-IR Spectroscopy of OB Stars. In: A. Moorwood (ed.), Science with the VLT in the ELT era (Springer Verlag, Berlin), 499–505.

Nieva M.F. and N. Przybilla: Improving stellar parameter and abundance determinations of early B-type stars. In: C. Leitherer, Ph.D. Bennett, P.W. Morris, J.Th. van Loon (eds)., Hot And Cool: Bridging Gaps in Massive Star Evolution, (ASP, San Francisco), in press

Nieva M.F. and N. Przybilla: Atmospheric Parameter Determination via Spectral Non-LTE Analysis of Massive Stars In: G.M. Wahlgren, B. Smalley, P. Stee, R. Monier (eds.), Non-LTE line formation for trace elements in stellar atmospheres, EAS Publ. Ser., in press

Pakmor, R., F. Röpke, A. Weiss and W. Hillebrandt: The impact of type Ia supernovae on main sequence companions. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 285–288.

Przybilla N., A. Seifahrt et al. (incl. M.F. Nieva): Near-IR Spectroscopy of Blue Supergiants. In: A. Moorwood (Ed.), Science with the VLT in the ELT era (Springer Verlag, Berlin), **55**, in press.

Przybilla N., M. Firnstein and M.F. Nieva: Tepid Supergiants: Chemical Signatures of Stellar Evolution & The Extent of Blue Loops. In: C. Leitherer, Ph.D. Bennett, P.W. Morris, J.Th. van Loon (Eds)., Hot And Cool: Bridging Gaps in Massive Star Evolution, (ASP, San Francisco), in press

Röpke, F. and W. Schmidt: Turbulent combustion in thermonuclear supernovae In: Proc. Interdisciplinary Aspects of Turbulence. Lecture Notes in Physics, Springer Verlag, Berlin, Vol. **756**, p. 255–289.

Scannapieco, C., P. Tissera, S. White and V. Springel: Effects of supernova feedback on the formation of galaxies. In: Proc. The Galaxy Disk in Cosmological Context. 254th Symposium of the International Astronomical Union, Cambridge Univ. Press, p. 369–374.

Schäfer, J.: Zero-phonon emission bands of solid hydrogen at 6 – 12 Âţm wavelength - an astrophysical phenomenon. In: Proc. 7th International Conference on Cryocrystals and Quantum Crystals. 'Low Temperature Physics' Vol. **35**, p. 311–317.

Silva Aguirre, V., J. Ballot, A. Serenelli and A. Weiss: Pulsation Period Changes as a Tool to Identify Pre-Zero Age Horizontal Branch Stars. In: Proc. HELAS Workshop on 'Synergies between solar and stellar modelling', Eds. M. Marconi, D. Cardini and M.P. Di Mauro, Astrophys. Space Sci. in press

Silva Aguirre, V., Ballot, J., Serenelli, A. and Weiss: Semiconvective Mixing in Low- ass Stars. Proc. HELAS Workshop on 'Synergies between solar and stellar modelling. Eds M. Marconi, D. Cardini and M.P. Di Mauro, Astrophys. Space Sci. in press

Sim, S., M. Kromer, W. Hillebrandt, and F. Röpke: Lopsided explosion models for type Ia supernovae. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 281–284.

Springel, V., S.D.M. White, J. Navarro et al.: The Aquarius project: cold dark matter under a numerical microscope. In: Proc. High Performance Computing in Science and Engineering, Garching/Munich 2007, Springer Verlag, Berlin 2009, p. 93–108.

Spruit, H.: The source of magnetic fields in (neutron-) stars. In: Proc. Cosmic Magnetic Fields: From Planets, to Stars and Galaxies. 259th Symposium of the International Astronomical Union. Cambridge University Press, p. 61–74.

Stasyszyn, F. and K. Dolag: MHD simulations of cool core clusters. In: Proc. Cosmic Magnetic Fields: From Planets, to Stars and Galaxies. 259th Symposium of the International Astronomical Union. Cambridge University Press, p. 565–566.

Sunyaev, R. and J. Chluba: Signals from the epoch of cosmological recombination. In: Proc. Formation and Evolution of Cosmic Structures. Joint European and National Astronomical Meeting JENAM 2008 on 'New Challenges to European Astronomy', Wiley-VCH, Weinheim. p. 1–38.

