Max-Planck-Institut
für
Astrophysik

Annual Report 2005

Contents

1 General Information

1.1 A brief overview 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, after the headquarters of the European Southern Observatory relocated to Garching, Biermann's successor, Rudolf Kippenhahn, moved 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 seven years: Simon White was the first Managing Director, followed by Wolfgang Hillebrandt beginning on January 2000. On January 1, 2003 Rashid Sunyaev took over this post and his term expired on the 31st of December 2005 and he was succeeded by Simon White, who took over for the next 3 years from January 1, 2006. The Managing Directorship will rotate every three years. The institute has three external Scientific Members: Rolf Kudritzki, Riccardo Giacconi and Werner Tscharnuter.

The MPA was founded specifically as an institute for theoretical astrophysics, intended to foster development of basic theoretical concepts and effective numerical methods to master the challenges of stellar constitution and evolution, interstellar media, their hydrodynamics and magnetic fields, hot plasmas, energetic particles, their orbits, and the calculation of transition probabilities and cross–sections important for astrophysical processes, especially in rarified media. These efforts led to manifold international cooperation and in later years also complemented the observational and instrumental activities carried out in other Max-Planck institutes.

The MPA also has an internationally-recognized numerical astrophysics program that is unparalleled by any other institution of similar size. In recent years, activities at the MPA have diversified and include a wide range of data analysis activities. Resources are channeled into specific areas where new instrumental or computational capabilities are expected to lead to rapid developments. In the MPA, the main areas of research include stellar evolution, stellar atmospheres, accretion phenomena, nuclear and particle astrophysics, supernova physics, astrophysical fluid dynamics, high-energy astrophysics, radiative processes, the structure, formation and evolution of galaxies, gravitational lensing, the large-scale structure of the Universe and physical cosmology. Several previous research areas (solar and solar system physics, the quantum chemistry of astrophysical molecules, General Relativity and gravitational wave astronomy) have been substantially reduced over the last decade.

A number of different aspects of the MPA's structure have historical origins. Its administration (which is housed primarily in the MPA building) is shared with the neighboring, but substantially larger MPI für extraterrestrische Physik. 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 staff 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 as a result a close working relationship is maintained between the MPA and the RZG.

1.2 Current MPA facilities

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 20000 books and conference proceedings, as well as reports, observatory publications and preprints, and it holds subscriptions for about 200 journals. The current holdings occupy about 1900 meters of shelf space. In addition the library maintains a pre– and reprint archive of MPA and MPE publications, two slide collections (one for MPA and one for the MPE) and keeps 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. This catalogue and the 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.

To serve the librarians' and users' needs the library has access to several copy machines, and is equipped with a microfiche reader/printer, 6 PCs, 2 laser printers and a fax machine.

Due to exploding costs introduced by most publishing houses, subscriptions of several journals had to be cancelled over the last few years. In order to cope with this continuing cost problem in the future, the general administration (GV - Generalverwaltung) has started some time ago the "elib - project" (electronic library project). In this scheme the GV keeps campus licenses for online electronically accessible journals whereas individual institutes subscribe only print copies for selected journals at a reduced price. The online journals are accessible via the institute's library homepages or MPA/MPE library catalogue.

Another activity launched lately by the GV is 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 people (e.g. ca. 900 publications in 2004). The institute's library also takes part in the "VLib" (Virtual Library) project of the GV, which is the general information portal of the MPG providing a common surface under which various scientific information resources become available.

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 computing center Garching (RZG).

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 bi-monthly basis to discuss issues concerning MPA's requirements at the RZG. The RZG and MPA try to 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 the following hardware housed at RZG: an IBM Power4 multiprocessor computer, an IBM blade center, an OPTERON-cluster with 16 2.4 GHz processors and 32 GB of memory, and an SGI Altix with 112 processors and 224 GB of memory. These machines satisfy the increasing needs for cheap, but effective CPU-resources for mid-range computing.

The MPA-computer centre consists of about 15 powerful workstations providing computer resources both for interactive work (text processing, electronic communication, program development, data visualization) and for small to intermediate-scale numerical applications. These machines Intel-based PCs, SUN workstations, and 7 64-bit architecture OPTERON system, with 2 or 4 processors each and memory of up to 32 GB. All users have free access to most resources; several central machines are however reserved for particular research groups. Two full-time and three part-time system administrators are responsible for the facilities; users have no administrative privileges or duties. Crucial services such as http, ssh, slogin, dns, etc. are distributed on several specialised and protected servers.

User access is mainly through desktop PCs (with Linux as the operating system and modern TFT-screens), which are also administered by the system managers. The average age of the desktop equipment is below three years. In 2005 more than 120 office places provided desktop access to the network and central installations. System software and the file system are set up so that users always have the same computer environment independent of the machine they are actually working on. This structure also minimizes the administrative work and guarantees a high level of system stability. Special requirements (high-end graphics software; large PC memory; dedicated compute servers; large disk storage) are met as well and on request. Since 2005 institute members have the possibility of obtaining insitute laptops on a long-term borrowing basis.

While MS Windows software is avoided as much as possible, access to such systems is possible by a number of public PCs and through servers and emulations. Minimum maintenance is provided by the system managers.

The data network is a structured 100Mbit one, with Gigabit backbones. It is divided into several sub-networks of increasing security. The most secure network is that of the server machines, the least one that for private computers connected to MPA. This network is separated from the others by an internal firewall in the same way as the whole campus network is protected by an external firewall at RZG. Thanks to a high degree of security MPA so fas har been spared from any computer attacks and viruses with the exception of Microsoft worms in the insecure guest network.

Major investment has been put into in-house mass storage. Because of the increasing demand for large data storage, several disk-array systems of Terabytes capacities with LINUX-PC or OPTERON-servers have been added to the central system. The total capacity is now close to 100 TB. All centrally stored data are saved daily by several and redundant backups; project data are saved on request or by need. These measures, the hardware-redundancy of all components, and the Advanced File-System (AFS) guarantee an almost 100% availability of data and a complete lack of data loss due to hardware or system failures. In addition, desktop PCs provide an increasing amount of scratch disk space, which, however, is not saved by the system.

The most important resources provided by the RZG are parallel and vector supercomputers, close to PByte mass storage facilities (also for backups), and the gateway to GWIN/Internet. The exchange of expert knowledge with RZG staff is also very valuable.

In addition to the central MPA computer services, both the Planck Surveyor project and the SDSS group operate their own computer clusters. Both installations are designed in a similar fashion as the general system, and are maintained by the MPA system managers.

We have seen lately an increasing demand for providing access to our system from private machines not under control of the system managers. This causes severe security problems. Secondly, a steadily growing number of people wants to work both on a desktop PC and a laptop; this requires more maintenance work and also more and better network connections to the offices. Along the same line, requests for WLAN (already available at MPA), intelligent multimedia and videoconferencing systems increase the tasks of the system managers beyond the classical management. Finally, the ever more complicated application software, in particular that for data management, presentations and communication would require system expertise and advise. In view of these developments, a second full-time system manager was hired in 2005, ensuring the high level of system support MPA is currently offering also in the future.

1.3 2005 at the MPA

Every year since 1997 the MPA has invited a world-class theoretical astrophysicist to give three talks over a one month period on a subject of his or her choice. The goal is to provide an opportunity for extended interactions between the visitor and the local astronomical community. This set of prize lectures, known as the Biermann Lectures, were given in 2005 by Shri Kulkarni from the Caltech in Pasadena. Professor Kulkarni have lectures on three different subjects: *"The multi-faceted core collapse cosmic explosions"*, *"Astrometric Searches for extra-solar plantes"* and *"Some recent advances in neutron stars"*. This series of excellent talks consistently filled the MPA lecture theatre to its limits.

Several workshops and conferences were organized by MPA scientists in 2005: "Planck HFI/LFI Consortium Meeting" (MPA, January 26.-28.); the Workshop on "Interdisciplinary Aspects of Turbulence" (Ringberg Castle, April, 18 - 22); the Workshop "From Simulations to Surveys" (Ringberg Castle, June 26 - July 1); the MPA/ESO/MPE conference "Open Questions in Cosmology: the First Billion Years" which was held in Garching (August 22 - 26); workshop "Carbon-rich ultra metal-poor stars in the Galactic halo" (November 28 - December 2).

MPA's national and international cooperations and collaborations continued to flourish in 2005. The following EU networks brought many new postdocs, students and visitors to MPA: – "The Physics of Type Ia Supernova Explosions", coordinated by Wolfgang Hillebrandt – RTN on "Gamma-ray Bursts" led by Rashid Sunyaev – "Optical-Infrared Co-ordination Network for Astronomy" (OPTICON) led by Henk Spruit – "Multi-wavelength Analysis of Galaxy Populations" (MAGPOP) coordinated by Guinevere Kauffmann – "Latin-American European Network for Astrophysics and Cosmology" (LENAC) led by Simon White". The Institute actively participates in the DFG programs including the DFG key program: Witnesses of Cosmic History; Formation and Evolution of Galaxies; Black Holes and Their Environment; Special Research Programme SFB375 on "Astroparticle Physics" and TRANSREGIO on "Physics of Colloidal Dispersions in External Fields".

As a consequence of the various European TMR and RTN networks involving MPA scientists, colleagues from all over Europe have been frequent visitors at MPA during 2005. Participation in the EARA Network (led by Guinevere Kauffmann and Henk Spruit), which unites leading European universities and institutes in the field of astrophysics, permits MPA to organize long term visits of PhD students to and from Garching. Young postdocs actively participated in the MPA exchange program with the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara, the Canadian Institute for Theoretical Astrophysics, and the Institute for Theory and Computation at the Theoretical Astrophysics Division of the Harvard Smithsonian Center for Astrophysics.

The research quality at MPA was recognized in 2005 by international prizes at both senior and junior levels. Simon White received the highly prestigious Gold Medal of the Royal Astronomical Society and the Dannie Heinemann Prize for Astrophysics from the American Astronomical Society and the American Institute of Physics. He was elected to the Academy of German Natural Scientists Leopoldina, and was Blauuw Professor of the Groningen University.

Rashid Sunyaev was the Karl Jansky Lecturer of the National Radio Astronomy Observatory, Sackler Lecturer for Astrophysics at Harvard University and the Bishop Lecturer at Columbia University; Volker Springel won the Nano Special Award for Scientific Visualizaton; Miguel Aloy received a Ramón y Cajal Fellowship at the University of Valencia. In other staff, Benedetta Ciardi was appointed to a tenure track staff position at MPA, increasing the number of tenure track staff members to 2.