Tanaka, M., K. Maeda et al. (incl.P. Mazzali): Optical emission from aspherical core-collapse supernovae. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 413–420.

Taubenberger, S. and S. Valenti: Emission-line profiles in SNe Ib/c–Probing the ejecta geometry. In: Proc. Probing Stellar Populations out to the Distant Universe. International Conference on Probing Stellar Populations out to the Distant Universe. AIP Conference Proceedings, American Institute of Physics, Melville, NY, USA. p. 402–405.

von Kienlin, A., M.S. Briggs et al. (incl. S. Tsygankov): Using GRB 080723B to cross-calibrate Fermi/GBM and INTEGRAL. In: Gamma-Ray burst: Sixth Huntsville Symposium. AIP Conference Proceedings, American Institute of Physics, **1133**, 446–448.

White, S.D.M.: Simulations of disk galaxy formation in their cosmological context. In: Proc. The Galaxy Disk in Cosmological Context. 254th Symposium of the International Astronomical Union, Cambridge Univ. Press, p. 19–20.

4.2.2 Publications available as electronic file only

Dolag, K., M. Kachelriess, and D.V. Semikoz: UHECR observations and lensing in the magnetic field of the Virgo cluster Journal of Cosmology and Astroparticle Physics, Issue 01, pp. 033 (2009). http://adsabs.harvard.edu/abs/2009JCAP...01..033D.

Jansson, R., G.Farrar, A. Waelkens, and T. Ensslin: Constraining models of the large scale galactic magnetic field with WMAP5 polarization data and extragalactic rotation measure sources. Journal of Cosmology and Astroparticle Physics, 1–26. http://adsabs.harvard.edu/abs/2009JCAP...07..021J

Miller-Bertolami, M. M., L. Althaus, K. Unglaub and A. Weiss: Journal of Physics: Confernce Series. 16th European White Dwars Workshop. Vol. 172 - page 1-4.

Nordlund, A., R. Stein, M. Asplund: Solar Surface Convection. Living Reviews in Solar Physics, vol. 6, no. 2 http://adsabs.harvard.edu/abs/2009LRSP....6....2N

Ritter, H. and U. Kolb: Catalogue of cataclysmic binaries, low-mass X-ray binaries and related objects (Editions 7.11 and 7.12).
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

4.3 Invited review talks at international meetings

R. Angulo: "Defining the Issues: Baryon Acoustic Oscillations", First Paris-Berkeley Dark Energy Cosmology Workshop (14.9.-18.9. APC and LPNHE, Paris, France)

M. Asplund: Invited review, "Neutrinos and beyond" (Munich, 29.1-30.1.)
– Invited review, "Galactic archeology" (Palm Cove, Australia, 3.5.-10.5.)
– Invited review, "Origins of solar systems" (Mt. Holyoke, USA, 5.7.-10.7.)
– Invited review, "IAU Division IV – stars" (Rio de Janeiro, Brazil, 3.8.-14.8.)
– Invited talk, "IAU Symposium 265 Chemical abundances in the Universe" (Rio de Janeiro, Brazil, 3.8.-14.8.)
– Invited talk, "IAU Joint Discussion 10 3D views of stellar atmospheres" (Rio de Janeiro, Brazil, 3.8.-14.8.)
– Invited talk, "IAU Joint Discussion 11 Helio- and asteroseismology" (Rio de Janeiro, Brazil, 3.8.-14.8.)
– Invited plenary review, "Astronomische Gesellschaft General Assembly" (Potsdam, 21.9.-24.9.)
– Invited review, "[alpha/Fe] as a tracer of formation and evolution of the Galaxy" (Beijing, China, 28.9.-30.9.)
– Invited review, "IAU Symposium 268 The light elements" (Geneva, Switzerland, 9.11.-13.11.)

M. Boylan-Kolchin: Invited Colloquium (UC Berkeley, USA; 27.9)

B. Catinella: "HI and Star Formation Properties of Massive Galaxies: First Results from the GALEX Arecibo SDSS Survey". Contributed talk at the "Hunting for the Dark: The Hidden Side of Galaxy Formation" conference (Malta, 19.10.–23.10.)
– "HI Properties and Star Formation of Massive Galaxies from the GALEX Arecibo SDSS Survey (GASS)". Contributed talk at the "Workshop on Galaxy Formation" (Sesto, Italy, 13.7.–17.7.)

P. Cerdá-Durán: "MICRA 2009" workshop, (Copenhagen, Denmark, 24.8.-28.8.)

E. Churazov: "Sakharov Conference", (Moscow, 18.5.-23.5.)
– "Marcel Grossmann meeting", (Paris, 13.7.-17.7.)
–"The Extreme sky: Sampling the Universe above 10 keV", (Otranto, Italy, 13.10.-17.10.)
– "High Energy Astrophysics 2009" (Moscow, Russia, 21.12.-24.12.)

B. Ciardi: "Cosmic Structure and Evolution" (Bielefeld, Germany 23.9.–25.9.)

K. Dolag: "Cosmological Simulations", 36th EPS Conference on Plasma Physics (Sofia, Bulgaria, 29.6-3.7.)

T.A. Enßlin: International conference on "Cosmological Magnetic Fields", (Ascona, Switzerland, 31.5.-5.6.)
– IAU JD 15 on "Magnetic Fields in Diffuse Media", (Rio de Janeiro, Brazil, 10.8.-12.8)

M. Frommert: The axis of evil - a polarization perspective International workshop on cosmic structure and evolution, (Bielefeld, 23.9.-25.9.))

M. Gilfanov: "Compact stars in the QCD phase diagram II" (Beijing, China, 20.5.–24.5.)
– "Astrophysics of Neutron Stars" Workshop (Istanbul, Turkey, 31.8.–4.9.)
–"High Energy Astrophysics 2009" (Moscow, Russia, 21.12.–24.12.)

S. Hachinger: – Determining He abundances in type Ib/c supernovae â spectral models with He 'heated' by non-thermal electrons.", Workshop, (Bonn, 17.7.)

W. Hillebrandt: "Structure Formation in Astrophysics - From Cosmology to Planets", Spring Meeting of the German Physical Society, (Munich, 9.3.-13.3.)

W. Hovest and J. Knoche: "The ProC Workflowengine" + "Installation tutorial" + "Demo and Usage tutorial" Summer school "Future cosmic sky surveys and huge databases", (Tartu, Estonia; 1.7.–3.7.)

H.-Th. Janka: "Argonne-Universe" Workshop (Munich, Germany, 25.5.–27.5.)
– "Nucleosynthesis – making the Elements in the Universe, International Workshop (Bad Honnef, Germany, 4.6.–6.6.)
– "Nuclear Matter at High Density" International Workshop (Hirschegg, Austria, 18.1.–24.1.)
– "Stellar Death and Supernovae" (Santa Barbara, California, 17.8.–21.8.)

G. Kauffmann: "Accretion and Ejection in AGN: a global view" (Como, Italy, 1.2.-3.2.)
– "IAU Symp 267: Evolution of Galaxies and Central Black Holes: Feeding and Feedback" (Rio de Janeiro, Brazil, 10.8.-14.8.)
– "Deciphering the Universe through Spectroscopy" (Potsdam, Germany, 10.8.-14.8.)
– "Hunting the Dark" (Malta, 10.8.-14.8.)

R. Krivonos: Invited talk, "The Extreme sky: Sampling the Universe above 10 keV" (Otranto, Italy, 13.10.-17.10.)

P. Mazzali: CasA and Hypernovae at the meeting "44Ti day" (ESO Garching, 15.1.)
– "Properties of SNe in Gamma-Ray Bursts:" at the meeting "High Energy Astrophysics" (Cairo/Alexandria, Egypt, 29.3.-3.4.)
– "Gamma-ray Bursts and Supernovae" at the meeting 'Gamma-ray Bursts' KIAA, (Beijing, 1.6.-12.6.)
– "Zorro and Type SNe Ia " at the meeting "Supernovae" (KITP, Santa Barbara, 17.8.-21.8.)

R.B. Metcalf: Danish Astrophysics Research School, (21.1.)

E. Müller: "From Disks to Jets - From Stars to Quasars" Symposium, (Heidelberg, Germany, 26.11.)
– "HLRB and KONWIHR: Review, Results and Future Projects" Workshop (LRZ Garching, Germany, 8.12.)