MPA Partner Group at the Shanghai Observatory

In 2005 the five year term of promotion of the Partner Group of the MPA at the Shanghai Astronomical Observatory (SHAO) expired, but the MPA has been encouraged by the MPG president to continue the successful cooperation in a somewhat different way. The partner group was founded in May 2000 with Jing Yipeng as head. Its support was based on the exchange program between the Chinese Academy of Sciences (CAS) and the Max-Planck Society. The first two years were devoted to developing basic structures with emphasis on the education of students. A number of Ph D students of the Partner Group were sent to the MPA for Ph D training. Usually after completion of a one year project at MPA they returned to Shanghai to submit their Ph D thesis there. In addition lively contacts were and will be maintained between the group and the MPA via the frequent short-term exchange of scientists. The Shanghai group has gradually grown in size and in 2005 consisted of fifteen members; four staff members including Jing, and eleven graduate students. Some students were jointly supervised in Shanghai and at Beijing University. and at the University of Science and Technology in Hefei. In addition to support from the MPG, the partner group has received strong funding and support within China which has enabled it to buy first rate equipment, and to develop into an active nucleus for cosmology research in China.

The research activities of the group are concentrated on the studies of large-scale structure, galaxy formation and gravitational lensing. High resolution simulations developed by Jing are a major ingredient in this work. A computer system has been set up consisting of a workstation and a cluster of PC's, and in 2004 a SGI Altrix 350 with 96 Gb memory and 4 Tb hard disk has been bought. This satisfies the computational needs for the group's research programme.

About 30 research papers have so far been published, mostly in the Astrophysical Journal, and about half of them in collaboration with scientists from the MPA. The close cooperation with MPA has led to four joint workshops on cosmology being held in Shanghai, Beijing, and Huangshan . Ten students have obtained their Ph D during this time.

The successful work of the past 5 years together with Yipeng Jing gives the MPA strong motivation to continue–especially in view of the growing influence of our partner within the Chinese astronomical community. Jing has received the Award in Science and Technology of the City of Shanghai for 2004 (in march 2005), the second highest in China. In february 2006 it was announced that he has won the 2005 National Award in Science and Technology, the highest scientific award in China, and the first time an astrophysicist has received this award. Jing's group by now has grown into a department of Astrophysics and Cosmology at SHAO, two active young Chinese scientists from the USA have been appointed as group leaders, and a joint Center for Cosmology has been established with the USTC in Hefei with Jing as director. Starting in 2006 the MPA will have two joint postdoc fellowships with this new group, and the establishment of a new MPA partner group within the SHAO-Hefei cosmology center is being considered.

Public relations

Traditional public relations activities at MPA include articles written for popular science magazines and science sections of newspapers (see Section 4.3). MPA scientists are also often consulted by journalists for information or input to news reports and television programs.

The highlight of MPA public outreach activities in 2005 was our biannual "Day of the Open House" on Saturday, Oct. 22. It attracted about 1000 visitors to the Institute, including a large number of pupils and students, who enjoyed various presentations of MPA research work. Besides lectures by scientists on cosmology, galaxy evolution, element formation, and black hole physics, which filled the MPA lecture hall to its capacity limit, our "Cosmic Cinema" show of computer simulations attracted large crowds of visitors. An extended collection of posters, which MPA researchers prepared for this event with the help of internship students, offered visitors a chance to get involved in conversations with presenting scientists. In the "Astro-Sprechstunde" in our coffee corner, staff members were busy with answering students' questions about internship possibilities and the career perspectives as a professional astrophysicist. For the first time we organized this year special events for young children of 5 to 10 years and for teenagers at the age of 11–16 years. The former group could enjoy tinkering little rockets made of paper and film containers, had a chance to learn more about fundamental physics phenomena in "astro-experiments", and could join us for a multi-media journey through the universe. Between 30 and 50 children, accompanied by their parents, participated in these activities at any time between 10 a.m. and 5 p.m. Finally, at the end of the day, about 300 children had assembled their rockets and had successfully launched them on the roof terrace of MPA. Computer workstations, on the other hand, were prepared for the teenagers, allowing them to test their abilities in diverse astro-games. The youngsters could, e.g., explore the action of gravity by landing a space probe on the moon, or could manoeuvre a space ship through the solar system and the galaxy, or test their astrophysics knowledge by taking part in a little quiz, whose winners were awarded with a collection of CD-ROMS of our "Cosmic Cinema" and with cups and puzzles that were produced using images from computer simulations performed by MPA scientists.

MPA considers education of pupils as a particularly important task. Therefore MPA scientists regularly visit schools for lectures and give seminars for teachers, e.g., at the teachers education center in Dillingen. A corresponding list of talks presented by MPA researchers at schools as well as public science events is given in the Section **??**. The institute also frequently hosts visitor groups and school classes, offering them the possibility to observe "scientists at work" and to learn about the problems discussed by modern astrophysics and astronomy. One of our scientific members emeriti, H.-U. Schmidt, is an invaluable help in such activities, because he enthusiatically takes care of typically 10–20 visiting school classes from Germany as well as other European countries every year.

Offering the possibility of "Praktika" or internships for pupils and students, MPA also contributes to the training and education of a future generation of astronomers. The demand for such internships at MPA has dramatically grown over the past years. MPA capabilities were strained to their limits by accepting about 10 high school and graduate students every year for periods between one week up to several months. The youngsters enjoyed the possibility to experience "science live" and to collaborate with MPA scientists on small research projects or public relation activities like the design of internet pages and the production of movies.

The "Cosmic Cinema", a multi-media computer presentation of MPA research highlights which uses interactive and technologically advanced forms of computer visualization and animation, has been updated and extended since its first version of 1999. New films about the Sun and cosmic magnetic fields were produced, and MPA simulations of planet formation were added to an already existing movie that shows the Orion Nebula as a cradle of new stars and planetary systems. The Cosmic Cinema has found extraordinarily large public resonance and was positively advertised by the popular astronomy magazine “Sterne und Weltraum”. Its is available to libraries, planetaria, school classes and interested individuals through orders to our library.

On August 2, 2005, a delegation of Chinese journalists, accompanied by a representative from the Chinese Academy of Sciences, visited MPA for several hours. Besides being introduced into MPA’s history and science, the group was particularly interested in obtaining information about the public relations activities at the institute and organisational aspects of this work. Obviously the Chinese visitors were eager to learn how scientists can be motiviated for more intense communication with the public.

1.4 How to reach us

- Postal address:

  MPI für Astrophysik
  Postfach 13 17
  D-85741 Garching
  Germany

- Telephone (country code 49):

  89-30000-0 (switchboard)
  89-30000-2214 (secretary)
  89-30000-2235 (FAX)

- Electronic address:

  e-mail:
  user-id@mpa-garching.mpg.de
  (initial + last name
  will reach most people,
  e.g. mdepner for Maria Depner)

  World Wide Web:
  http://www.mpa-garching.mpg.de
  anonymous ftp:
  ftp.mpa-garching.mpg.de

- MPA (reference) library:

  phone: +49-89-30000-2305/6
  FAX: +49-89-30000-2378
  email: lib@mpa-garching.mpg.de
  URL: http://www.mpa-garching.mpg.de/libris.html
  homepage: only local access

2 Scientific Highlights

2.1 A Violation of Cosmological Isotropy?

Since the Copernican Revolution removed humanity from the center of the Universe, two of the most fundamental principles guiding cosmologists have been the principles of cosmological homogeneity (the Copernican Principle - that any measurable property of the Universe is the same from all locations) and of cosmological isotropy (that the Universe looks the same in all directions). Observations show that these approximately hold true in the region of space we can observe, but new data from NASA's *Wilkinson Microwave Anisotropy Probe (WMAP)* yield provocative indications that the principle of isotropy may need to be abandoned.

The Cosmic Microwave Background (CMB) radiation is one of the cleanest probes available for studying the largest scale structures in the Universe. According to the Big Bang picture, small inhomogeneities in the initial distribution of matter must be present in order to allow the formation of galaxies, stars, and planets under the action of gravitational instability. Associated variations must also be present in the CMB, as a consequence of the tight coupling between matter and radiation during the so-called recombination epoch. Finally, the expanding Universe becomes cool enough for the plasma of free electrons and protons to form neutral hydrogen and thus to become transparent to photons - the observed structure seen in the CMB today largely originated at this moment and is a snap-shot of conditions when the Universe was only a few hundred thousand years old. If the Universe were exactly homogeneous and isotropic, the CMB would be exactly the same in every direction on the sky, but then no observer would be present to record that fact. Instead, small fluctuations in temperature on the level of one part in 10^5 are found about a mean value of 2.725 K. Statistically speaking, these fluctuations would be uniformly distributed over the sky if the Universe were isotropic, and this was precisely the initial picture provided by the *COBE* satellite in 1992.

Unfortunately, the ability to study questions related to isotropy were limited by the low angular resolution and sensitivity of this direct predecessor to the *WMAP* satellite. This is no longer the case following the release of the first batch of results from the latter in early 2003. While the new data are generally considered to be in very good agreement with the standard view, increasing scrutiny of the *WMAP* data reveals that the CMB contains anomalies on large angular scales that indicate the presence of a preferred direction to the Universe. In particular, researchers at the Max Planck Institute for Astrophysics and their collaborators in Oslo (Norway), and Pasadena (USA) have found evidence that, if the sky is analysed in a particular coordinate frame, then the fluctuations show more power in one hemisphere than in the other. Motivated by this result, and corroborating evidence of anomalous behaviour by other groups, a specific class of cosmological model which is homogeneous, but admits anisotropy has been investigated.

Homogeneous models that include anisotropic expansion (shear) and global rotation (vorticity) are known as Bianchi type VIIh models. The presence of the shear and vorticity terms then provide a new source of anisotropic structure in the microwave sky. CMB photons propagate along geodesics that are rotating about the symmetry axis and are "stretched" (or redshifted) due to the shear expansion. The radiation will then appear hotter or colder depending on the particular path the photons have taken, resulting in an additional anisotropy in the observed CMB in the form of a spiral pattern (see Fig. 2.1).

An explicit comparison of these models to the data show that the observed asymmetry in power may indeed be due to a specific combination of shear (along a particular axis) and vorticity (about that axis). The data and the matching Bianchi model are shown in Fig. 2.2. If the anisotropic Bianchi component is removed from the CMB data, the power asymmetry and several related statistical anomalies are corrected. In particular, an unexpectedly cold spot on the sky aligns well with the preferred axis, and corresponds to a decrement in the Bianchi temperature distribution. Unfortunately, the best-fit model has a low value for the cosmological energy density and is, therefore, inconsistent with both the inflationary paradigm and with the measured total energy density of the Universe. Indeed, the fluctuations on smaller angular scales in the CMB itself directly contradict such a value.

Ultimately, a viable theory must be developed to self-consistently explain the observations on all angular scales, and make independently verifiable predictions for other cosmological probes. Alternatives to explain the anomalous large angular scale behaviour of the CMB include models with non-trivial topologies, which purport a finite size for the Universe. For our part, we have extended the Bianchi formalism to account for its most glaring inconsistency with the current understanding of the cosmological model. The inclusion of a dark energy term allows the same anisotropic structure from the previous analysis to be reproduced with a range of cosmological parameter values. If the allowed solutions are constrained further by the requirement to match the observed CMB structure on smaller angular scales, then the best models are forced to high values of the cosmological constant, sadly still in contradiction with a wide range of other evidence (see Fig. 2.3).

However, it is our opinion that a pragmatic approach should be adopted in the interpretation of the results. In particular, i) the Bianchi model provides a means to statistically quantify deviations from isotropy, and ii) the best-fit model provides a template temperature pattern which other models may need to reproduce in order to explain the observed anomalies. Irrespective of our current ability to provide a physical explanation, the results do suggest that the long-held assumption of cosmological isotropy may need to be reconsidered. (A.J. Banday and T.R. Jaffe)

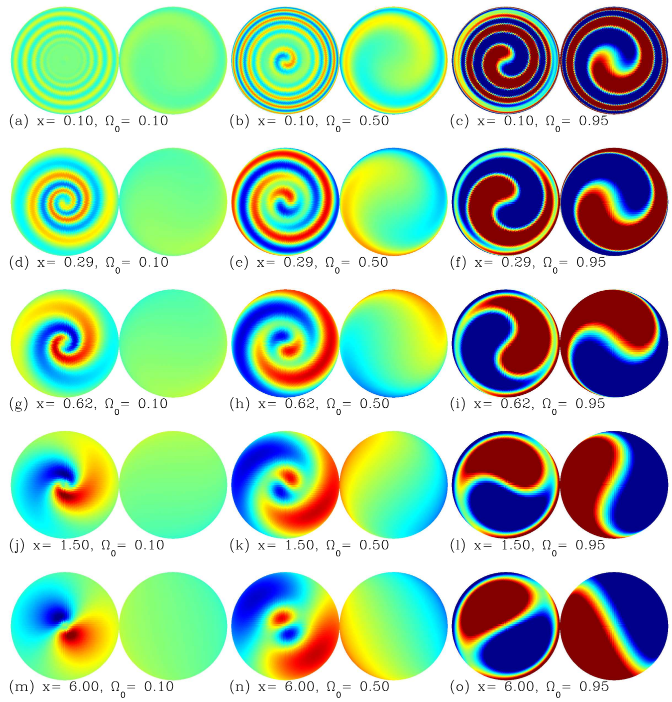

Figure 2.1: Examples of CMB anisotropy patterns generated in Bianchi cosmological models as a function of various parameters. Each plot shows the full sky in orthographic projection, with the northern hemisphere to the left. The effect of shear and vorticity result in a spiral pattern for which the tightness of the winding is inversely related to x. In low density (Ω_0) models, significant asymmetry in power can develop between the two hemispheres.

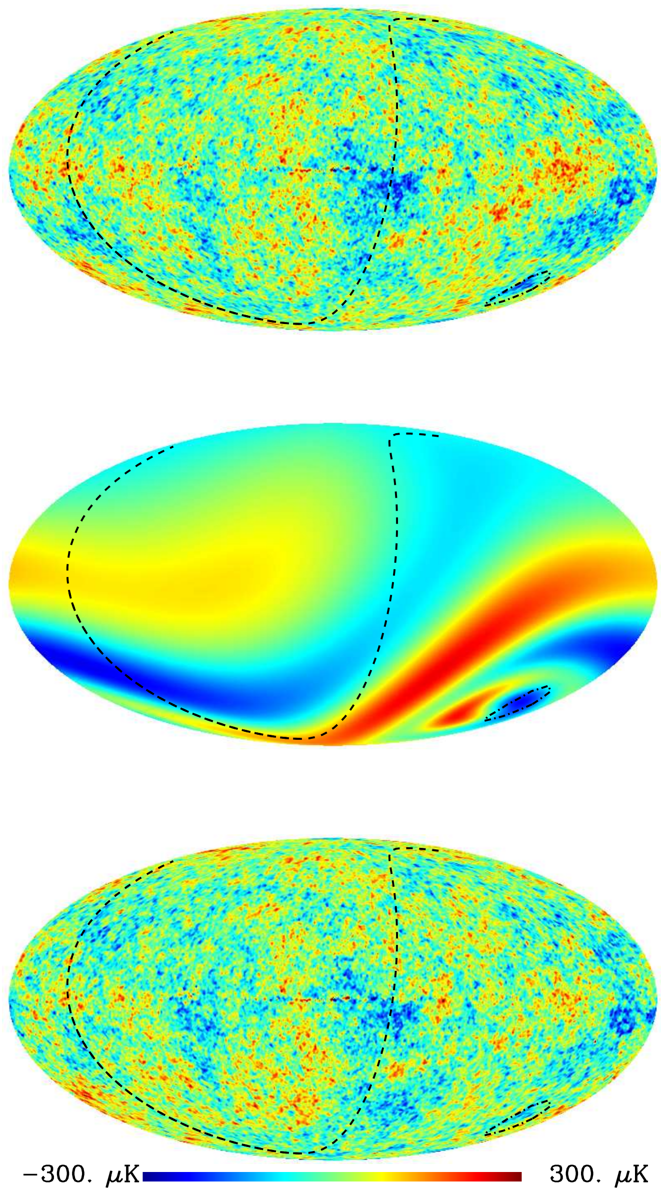

Figure 2.2: *Upper panel*: shows a full sky image of the CMB temperature fluctuations measured by NASA's *W*MAP satellite. The sky is shown as a Mollweide projection, overlaid on which is a dashed line delineating the equator of a reference frame in which the asymmetry in power between the northern and southern hemispheres is most pronounced. The dashed-dotted circle in the southern hemisphere corresponds to an unusually cold spot. *middle*: depicts the Bianchi model which demonstrates the most significant correlation with the *WMAP* data. Note the relative lack of power in the "preferred" northern hemisphere, and the spiral pattern focussed into the corresponding southern hemisphere. (The amplitude of the structure is enhanced by a factor of 4 for visualisation purposes). *lower*: reveals the *WMAP* data after correction for the Bianchi contribution: the power asymmetry is no longer significant, and the anomalous cold spot is no longer present.

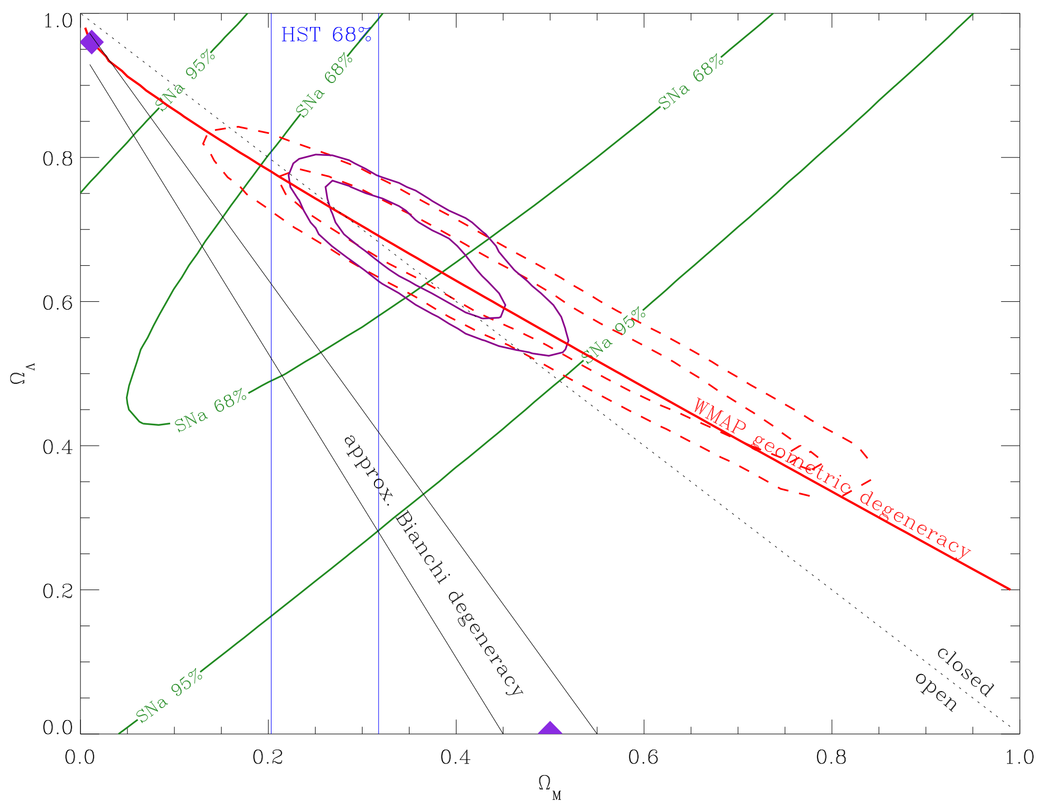

Figure 2.3: The $\Omega_\Lambda - \Omega_m$ parameter space. The solid red line is the geometric degeneracy curve which corresponds to the set of values that reproduce the observed small angular scale anisotropy observed in the *WMAP* data. The black solid lines show an approximate representation of the Bianchi degeneracy - the set of Bianchi models which exhibit identical spatial structure to the the original model at $(x, \Omega_{\Lambda 0}, \Omega_{m0}) = (0.62, 0, 0.5)$ (violet triangle). The likelihood contours from *WMAP* data alone are shown with the red dashed lines. In green are constraints from observations of type Ia supernovae; in blue are the HST Key Project constraints; and finally in solid magenta are the contours from the combined *WMAP*, supernovae, HST, and SDSS data. The best-fit Bianchi model which includes a cosmological constant term lies on the *WMAP* geometric degeneracy curve at $(0.028, 0.96, 2.5)$ (violet diamond). This remains inconsistent with the other constraints on the parameter space.

2.2 Spectral Tomography of Type Ia Supernovae: A Direct Look into the Exploding White Dwarf

In recent years type Ia supernovae (SNe Ia) have received considerable attention, mostly because of their use as (calibrated) distance indicators. Supernova observations lead to the unexpected result that the Universe entered a stage of accelerated expansion a few billion years ago, commonly attributed to a yet unexplained new form of energy with negative pressure, the 'dark energy', or a cosmological constant.

This result is based on the assumption that we can parameterise the observed properties of these bright explosions and hence estimate their intrinsic luminosity. Although these empirical correlations, based on the shape of the light curve, appear to work very successfully, they do rest on rather thin theoretical grounds. In particular, we understand that the brightness of SNe Ia depends almost linearly on the synthesised mass of radioactive ^{56}Ni, but we can only conjecture that this affects the width of the light curve also in a linear way. Additionally, this construction still rests on the uncertain hypothesis that all SNe Ia originate from progenitors that have the same mass.