M. Obergaulinger: "4th International Conference on Numerical Modeling of Space Plasma Flows – ASTRONUM-2009" (Chamonix, France, 29.6.-4.7.)
– "Microphysics in Computational Relativistic Astrophysics: MICRA2009" (Copenhagen, Denmark, 24.8.-28.8.)

A. J. Ruiter: Stellar Mergers Workshop, (Leiden, The Netherlands, 29.9.)

I. Seitenzahl: "6th Russbach workshop on Nuclear Astrophysics" (Russbach, Austria, 2.3.-6.3.)

A. Serenelli: "Initial-final mass relation for low-intermediate mass stars", (The Giant Branches, Lorentz Center (Leiden, The Netherlands, 11.5.-15.5.)
– "New results on standard solar models", Synergies between solar and stellar modelling, (Rome, Italy, 22.6.-26.6.)

– Invited Review Talk RA F Science Day (MPE, Garching; 29.9)
– Invited Review Talk (Alexander von Humboldt Foundation Meeting, Heidelberg; 25.11)

S. A. Sim: "4th International Conference on Numerical Modeling of Space Plasma Flows" (Chamonix, France, 29.6.-3.7.)

V. Springel: “The tumultuous lives of galaxies, supermassive black holes and their dark matter halos” (Kunming, China, 23.2.–28.2.)
– ”Hunting for the Dark: The Hidden Side of Galaxy Formation” (Malta, 19.10.–23.10.)
– “Subdivide and tile: Triangulating spaces for understanding the world” (Leiden, Netherlands, 16.11.–20.11.)

R. Sunyaev: “Physics of reionization”, (Ringberg, Tegernsee, 24.3)
– Sunyaev-Zeldovich Universe and the Future of Cluster Cosmology, (Canada, 27.4.-1.5.)
– Sakharov Conference (Moscow, 18.5.-23.5.)
– “High Energy and Cosmology”, Ioffe Institute, (St. Peterburg, 14.8.)
– “Special Antoinette de Vacouleurs talk”, Astronomy Department, Texas University, 28.10.)
– Second Texas Cosmology Network Meeting, (Austin, 29.10.-30.10.)
– High Energy Astrophysics 2009 (Moscow, Russia, 21.12.-24.12.)
– Jerusalem Winter School on High Energy Astrophysics, (Jerusalem 27.12.)

S. White: – Galileo Galilei Workshop on Dark Matter, (Florence, Italy 9.2.–11.2.)
RAS Worshop, Galaxy Luminosity Function, (Liverpool, 17.4.)
– European week of Astronomy and Space Science (Hatfield, 23.4.)
– Unveiling the Mass: Extracting and Interpreting galaxy mass, (Kingston, Canada, 14.6.–20.6.)
– The Unity of the Universe, (Portmouth, U.K. 26.6.–1.7.)
– IAU General Assembly, Invited Discourse and two reviews at Joint Discussions (Rio de Janeiro, 3.8.–14.8.)

J. Zavala: “LAUNCH 09: Neutrinos and Beyond”, (Heidelberg, Germany, 9.11.-12.11.)

4.3.1 Public talks

M. Bergemann: “Wie und wofür studiert man die chemische Zusammensetzung der Sterne?” GirlsDay at MPA (23.4.)

G. Börner: “Die dunkle Seite des Universums - dunkle Materie und dunkle Energie – Open house at MPA (24.10.)

A. Chiavassa: 2 talks in France (Barcelonnette) in occasion of the Year of Astronomy (August 2009)

E. Churazov: Planetarium (Nizhny Novgorod, Russia; 23.09)

T.A. Enßlin: Lehrerfortbildung Bad Honnef (16.7.)
– Garchinger Weltraumtage (18.7.)
– “Der Planck-Satellit und das frühe Universum” Open house at MPA (24.10.)
– Aachener Weltraumtag (19.11.)

M. Frommert: “Ein Blick zurück bis fas zum Urknall” GirlsDay at MPA (23.4.)

M. Gilfanov: UNESCO conference ”Astronomy and world Heritage: across time and continents” (Kazan, Russia, 19.08-24.08)

W. Hayek: “Das Licht der Sterne: was es uns über die Sonne und den Kosmos erzählt - Open house at MPA (24.10.)

W. Hillebrandt: “Vom Anfang und Ende des Universums”, Förderkreis Planetarium Göttingen (10.2.)

H.-Th. Janka: Volksbank Basel, Switzerland (13.05.)
– Shanghai, China (18.07.)
– Wuhan, China (21.07.)
– Lijiang, China (24.07.)