In the currently favoured theory the progenitor of a SN Ia is a white dwarf star, composed of carbon and oxygen, accreting mass from a companion star in a binary system. The homogeneity of the SN Ia phenomenon is explained by the assumption that the white dwarf undergoes a thermonuclear runaway when the central temperature, which increases as more mass is piled on to the star, reaches the threshold value for the fusion of carbon to heavier chemical elements. In the absence of rotation, this temperature is achieved once the star reaches a mass close to but slightly smaller than the Chandrasekhar mass limit for a degenerate star, approximately 1.4 times the mass of the sun.

From this point on, our understanding is more controversial. Nuclear burning of the C+O mixture is supposed to start somewhere near the centre of the white dwarf as a relatively slow, subsonic deflagration front, a 'nuclear flame', similar to premixed chemical combustion flames, gaining some speed from turbulence. This is very efficient process, burning material to nuclear statistical equilibrium (NSE) if the density is sufficiently high. Most of this NSE material consists of radioactive ^{56}Ni which later powers the optical display of the supernova. However, because the speed of the burning flame is subsonic, the star has time to expand under the effect of the energy released by nuclear fusion. This expansion reduces the density of the unburned matter such that it burns no longer to NSE but rather to lighter elements such as silicon and sulfur. This is a wanted effect since the spectra of SNe Ia show lots of these elements. On the other hand, it is not clear yet if such a deflagration alone is sufficient to produce the large amount of ^{56}Ni required to explain all the observed SN Ia light curves and, in particular, the brightest ones. For most of the models the predicted amount of ^{56}Ni is somewhat on the low side.

While sophisticated 3D codes are being developed at MPA to follow the explosion and check how efficient it can be, other possible paths have been suggested, e.g. that the explosion makes a sudden transition from a subsonic deflagration to a supersonic detonation. this being the case, the star would burn more rapidly to ^{56}Ni and to intermediate-mass elements, depending again on the density. While a physical reason for such a transition in a white dwarf is not known (in contrast to chemical explosions where a transition can happen because of flame-wall interactions or the complex nature of chemical reactions) it is nevertheless interesting to ask the question of whether the available SN data can help us to add evidence to one of the competing models. For instance, deflagrations are supposed to lead to a fair amount of mixing of abundances in the ejected material, while detonations are thought to lead to sharper changes in abundance between zones where different burning products are present.

Observationally, a SN Ia evolves rapidly, becoming brighter initially until a peak luminosity is reached and then declining. The spectrum of the SN also changes: As time goes on deeper and deeper layers of the exploding star become visible thanks to the expansion. The spectra therefore change for two main reasons: The change in luminosity leads to a change in temperature, and the abundances change with depth in the ejecta. Thus, if we have available a closely time-spaced series of spectra describing the SN evolution from an early date, supplemented by photometry to describe the light curve, we can apply theoretical modelling to reproduce the time series of spectra and derive the distribution of abundances with depth. In a supernova, depth is equivalent to velocity: The outer ejecta expand more rapidly. Therefore, spectral features evolve to the red over time, since they are

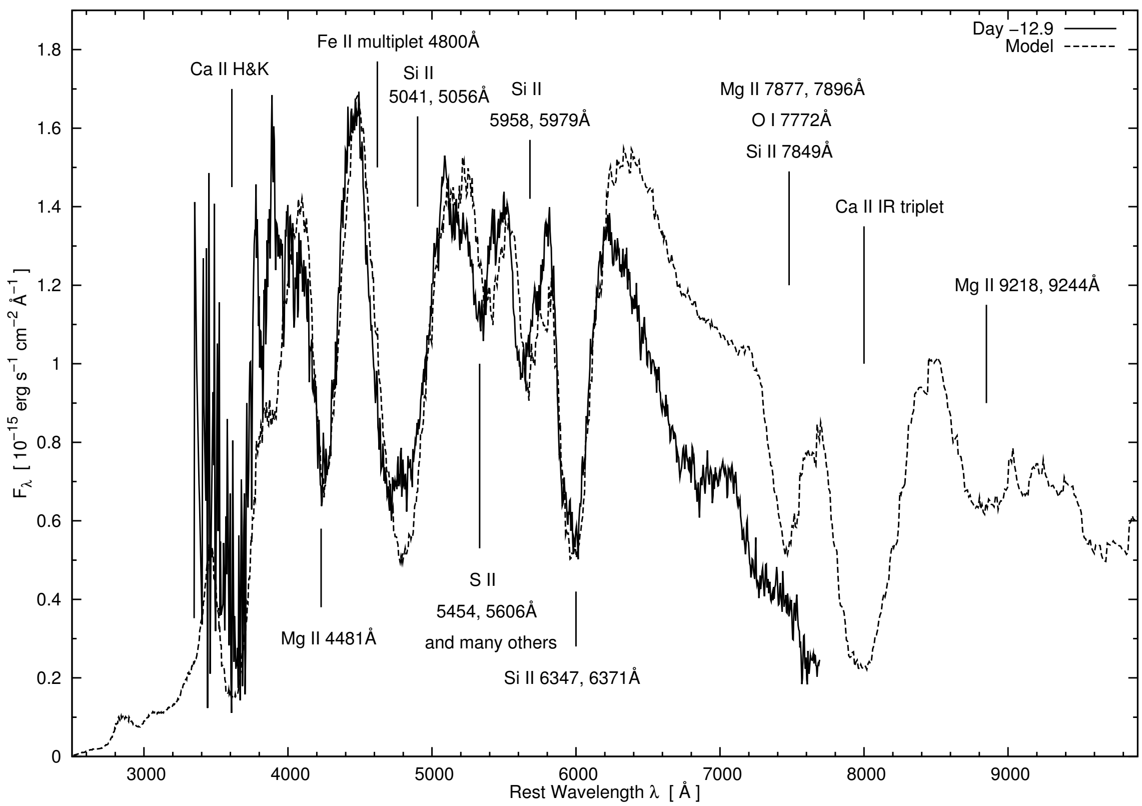

Figure 2.4: Observed Spectrum of SN 2002bo and synthetic fit.

formed in material that is moving towards us and lower velocity means less blue-shift.

To obtain SN data as described above is one of the aims of the European Supernova Collaboration, a consortium of European researchers which has launched an EU Research Training Network (RTN) on SNe Ia. The team is led by Wolfgang Hillebrandt and includes groups in France, Italy, Spain, Sweden and the United Kingdom. Thanks to its access to a large number of telescopes, the RTN has now collected data of unprecendented quality for almost a dozen SNe Ia. The team in Garching has been responsible for the modelling work. As part of his PhD thesis Matthias Stehle, supervised by Paolo Mazzali (also at INAF-Triest) has developed a technique to model a time-series of spectra of SNe Ia. This is based on a Monte-Carlo spectral synthesis code developed over the years by Leon Lucy of Imperial College, London, and Paolo Mazzali. This approach has been nicknamed 'Abundance Tomography', and it amounts to modelling the spectra evolution sequentially, preserving the information derived about the outer layers from the earlier spectra and using it in the calculation of the later spectra, which explore deeper parts of the ejecta. In practice this approach allows only a small region of the ejecta to be treated as a free parameter as far as the abundances are concerned, and thus to achieve a great degree of constraining of the abundance distribution.

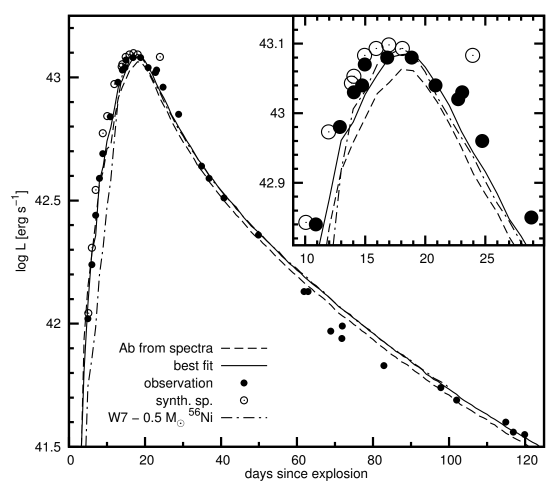

Figure 2.5: Observed lightcurve of SN 2002bo and synthetic fits.

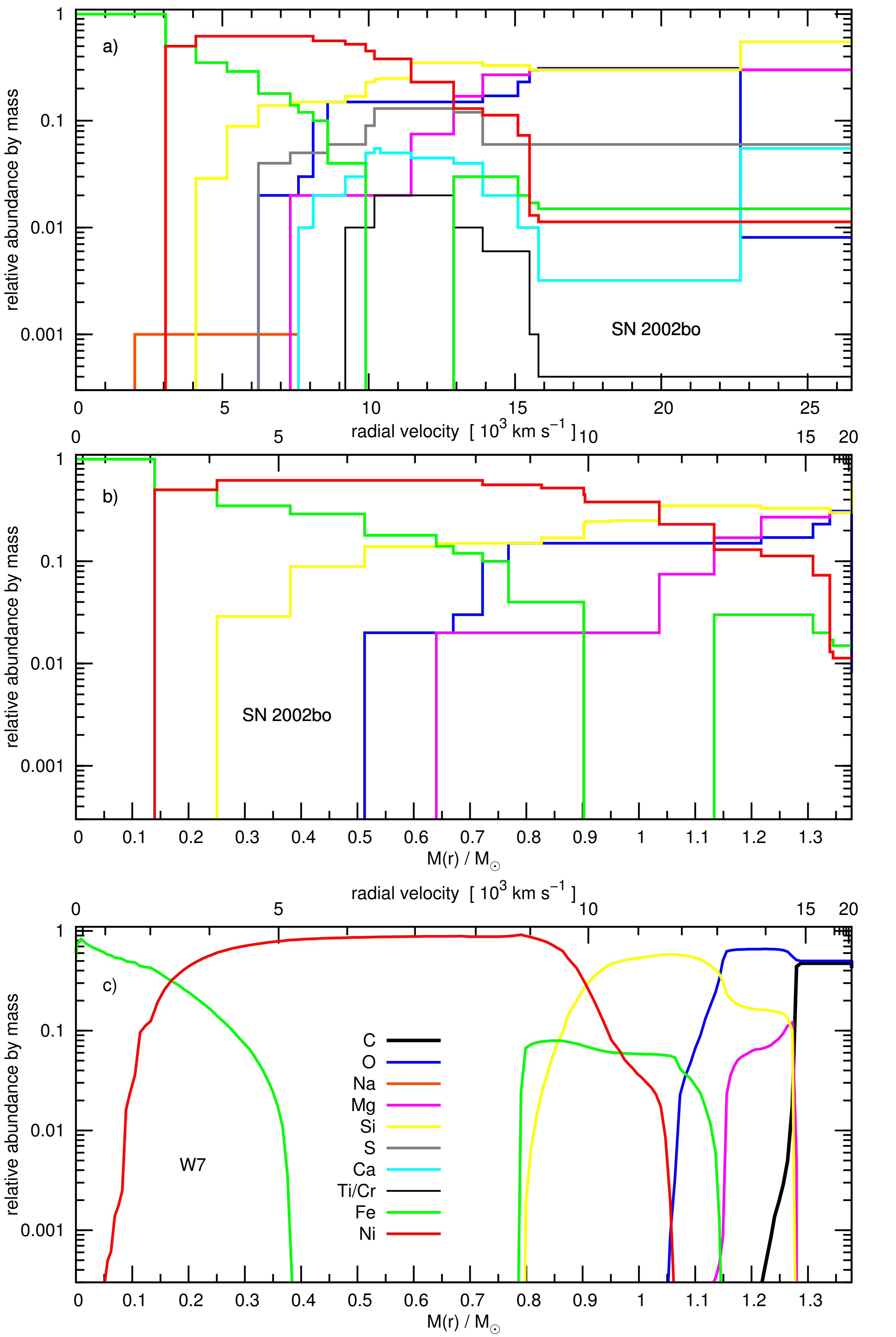

Figure 2.6: Reconstructed elemental abundance in 'velocity space' (upper panel) and versus mass (middle panel) in comparison with the results from spherically symetric (1D) pure deflagration model.