E. Müller: 100. MNU National Congress, Regensburg (7.4.)
– five talks at various schools during the MPG General Assembly in Mainz (17.6.–19.6.)
– MPG General Administration, Munich (24.6.)
– "Gravitationswellen: wenn die Raumzeit bebt" – Open house at MPA (24.10.)

R. Schönrich: "Die Milchstraße, unsere kosmische Heimat – Open house at MPA (24.10.)

V. Springel: Magnus-Haus of the DPG, Berlin (8.6.)

H. Spruit: "Wie sieht ein schwarzes Loch aus ? Open house at MPA (24.10.)

R. Sunyaev: Public Lecture, King Faisal University, Riyadh, (Saudi Arabia, 29.3.)

S. Wanajo: Argonne-Universe Workshop (TUM, Garching, 25.05.-27.05.)
– Nucleosynthesis - making the Elements in the Universe (Physik Zentrum Bad Honnef, 04.06.-06.06.)
– Third Joint Meeting of the Nuclear Physics Divisions of the APS and JPS (Hawaii, USA, 13.10.-17.10.)

S. Weinmann: "Das Leben der Galaxien" GirlsDay at MPA (23.4.)

A. Weiss: Stadt Lauffen a.N. (28.5.)

S. White: – Entstehung des Kosmos (Mainz 6.5.) – CosmoCaixa, Dark Matter and Dark Energy (Barcelona, 2.4–12.4.)
– Dark Matters, (Aspen, Colorado, 14.7.)
– All from Nothing (Rio de Janeiro, 13.8.)
– Alles aus Nichts (Chemnitz, 23.9., Open house at MPA, Garching 24.10. and Hamburg, 26.10.)

4.3.2 Lectures

W. Hillebrandt, SS09, TU München.

H.-Th. Janka, SS09, TU München.

P. Mazzali: WS09/10, Scuola Normale Superiore, Pisa, Italy

E. Müller, SS2009 and WS09/10, TU München.

H. Ritter, SS 09 und WS 09/10, LMU Muenchen

F. Röpke, WS08/09, SS09 and WS09/10, TU München

A. Weiss, WS08/09, SS09, WS09/10, LMU München.

Short lectures

G. Börner "Cosmology" (Bad Honnef, 20.9.–21.9.)

T.A. Enßlin: "Cosmic Mikrowave Backgrouind" (IMPRS School Munich, 9.3.–11.3)

M. Gilfanov: "Astrophysics of compact X-ray sources" ("Dinastia" Foundation and Space Research Institute, Moscow, Russia, 26.10.–2.11.)

W. Hillebrandt: Summer School NOVICOSMO 2009; Highlights in Astrophysics; Rabac, Croatia, 20.9.–30.9.)

V. Springel: "Computational Cosmology", Prospects in Theoretical Physics 2009 (Institute for Advanced Study, Princeton, 13.–24.7.)
– "IMPRS Advanced Course II" (Garching, 26.–30.11.)

R. Sunyaev: Russell Lecture, AAS Meeting, (Long Beach, 5.1.)
– Niels Bohr lecture, (Copenhagen, 4.2.)
– Antoinette de Vaucouleurs Memorial Lecture, (University of Texas, 27.10)