This technique, which is simple conceptually but rather laborious, has been applied to the first RTN SN, 2002bo. Some 12 spectra of the SN were available, covering from $\sim$ 10 days before maximum to $\sim$ 15 days after. The spectra cover ejecta velocities from $\sim$ 15000 down to $\sim$ 8000 km/s. Figure 2.4 shows a representative fit to one of the spectra. Modelling the spectra shows that the outer part of the ejecta is dominated by intermediate mass elements (Si, S). Surprisingly, very little oxygen and almost no carbon are observed. This is at odds with the prediction of deflagration models, and seems to agree better with delayed detonations. Regions below $\sim 10,000$ km/s show a progressive decline of the intermediate mass elements and a rise of the Fe-group, indicating that complete burning occurred in a large part of the star. After about one month, densities in the ejecta become very low, and the SN spectrum starts to change into that of a nebula, being composed of forbidden emission lines. A different technique must be used to model this physical situation, but there is the advantage that now the inner parts of the ejecta are visible. Also, since the ejecta are no longer optically thick to radiation, the shape of the nebular emission line profiles can be used to determine the distribution of abundances at all velocities within the emitting nebula, down to the very centre. Combining these 'late time' results with the 'early time' results described above, the full distribution of abundances with radius can be determined and compared to theoretical models.

The results are shown in Figure 2.6. The inner part of the ejecta is composed almost entirely of NSE material. Among this, ^{56}Ni dominates. Further out, intermediate-mass elements are present, dominated by Silicon. The outer part contains oxygen, but almost no carbon, and it still has lots of intermediate-mass elements. SN 2002bo produced $\sim$ 0.5 solar masses of ^{56}Ni. This is rather average for a SN Ia. If we take the density structure of a standard explosion model, such as W7, and the abundance distribution determined from the tomography, we can compute a synthetic light curve. This is shown in Figure 2.5. The agreement with the observed light curve is exceptionally good, indicating the power of the method.

While we are working on developing explosion models that can be compared with the derived properties of SN 2002bo in detail, we are applying the abundance-tomography method to other SNe Ia from the RTN sample.
(Wolfgang Hillebrandt, Paolo Mazzali and Matthias Stehle).

2.3 Magnetic Turbulence in Clusters of Galaxies

Magnetic turbulence in the central gas of a galaxy cluster was for the first time successfully detected and its strength and power spectrum measured. Strengths and lengths of the magnetic eddies support novel theories about the highly complex life within the centers of clusters of galaxies, where gas and a massive Black Hole cyclically exchange matter and energy.

The hot (10 million degrees) gas in the centres of galaxy clusters emits its heat as X-ray radiation allowing the mapping of this gas with X-ray telescopes (Fig. 2.7). As soon as the gas has cooled down it falls into the central galaxy of the galaxy cluster due to gravity. In its centre a massive Black Hole of a few billion solar masses exists which injests most of the infalling gas, thereby getting more massive. At the same time, enormous amounts of energy are released at the Black Hole by this process and enormous amounts of ultra-hot, radio-emitting gas are ejected. The ejected gas forms bubbles in the galaxy cluster (Fig. 2.7 and 2.8) which rise quickly within the surrounding cluster gas due to their small density. The surrounding cluster gas rapidly moves downwards passing the bubbles. The opposing gas movements lead to turbulence in small eddies eventually providing heat for the cooling gas in the galaxy cluster. This heating-up prevents all of the gas from catastrophically collapsing rapidly into the central galaxy. But the gas collapse is delayed only for a cosmic moment and then the turbulence decays, the heating power decreases and the cooling of the gas by radiation of X-rays dominates again. Another heart beat starts in the galaxy cluster: gas clouds again fall into the Black Hole and a new cycle begins...

So much to the novel theory about the complex life within the hearts of clusters of galaxies. What about the confirmation of this theory by observation? The cooling gas can be observed by X-ray satellites, the radio emission from the bubbles provides impressive pictures for terrestrial radio telescopes (Fig. 2.7) and the gigantic Black Holes can be inferred from other observations. But is there really turbulence in the cooling gas which eventually heats it up again? Direct evidence was missing until now.

An indirect proof was provided through the detection of magnetic turbulence in the gas of the Hydra cluster of galaxies by Corina Vogt and Torsten Enßlin. The movements of the gas in galaxy clus-

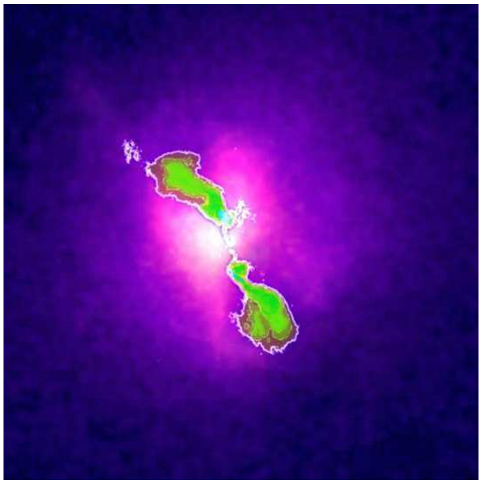

Figure 2.7: The centre of the Hydra cluster of galaxies. Two radio-emitting gas bubbles ejected by the central Black Hole represented in green are ploughing through the hot gas represented in purple. Credits: X-ray: NASA/CXC/SAO; Radio: Greg Taylor (NRAO).

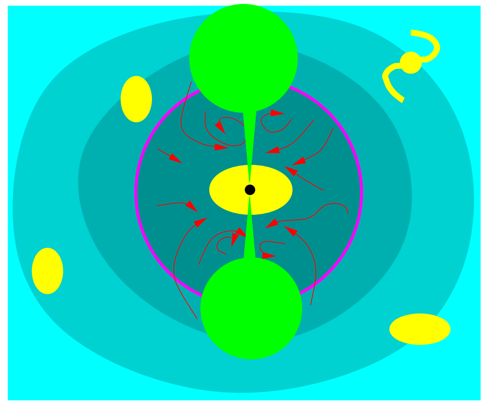

Figure 2.8: The new theory about the flow of matter and energy in the hearts of galaxy clusters. Within the dense inner regions of the galaxy cluster (purple), the gas is cooling and falls through the central galaxy (yellow) into its central massive black hole (black). The black hole reacts to the infalling cooled gas by ejection of ultra-hot, radio-emitting jets of gas which inflate two radio bubbles (green). The bubbles rise and stirr turbulent motions in the gas of the galaxy cluster (red arrows). The gas motion heats up the cooled gas and delays the gas from falling into the black hole. At the same time, the gas eddies impart turbulence into the magnetic fields which can be observed by Faraday rotation.

ters should stretch, wrap up and amplify the magnetic fields interwoven within the gas. The theory predicts that the magnetic eddies are somewhat weaker and smaller compared to the gas eddies. Therefore, a measurement of the magnetic eddies provides information about the turbulence in the gas.

The measurement of the magnetic turbulence was realised by a statistical analysis of a so-called Faraday rotation map. Faraday rotation is the rotation of the polarisation direction of the radio emission when passing through magnetised gas. The strength of the rotation is dependent on the strength of the magnetic fields along the path of the radio radiation. This Faraday rotation can be measured by multi-frequency observations with radio telescopes. These maps yield a two dimensional image of the three dimensional magnetic fields between the source of the radio emission and the Earth (Fig. 2.9). Observations of the radio bubbles in the Hydra cluster of galaxies therefore allow the mapping of the magnetic fields residing within the cluster (Fig. 2.10). This map already gives an impression of the chaotic magnetic field structure. But are the magnetic fields as turbulent as expected by the theory of gas motion?

A detailed, statistical analysis of the Faraday rotation map shows that the typical length scales and the typical magnetic field strengths match the expected but unobserved gas turbulence (Fig. 2.10). The strongest magnetic eddies reach about 10,000 light years and are, as expected, smaller than the radio bubbles which are about 30,000 to 100,000 light years in size. The strength of the magnetic eddies are also, as expected, one hundred thousandth of the Earth's magnetic field (the latter being about one Gauss). Furthermore, the statistics of the small magnetic field eddies follow a Kolmogorov-spectrum which is universally valid for gas turbulence. The statistics indicate to which degree the strength of the turbulent eddies lessens with decreasing scales of the eddies (Fig. 2.11). Practically, the Kolmogorov-spectrum is the fingerprint of turbulent gas motions. The discovery of the Kolmogorov-spectrum as revealed by the statistics of magnetic eddies means that the turbulence suspected in the gas of the Hydra cluster of galaxies is actually present there and thus, provides the surrounding gas with heat even as heat escapes from the gas by X-ray emission cooling. - A first confirmation of the new theory about flows of energy and matter in the hearts of galaxy clusters. (Torsten Ensslin and Corina Vogt).

2.4 The 3-dimensional structure of a sunspot

What would a sunspot look like if one could see below the surface of the Sun? The answer turns

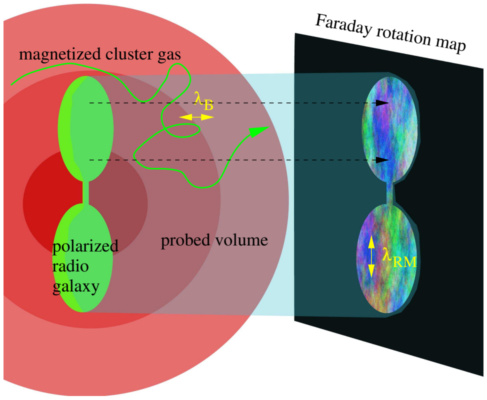

Figure 2.9: The polarised radio radiation of the gas bubbles (green ellipses) is rotated by the magnetic fields (green line) in the gas of the galaxy cluster (red) by the Faraday effect. This rotation is observable by multi-frequency measurements with radio telescopes and allows the construction of maps of the Faraday rotation. These maps show the projection of the existing magnetic fields located in front of the radio bubbles (shaded blue-grey). An analyis of these maps allows one to draw conclusions about the structure of the magnetic fields.

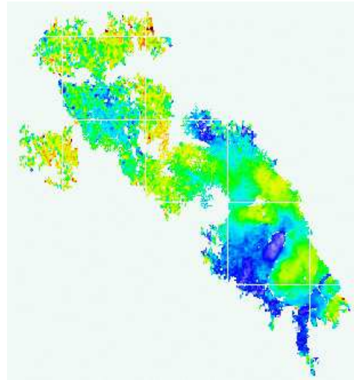

Figure 2.10: Faraday rotation map of the northern radio bubble in the Hydra cluster of galaxies. Blue regions indicate magnetic fields oriented towards Earth while red regions indicate magnetic fields pointing away from Earth. The distribution of scales in the Faraday structures gives information about the typical lengths of the magnetic field eddies in the galaxy cluster.

out to be rather clear if one looks carefully enough at the surface itself, but the result is not quite what one might have expected.

A sunspot is a magnetic patch, with a field strength of 1000-3000G (similar to the magnets used in industry and household). The field lines are roughly perpendicular to the surface of the Sun. Since magnetic field lines have no ends, both the atmosphere above and the layers below the surface of the spot must also be magnetic: it is a 3-dimensional structure (Fig. 2.12). While the field in the atmosphere can be studied in detail, the configuration below the surface cannot be observed directly, and must be inferred by combining observations at the surface with theoretical modeling.

A sunspot shows a lot of light and dark fine structure, both in the umbra (the central dark area) and the surrounding penumbra (Fig. 2.14). This fine structure has not been reliably resolved with previous telescopes, but with the dramatically improved observations from the new Swedish 1-meter Solar Telescope (SST) on La Palma it is now possible to identify its cause. It turns out that what at the surface looks like a compact magnetic patch is actually a loose cluster of magnetic strands underneath, similar to the frayed end of a piece of rope (Fig. 2.14). Close to the observed surface these strands merge into a space-filling magnetic field (Fig. 2.15). With this structure as a framework, a whole range of old and new puzzling observations neatly fall into place.

One of the oldest of these puzzles is the brightness of sunspots. The strong magnetic field of a spot is known to suppress the transport of heat from deeper layers to the surface, causing the spot to look dark. In fact, this suppression is so effective that the observed radiation from even the darkest parts of spots is actually hard to explain. Since the solar plasma below the surface is quite opaque, the observed heat flux must be carried by bulk flows. Outside spots, these are observed in the form of *granulation*, but inside spots the observed velocities are too small to account for observed radiation.

In the tenuous visible layers of the Sun the magnetic field lines of a sunspot fill up all available space, but below the surface they can be kept apart by the gas pressure. The calculations now show that below the surface the magnetic field is in all likelihood organized differently from above: below the surface, it consists of narrow gaps, free of magnetic field, between bundles of strong field, and the bright filaments are just a reflection of the field free gaps below. This structure would become clear if one could look only a bit deeper into the Sun (Fig. 2.14, lower panel). Through the gaps (Fig. 2.15) heat reaches the surface much more easily than through the magnetic field itself. It is supplied from below by ordinary overturning convection, unimpeded by a magnetic field.

The predicted structure of the magnetic field lines near such a gap (Fig. 2.15) agrees nicely with the pattern of field strengths and inclinations observed with the SST. In particular, it explains

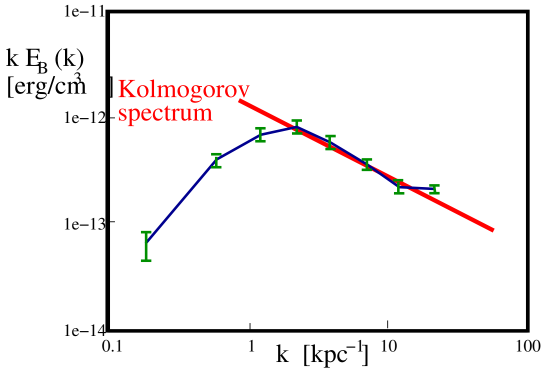

Figure 2.11: Power spectrum of the magnetic fields in the Hydra cluster of galaxies (green data points) from the analysis of the map shown in Fig. 2.10. A power spectrum shows how strong magnetic eddies of a certain length are. The large spatial eddies are at left and the small spatial eddies are at right in the graph. Especially strong are the eddies which are about 10,000 light years (3 kpc) large. This fits well to their production by the radio bubbles which are 3–10 times larger. On smaller scales, the magnetic field follows a Kolmogorov-spectrum (red line) which is typical for turbulence. This is the first direct detection of magnetic turbulence in clusters of galaxies.

why the incilnations change over only a very short length scale above the surface. Apart from the brightness of spots, the model also explains the close connection between penumbral filaments and bright 'dots' in the umbra, as well as the so-called 'dark cores' overlying the bright penumbral filaments, and the mysterious 'stray light' component needed to account for the magnetic line profiles of filaments. It makes predictions about the polarization of light from sunspots that can be tested in the near future. (Henk Spruit, Göran Scharmer)

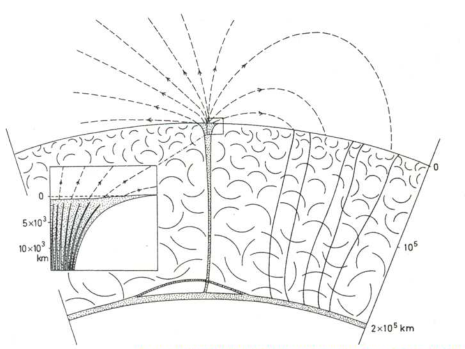

Figure 2.12: Vertical section through a sunspot and the convective envelope (swirls) of the Sun. What is just a dark patch at the surface is part of a magnetic structure that continues above the surface of the Sun (dashed lines) and into the interior.

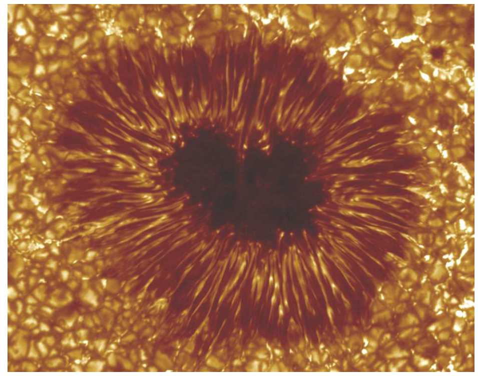

Figure 2.13: Image of a sunspot made with the Swedish 1-m Solar Telescope. This telescope has produced time sequences with a resolution close to its diffraction limit (0.12 arc sec); for examples see http://www.solarphysics.kva.se/gallery

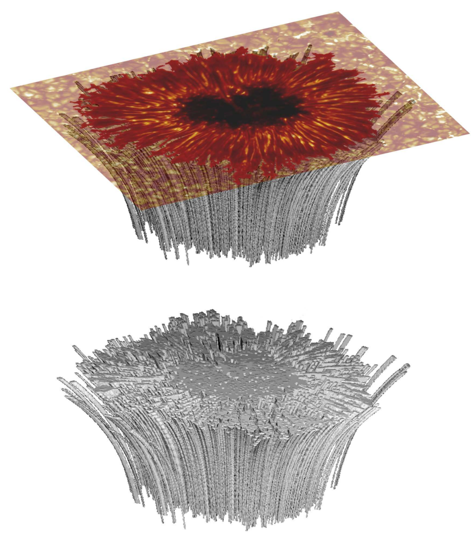

Figure 2.14: Top: Image of Fig.2.13 combined with a sketch of the inferred 3-dimensional structure underneath the spot (schematic). The structure consists of a cluster of magnetic strands which continue down into the interior of the Sun (see sketch in Fig. 2.12). Only the uppermost part of this cluster is shown here and the continuation of the magnetic field lines above the surface is also left out. When the surface layers are stripped away (bottom panel), gaps in this cluster become visible. They are mostly present in the penumbra (the filamentary outer part of the spot) but gaps remain even in the dark umbra. [Schematic, in reality the gaps are much narrower and more numerous.]

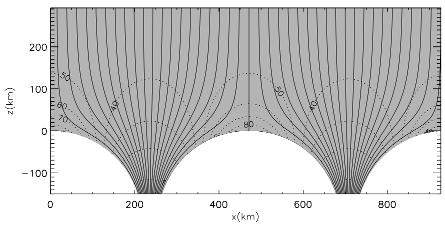

Figure 2.15: Vertical cross-section through the penumbra of a spot. The model (potential field model) shows the shape of the field lines between field-free gaps just below the visible surface of the spot (white), merging into a uniform field above the surface. In addition there is a component of the magnetic field perpendicular to the plane of the drawing (shaded). Strong variations in field strength and direction are present, but only over a few hundred km above the surface, in agreement with observations