A. Weiss: University of Canterbury, Christchurch (New Zealand, 1.9.–31.10.)

S. White: Cosmology at the Beach, Cabo San Lucas, (Mexico, 12.-16.1.)

5 Personnel

5.1 Scientific staff members

Directors

M. Asplund, W. Hillebrandt (managing director), R. Sunyaev, S.D.M. White

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, P. Arevalo (since 1.8.), J. Bolton (till 30.9.), M. Boylan-Kolchin, L. Casagrande, B. Catinella, P. Cerda-Duran, Y.M. Chen (since 1.4.), A. Chiavassa, B. Ciardi, D. Christlein, E. Churazov, R. Collet, J. Cuadra (since 1.8.), G. De Lucia (till 31.1.),K. Dolag, M. Dotti (since 1.11.), T. Enßlin, A. Faltenbacher (till 15.7.), D. Gadotti (till 30.10.), M. Gilfanov, T. Greif (since 1.10.), A. Gualandris (since 1.10.), C. Hernandez-Monteagudo, J. Hu, H.–T. Janka, G. Kauffmann, R. Krivonos, Ch. Li, S. Lucatello, A. Marek, A. Maselli (till 31.3.), P. Mazzali, B. Metcalf, P. Montero, B. Müller (since 1.6.), E. Müller, M. Obergaulinger, R. Overzier, E. Puchwein, I. Ramirez, M. Reinecke, H. Ritter, F. Röpke, A. Ruiter (since 1.9.), A. Saintonge (since 1.10.), L. Sbordone (since 1.9.), C. Scannapieco (till 30.8.), C. Scoccola (since 1.7.), I. Seitenzahl, A. Serenelli (since 1.9.), F. Shankar, S. Sim, V. Springel, H.C. Spruit, S. Taubenberger, S. Tsygankov, S. Weinmann, A. Weiss, J. Zavala-Franco, L. Wang (since 15.10.), R. Wiersma (since 1.10.),

Associated Scientists:

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

Alexander von Humboldt Awardees

Dick Bond (1.5.-30.6.), Craig Hogan (1.5.-30.5.), A. Szalay (1.6.-30.6.)

Minerva awardee

E. Neistein (till 31.12.)

DAAD awardee

S. Nuza (since 1.2.)

Ph.D. Students

[1] M. Alves-Cruz*, M. Baldi* (till 31.3.), P. Baumann (since. 1.9.), A. Bauswein, V. Biffi*, R. Birkl, A. Bogdan*, S. Bonoli*, M.-P. Bottino*, M.A. Campisi*, M. Carrasco-Kind* (left before PhD), F. Ciaraldi-Schoolmann, C. D'Angelo*, F. De Gasperin (since 1.5.), J. Donnert, E. Donoso* (till 15.12.), F. Elsner, S. Fabello*, M. Fink, M. Frommert, M. Gabler, L. Graziani*, M. Grossi*, Q. Guo*, S. Hachinger, N. Hammer (till 30.4.), W. Hayek, M. Herzog (since 1.5.), S. Hess, L. Hüdepohl (since 15.11.), F. Ianuzzi*, J. Jasche, A. Jeeson-Daniel*, P. Jofre-Pfeil*, M. Kromer, T. Mädler, U. Maio* (till 30.3.), I. Maurer, F. Miczek, S. Mineo*, M. Mocak* (till 31.1.), R. Moll, B. Müller (till 31.5.), S. Oslowski (left before PhD), R. Pakmor, M. Petkova*, M. Pierleoni* (left before PhD), P. Piovezan* (left before PhD), L. Porter*, T. Rembiasz* (since 1.9.), T. Sawala*, R. Schönrich (since 1.4.), V. Silva*, F. Stasyszyn*, M. Ugliano*, M. Vogelsberger, A. Waelkens (till 31.7.), M. Wadepuhl, L. Wang, J. Wang* (till 30.7.), A. Wongwathanarat*, F. Zaussinger, Z. Zhang*, I. Zhuraleva*.

Diploma students

S. Benitez (till 30.8.), Ph. Edelmann (since 1.2.), M. Häberlein (till 30.10.), F. Hanke (since 1.10.), L. Hüdepohl (till 30.10.), H. Junklewitz (since 1.3.), P. Kuchar (till 30.9.), Z. Magic (since 1.7.), J. von Groote (since 1.6.), C. Weig (since 1.2.), R. Yates (since 1.9.)

Technical staff

Computational Support: H.-A. Arnolds, B. Christandl, N. Grüner, H.-W. Paulsen (head of the computational support), M. Reuter (till 31.12.)
PLANCK Programmer: U. Dörl, W. Hovest, J. Knoche, J. Rachen, T. Riller, G. Robbers (since 1.8.).
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.

Staff news

B. Ciardi: Tenure Position at the Max Planck Institute for Astrophysics.

H.-Th. Janka: has been promoted to W2 position.