2.5 Acoustic oscillations in the large scale matter distribution

During the last decade, observational cosmology has witnessed extremely rapid development. Currently several key parameters describing our universe, such as the global densities of various matter/energy components, Hubble parameter, etc. have been measured to an accuracy better than 10%. This rapid progress is largely driven by precision measurements of the angular temperature fluctuations of the Cosmic Microwave Background (CMB). Since the density inhomogeneities at the time when the universe recombined and the CMB was emitted (at redshift $z \sim 1100$) were only one part in $100,000$ the Einstein-Boltzmann equations describing the evolution of these fluctuations can be linearized to a very good approximation, which makes the solution of this complicated equation set possible. In general, the success of the current theoretical models in explaining many of the observed features of the CMB to a high precision can be seen as a guarantee that these models are on the right track. We have learned several important things about the primordial seed fluctuations, presumably generated during the early accelerating expansion phase of the universe (the so-called inflationary phase), in analyzing these small fluctuations imprinted onto the CMB sky. First, the CMB data demands the dominant fluctuation mode to be adiabatic, i.e. the initial number-density fluctuations $\delta n_i/n_i$ for all components of the cosmic fluid follow each other. Second, the initial fluctuations are compatible with being Gaussian with a roughly scale-free power spectrum. These observations are in full agreement with the predictions of the simplest inflationary universe models. As the seed fluctuations are of Gaussian nature they are fully described by the two-point function (since we are defining the fluctuations around the mean CMB temperature, the mean fluctuation itself is zero), which in harmonic space is known as the power spectrum. Roughly speaking, the power spectrum shows how the fluctuation power is distributed amongst the perturbations having different wavelengths. The angular spectrum of the CMB temperature fluctuations as measured by the WMAP team together with a best fitting ΛCDM model with approximately scale-invariant adiabatic initial conditions is shown in the upper panel of Fig. 2.17. Here the most characteristic features are the so-called acoustic peaks with the most prominent first peak corresponding to an angular scale of $\sim 0.6^\circ$. Thus the temperature fluctuations of the CMB sky have the strongest contrast (after removing the dipolar temperature anisotropy caused by the motion of the Local Group) for the patches with a typical size of $\sim 0.6^\circ$. This typical scale is directly related to the distance the sound waves in the tightly coupled baryon-photon fluid in the pre-recombination universe can have traveled since the Big Bang. According to the currently most favorable model for the large-scale structure formation– the gravitational instability theory– these tiny high-redshift fluctuations, as probed by the CMB, serve as seeds for the highly evolved cosmic structure surrounding us. The important consequence of the linear gravitational instability theory is that all the features present in the initial matter fluctuation spectrum should survive throughout cosmic evolution. The "concordance" cosmological model due to its relatively low baryonic matter fraction (only $\sim 15\%$ of the matter is in the form of the baryons, the rest being contributed by the cold dark matter (CDM)) predicts that the low redshift matter power spectrum should contain small ($\sim 5\%$) fluctuations due to the acoustic phenomena. And this is indeed the case, as has now been confirmed by analysis of the spatial clustering of the Sloan Digital Sky Survey (SDSS) Luminous Red Galaxy (LRG) sample by D.Eisenstein (University of Arizona) and collaborators (who determined the two-point correlation function) and more recently by G.Hütsi (who determined both the power spectrum and two-point correlation function). S.Cole (University of Durham) and collaborators have similarly detected acoustic oscillations in the power spectrum of the 2dF galaxy sample. The SDSS LRG power spectrum as measured by G.Hütsi is shown on the lower panel of Fig. 2.17. In order to ease the comparison with the upper panel we have converted the comoving wavenumbers to the corresponding multipole numbers, as explained in the figure caption. Here the lower dashed line corresponds to the linearly evolved matter power spectrum for the same ΛCDM model whose CMB power was shown on the upper panel. The upper dashed curve shows the model spectrum after the corrections for the nonlinear effects and redshift space distortions are taken into account. The solid green line represents the cubic spline fitted to the data points and the vertical dotted lines give the locations of the CMB acoustic peaks. An important point to note here is the fact that the CMB spectrum has an oscillation frequency approximately two times higher than the corresponding frequency in the matter power spectrum. The reason for this will be explained below.

Usually the cosmological perturbation equations are solved in harmonic space, i.e. all the quantities are expressed as superpositions of plane waves (or their generalizations if the spatial sections of the space-time are not flat). This representation is very convenient for numerical studies, since due to the motion invariance of the evolution equations the time dependence factorizes out and thus we are basically left with a standing wave decomposition whose amplitudes can just be appropriately adjusted as the time goes by. Although numerically convenient this representation is not very intuitive. A more enlightening picture arises if the analysis is carried out in real space instead. In Fig. 2.16 we show a pedagogical example by D.Eisenstein, that itself is based on an original work by S.Bashinsky (ICTP,Trieste) and E.Bertschinger (MIT) The figure displays an evolution sequence of the initial adiabatic spherical density perturbation. Here the $x-$axis displays the comoving radius r and the $y-$axis presents the mass profiles of the several perturbation components (as listed in the legend), i.e. the fractional overdensities $\delta\rho_i/\rho_i$ times r^2, in arbitrary units. For clarity the extra factors of 4/3 have been omitted for the relativistic components. Initially all the components are confined inside the perturbation. Since the initial overdensity in the tightly coupled baryon-photonfluid also corresponds to the initial overpressure, an outward-moving spherical sound wave will be launched. As the neutrinos are not coupled to the rest of the matter at these relatively low redshifts, they start to diffuse out of the sound wave. CDM distribution is also significantly "smoothed" due to the gravitational pull of the outward-traveling baryon-photon perturbation. (This "smoothing" gives the final CDM spectrum with its characteristic turnover.) At redshifts around $z \sim 1050$ the tight coupling between the baryons and photons breaks down as the universe starts to recombine and thus the photons can begin to diffuse out of the sound wave. As the baryons are released from the photon pressure the sound speed drops radically and the sound wave practically stalls. In fact the slow motion of the baryonic shell continues down to $z \sim 200$ (the so-called drag epoch). After that redshift the baryons decouple from the photons completely and can start to fall back onto the central CDM density peak that has grown significantly since the matter-radiation equality. Because in the "concordance" cosmological model the baryonic density is not completely negligible it has also some gravitational effect on the CDM component. Thus the final density profile will have a small density enhancement at the distance corresponding to the size of the sound horizon at the end of the drag epoch. A more general initial density field can always be expressed as a superposition of δ-spikes. As we are dealing with linear perturbation theory the evolved field can be expressed as the sum of the separately evolved $\delta-$functions, i.e. the ordinary Green's function method. Thus in the more general case one would also expect an enhancement in the two-point correlation function at the separation corresponding to the sound horizon. This relatively narrow peak in the correlation function leads to the oscillating behavior of the power spectrum shown in Fig. 2.17. The CMB sky in this picture corresponds to the superposition of the "photon shells" (whose thickness is determined by the efficiency of the diffusive processes) that are cut by the last scattering surface which itself is a shell with a thickness of $\sim 30\,h^{-1}$ Mpc. Since in the case of the "photon shells" no perturbation is left in the center the corresponding correlation length is approximately twice as large as the one for the matter component and thus the CMB angular spectrum also fluctuates twice as frequently. To be more precise the acoustic horizon as measured from the CMB sky is slightly smaller than the one imprinted in the matter distribution, since as mentioned above, the sound wave does not stall completely at recombination.

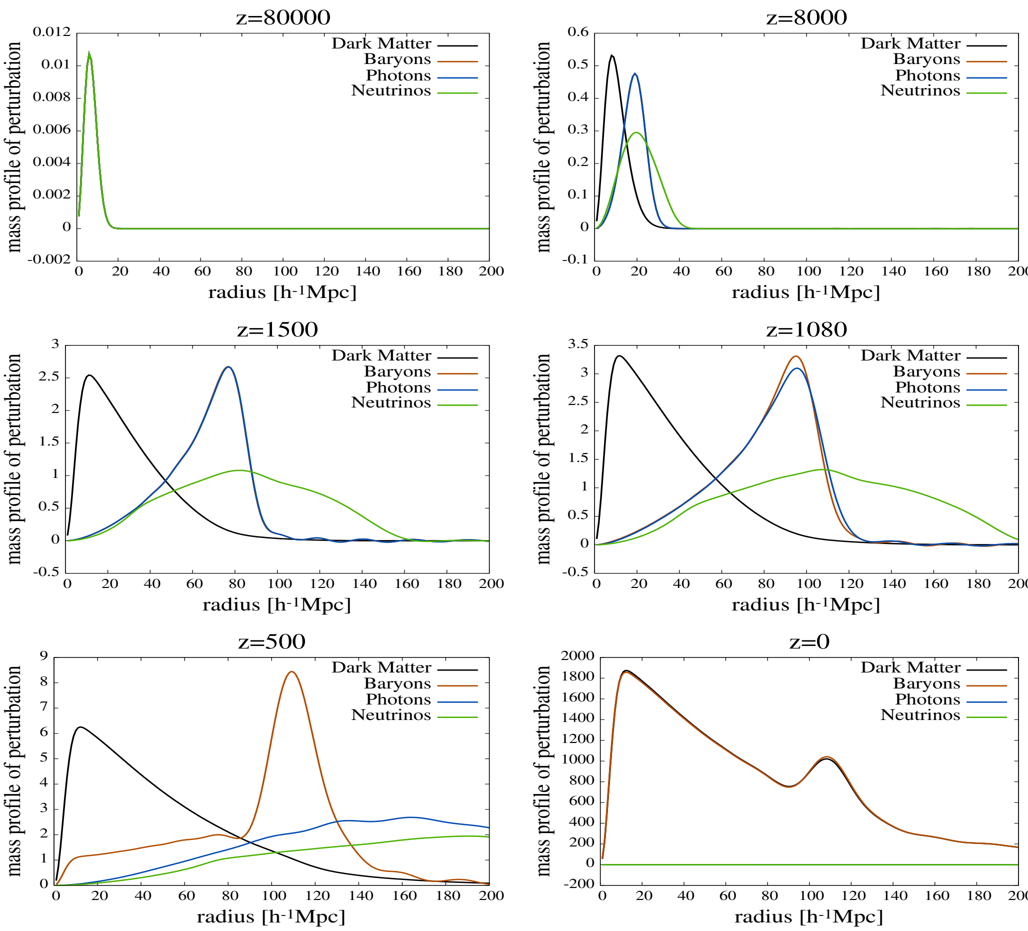

Figure 2.16: The evolution sequence of the initial adiabatic density peak. The x-axis shows the comoving distance in h^{-1} Mpc, while the y-axis displays the mass profile of the perturbation in arbitrary units. Black, orange, blue and green lines correspond to the CDM, baryons, photons and neutrinos, respectively. The redshifts corresponding to each of the "snapshots" are given above each panel. The linearized Einstein-Boltzmann equation set was solved using publicly available CAMB software. (Example originally due to D.Eisenstein)

The acoustic scale measured from the SDSS LRG power spectrum shown in Fig. 2.17 was found to be $(105.4 \pm 2.3)\, h^{-1}$ Mpc. This value assumes that the background model used to calculate distances is the WMAP best-fit "concordance" model. For different background models this value can easily be "rescaled". It is worth pointing out that WMAP data together with a prior on the Hubble parameter from the HST Key Project would predict the corresponding scale to be $(107 \pm 20)\, h^{-1}$ Mpc. Thus the measurement given above provides a factor of ~ 10 improvement in accuracy. Also it turns out that the models with baryonic features are favored by 3.3σ over their "smoothed-out" counterparts without any oscillatory behavior, i.e. the acoustic features are detected at a relatively high confidence level. All of this demonstrates the great promise of the future dedicated extremely large galaxy redshift surveys like K.A.O.S./WFMOS[1]

The full consequences of the acoustic scale measurement as quoted above for the cosmological parameters have not yet been fully worked out. As the acoustic scale equips us with a very good "standard ruler", one certainly hopes to get a tight constraint on the Hubble parameter and maybe also to obtain interesting constraints on the dark energy equation of state parameter w. (Gert Hütsi)