G. Kauffmann: Elected to American Academy of Arts and Sciences.

P. Mazzali: 2-yr assignment to Scuola normale Superiore, Pisa, Italy, in order to start High Energy Astrophysics group, as of 1.5.09

V. Springel: received the Klung-Wilhelmy-Weberbank Prize for Physics 2009.

R. Sunyaev: received the King Faisal International Prize for Science (Physics) and Gold Medal Antoinette de Vaucouleurs Medal, University of Texas, Austin.

R. Sunyaev: elected as Foreign Member of the Royal Society.

A. Weiss: Erskine Fellowship (University of Canterbury, Christchurch, New Zealand)

J. Zavala: Elected as a member of the Mexican National Researchers System (level I).

[1] *IMPRS Ph.D. Students

Ph.D. theses 2009

Marco Baldi: Interactions between Dark Energy and Dark Matter. Ludwig-Maximilians-Universität, München.

Reiner Birkl: Stationary, axisymmetric neutron stars with meridional circulation in General Relativity. Technische Universtität München (submitted).

Akos Bogdan: X-ray emission from nearby early-type galaxies and origin of Type Ia Supernovae. Ludwig-Maximilians-Universität, München (submitted).

Maria Angela Campisi: Gamma-ray Bursts and their Host Galaxies from Cosmological Simulation. Ludwig-Maximilians-Universität, München.

Mona Frommert: Temperature and Polarization Studies of the Cosmic Microwave Background. Ludwig-Maximilians-Universität, München (submitted).

Margherita Grossi: Probing Early Dark Energy and primordial non-Gaussianity with cosmological simulations. Ludwig-Maximilians-Universität, München (submitted).

Nicolai Hammer: Simulating Supernova Shock Propagation Through Stellar Envelopes in 3D. Technische Universität München.

Markus Kromer: Synthetic spectra and light curves of type Ia supernovae. Technische Universität München.

Miroslav Mocak: Multidimensional hydrodynamic simulations of the core heleium flash in low-mass stars. Technische Universität München.

Bernhard Müller: Multi-dimensional relativistic simulations of core-collapse supernovae with energy-dependent neutrino transport. Technische Universität München.

Guo Qi: Galaxy Formation and Evolution in a LCDM Universe. Ludwig-Maximilians-Universität, München.

Mark Vogelsberger: The internal structure of Cold Dark Matter Haloes. Ludwig-Maximilians-Universität, München (submitted).

Andre Waelkens: Studying magnetic turbulence with radio polarimetry. Ludwig-Maximilians-Universität, München.

Diploma theses 2009

Christian Auer: Implementation of Fast Marching Methods for the simulation of burning fronts in explosion models of Type Ia Supernovae. Technische Universität München.

Sandra Benitez: A Model-Independent Analysis of the Expansion History of the Universe with Type Ia Supernovae. Universidad Complutense Madrid.

Max Häberlein: Full scale simulations of highly variable blazars. Technische Universität München.

Lorenz Hüdepohl: Neutrino cooling evolution of the newly formed neutron stars from electron capture supernovae. Technische Universität München.

Petr Kuchar: Characteristics of magnetic fields in galaxy clusters from Faraday rotation data. Technische Universität München.

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
Mashhoor Al-Wardat	Bin Talal Univ. Jordanien	13.6.–12.9.
Patricia Arevalo	Shanghai Astr. Obs., China	26.1.–15.2.
Petr Baklanov	ITEP Moscow	11.8.–10.9.
Anthony Banday	Toulouse, Frankreich	5.8.–18.8.
		and 25.5.–5.6.
Isabelle Baraffe	Ecole Normale Sup., Lyon	1.11.–30.11.
Altan Baykal	East Technical Univ., Ankara	4.7.–24.8.
Andrey Belyaev	St. Petersburg, Russia	4.11.–29.11.
Sergey Blinnikov	ITEP, Moscow	11.8.–18.9.
Richard Bond	Toronto, Canada	01.5.–30.6.
Gilles Chabrier	Ecole Normale Sup. Lyon	1.11.–30.11.
Yan–Mei Chen	Key Lab for Particle Astr. Peking	since 30.3.
Jens Chluba	CITA, Toronto, Canada	29.6.–6.8.
Nikolai Chugai	Institute of Astron., Moscow	15.11.–15.12.
Jorge Cuadra	Shanghai Astron. Obs., China	26.1.–15.2.
Weiguang Cui	Shanghai Astron. Obs., China	since 19.2.
Marc Davis	Univ. of California, Berkeley	1.9.–31.10.
Cristiano de Boni	Univ. of Bologna, Italy	9.3.–8.6.
Guillaume Faye	Inst. Astrophys. de Paris	12.10.–25.10.
Anna Frebel	Univ. of Texas at Austin, USA	7.9.–21.9.
Jian Fu	Shanghai Astron. Obs., China	15.2.–5.10.
		and since 15.10.
Jeffrey Fung	Univ. of Toronto, Canada	13.7.–29.7.
Hong Guo	Shanghai Astron. Obs., China	since 7.9.
Timothy Heckmann	Johns Hopkins University	1.6.–30.6.
Bruno Henriques	Univ. of Sussex, UK	18.1.–30.1.
Craig Hogan	Univ. of Washington, USA	1.5.–30.6.
Nail Inogamov	Landau Inst. Moscow	1.8.–30.9.
Xu Kong	Center for Astr. Hefei, Anhui/China	8.10.–21.10.
Lixin Li	Peking University, China	11.7.–22.8.
Liu Lei	Shanghai Observatory, China	7.12.–19.12.
Luo Wentao	Shanghai Observatory, China	7.12.–19.12.
Brice Menard	CITA, Toronto, Canada	15.9.–14.10.
Peter Mendygral	Minneapolis, USA	19.10.–6.11.
Marcelo Miller–Bertolami	La Plata, Argentina	23.5.–1.7.
Maryam Modjaz	UC Berkeley, USA	21.9.–10.10.
Dmitrij Nadyozhin	ITEP, Moscow, Russia	13.3.–12.5.
Sergei Nayakshin	Leicester Univ., UK	23.7.–22.8.
Peng Oh	UC Santa Barbara, USA	6.7.–29.8.
Teppei Okumura	Shanghai Astr. Obs., China	2.9.–31.10.

Name	home institution	Duration of stay at MPA
Zhizheng Pan	Univ. of Science and Technology, Hefei,	since 3.11.
Beate Pasternak	Univ. Jagiellonski, Krakow, Poland	7.10.–16.12.
Lorenzo Piovan	Univ. of Padova, Italy	1.8.–30.8.
Jonathan Pritchard	Harvard CfA, Cambridge/USA	15.3.–14.4.
Igor Prokopenko	Space Research Inst., Moscow	8.2.–7.5.
		and 1.9.–30.11.
Maximilian Ruffert	Univ. of Edinburgh, U.K.	1.1.–30.6.
Maurizio Salaris	Liverpool John Moores Univ., U.K.	29.7.–28.8.
Sergey Sazonov	Space Research Inst., Moscow	2.6.–18.8.
Nikolai Shakura	Sternberg Astron. Inst., Moscow	01.9.–30.9.
Pavel Shtykovskiy	Space Research Inst., Moscow	23.6.–5.9.
Yudai Suwa	Univ. of Tokyo	20.4.–17.7.
David Schiminovich	Colombia Univ., USA	23.8.–5.9.
Rodion Stepanov	Russian Academy of Sciences	18.1.–13.2.
Nicolas Taburet	Univ. Paris–Sud, Orsay/Frankreich	21.10.–4.11.
Tomas Tecce	Ciudad Univ. Buenos Aires	1.10.–31.10.
Regner Trampedach	Australian Nat. Univ.	3.1.–18.1.
		and 15.5.–29.5.
Michael Turner	Univ. of Chicago, USA	5.7.–30.7.
Victor Utrobin	ITEP Moscow	1.10.–30.11.
Shinya Wanajo	Cluster, TUM	since 1.1.
Stuart Wyithe	Univ. of Melbourne	2.3.–27.3.
Stanford Woosley	UC Santa Cruz, CA/USA	22.6.–21.7.
Xu Kong	Hefei, China	9.10.–21.10.
Tatsuya Yamasaki	CEA, Paris	till 31.5.
Heling Yan	Peking University, China	2.5.–1.6.
		and since 14.10.
Kai Zhang	Heifei, China	15.2.–30.9.
Wei Zhang	Nat. Astron. Obs. Peking, China	21.1.–17.2.
Youcai Zhang	Shanghai Astron. Obs. China	19.2.–18.2.
Jie Zhou	Nat. Astron. Obs. Peking, China	5.11.–4.11.