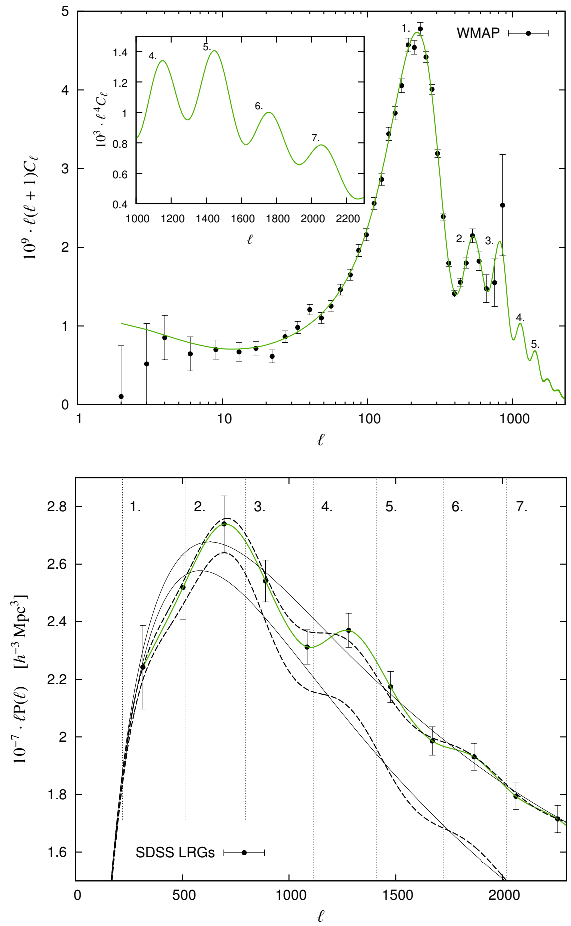

Figure 2.17: Upper panel: The CMB angular power spectrum as measured by the WMAP team together with the best-fitting ΛCDM model curve. The inset shows the zoom into the damping tail. Due to very strong decline of the CMB angular spectrum at large multipoles the $y-$axis is multiplied with an extra factor of ℓ^2 in comparison to the main figure. Lower panel: The power spectrum of the SDSS LRGs plotted in a way allowing for a direct comparison with the corresponding CMB spectrum provided in the upper panel. The comoving wavenumber k was transformed to the multipole number ℓ such that $\ell \simeq 9940 \cdot k[h\,\mathrm{Mpc}^{-1}]$, where $9940\, h^{-1}$ Mpc is the comoving angular diameter distance to the last scattering surface for the best-fit WMAP "concordance" model. The solid green line is the cubic spline fitted to the observational data. The lower dashed curve is the linearly evolved matter spectrum corresponding to the best fitting model from the panel above, while the upper dashed line shows the spectrum after incorporating the treatment for the redshift space distortions and nonlinear evolution. The thin solid lines represent the "smoothed" models without baryonic oscillations. All the model spectra here are convolved with a survey window function. The vertical dotted lines mark the positions of the acoustic peaks in the CMB power spectrum.

2.6 Hysteresis in spectral state transitions of accreting black holes

We describe a further step in understanding the flow of matter towards objects of very high concentration of mass. These compact objects are known as "black holes", with gravitation so dominant that all matter and radiation fall into it if close enough. The accreting black holes (black holes of stellar mass or supermassive black holes in the centers of galaxies) are of great interest for researchers. Due to the angular momentum of the infalling gas the matter does not fall directly towards the compact object but spirals inward forming a flat accretion disk around the black hole. This is always the case far away from the center. Close to the compact object two different modes of accretion are possible: either in form of a thin accretion disk or as a more spherical hot flow, which due to the nature of the very hot gas cannot radiate away the energy released when gas settles in the gravitational potential. Rather the energy is advected

[1] http://www.noao.edu/KAOS

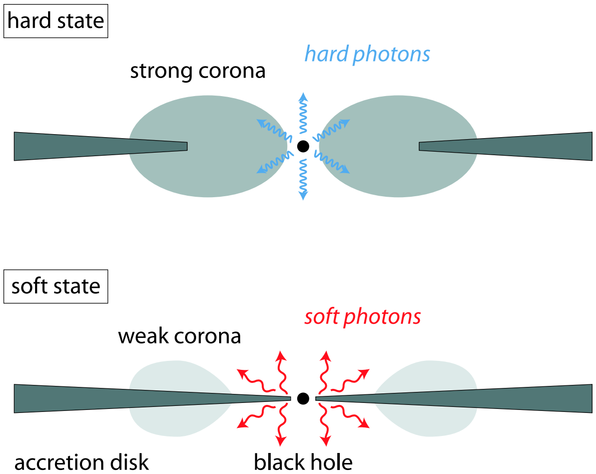

Figure 2.18: Schematic view of the accretion geometry in the hard state (truncated disk and advection-dominated flow in the inner region, strong corona) and the soft spectral state (disk reaches inward to the black hole, only weak corona).

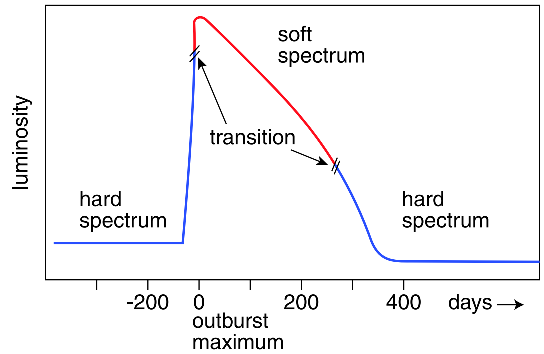

Figure 2.19: Schematic standard lightcurve of an X-ray nova outburst, changes between hard and soft spectrum

towards the center (advection-dominated accretion flow, ADAF). We here discuss the accretion flows that are observed from low-mass X-ray binaries, close binary stars where one of them is a black hole or a neutron star. The spectrum of the observed X-ray light is different for the two accretion modes: (1) a very hard spectrum (up to 100 keV) originates from the very energetic particles of the hot flow or (2) a soft spectrum (a few keV) is radiated from the thin accretion disk which is much cooler. The radiation from the region close to the black hole dominates the spectrum. The mode of accretion in the inner region therefore determines the spectrum.

A schematic description of the accretion flow geometry is shown in Figure 2.18. The situation is the same for accretion onto supermassive black holes, only distances are much larger and timescales are much longer. Interesting now is the fact that the spectra change between the two types as documented by long-time observations.

During the long lasting ”quiescent” phases of X-ray binaries the spectrum is hard. This means that at a certain distance from the black hole the disk accretion turns into the hot ”coronal” flow (the word ”corona” is used in analogy with the solar corona, where we recognize the hot flow as a ”crown” around the sun during a solar eclipse). Taking into account the physics of the interaction between disk and corona we can determine which amount of gas evaporates from the thin cool disk to the coronal hot flow. From these rates (which are a function of the distance from the black hole) one can further determine whether all matter from the outer regions is transferred to the hot flow. This depends on the mass flow rate in the cool disk. The lower this mass flow rate is the farther out the cool disk is truncated. During an outburst the mass flow rate in the disk rises. If it becomes higher than the maximal evaporation rate, present at a certain distance from the black hole, the disk can not be completely evaporated anymore and instead continues all the way to the central black hole. The radiation that determines the spectrum now originates from the surface of the inner disk and the spectrum becomes soft. Therefore, with increasing and decreasing mass flows as they occur during X-ray novae outburst cycles the accretion mode changes, and simultaneously the spectrum changes from hard to soft and back to hard again. In Figure 2.19 we show the typical changes during a standard outburst.

A surprising feature is found in the observations of such spectral transitions: the changes hard-soft and soft-hard do not occur at the same luminosity, which means the same mass accretion rate. Instead the second transition occurs at a luminosity lower by a factor of about 3 to 5 (as indicated in Figure 2.19). This hysteresis is unexpected since the transition in both cases should correspond to the maximal evaporation rate. To understand this surprising phenomenon is a challenge for modeling the interaction of disk and corona.

Detailed analysis of the effect that the radiation from the innermost region has on the coronal structure shows that the irradiation has an essential influence on the evaporation process. During luminosity increase in the rise to an outburst the disk is truncated and the hot flow in the inner region which irradiates the corona has a hard spectrum.

On the other hand, during decline from the outburst the disk reaches inward to the black hole and the radiation is soft.

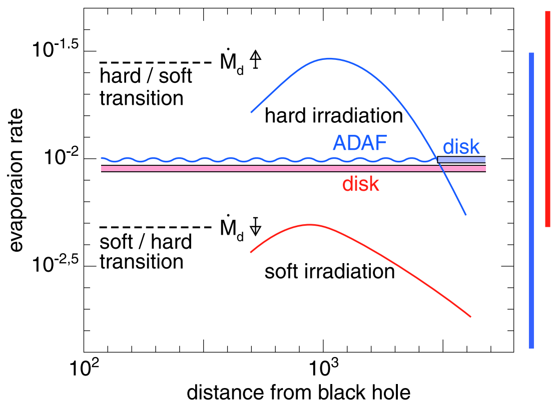

Figure 2.20: Evaporation rates with hard and soft irradiation as function of the distance from the black hole (units are the Eddington rate and the Schwarzschild radius, a scaling with the black hole mass). Soft irradiation yields lower evaporation rates than hard irradiation from the central region: The maximal rates (dashed lines) differ, therefore the disk becomes truncated for different mass accretion rates $\dot{M}_{\rm d}$. As an example the situation is shown for the accretion rate of 0.01. With hard irradiation the disk is truncated at the distance $10^{3.5}$ from the black hole, where the evaporations balances the mass inflow. With soft irradiation, lower evaporation rate, the disk extends inward to the black hole. The vertical lines at the right side indicate for which range of accretion rates the spectrum can be hard only (blue line only), hard or soft (both lines) or soft only (red line only).

In Figure 2.20 we show the results of our computations, the mass evaporation rates for hard and soft irradiation. For the two accretion modes the irradiation yields different Compton cooling and heating of the coronal gas. In the figure we also point out the geometry for a mass accretion rate of 0.01 $(\dot{M}_{\rm d})_{\rm Eddington}$: with hard irradiation the evaporation rate is higher than the mass flow rate and the disk is truncated at a distance of 3000 Schwarzschild radii; with soft irradiation the evaporation rate is much lower and the disk reaches inward. The hysteresis in spectral state transition follows from the difference in luminosity that corresponds to the accretion rates equal to the maximal evaporation rates. The spectral mode is indicated. We find that generally the hysteresis increases with the hardness of the spectrum in the hard state. These results contribute to the growing insight into the physical processes underlying accretion flows onto black holes on all scales. (Friedrich Meyer, Emmi Meyer-Hofmeister and Bifang Liu)

2.7 Origin of the Galactic Ridge X-ray Emission

There are two major large-scale features in the X-ray (at energies above 2 keV) sky: the almost uniform cosmic X-ray background (CXB) and an apparently diffuse emission concentrated towards the Galactic plane – the Galactic ridge X-ray emission (GRXE). While the CXB is now known to consist of millions of point-like extragalactic sources (active galactic nuclei), the origin of the GRXE remained a puzzle so far.

According to previous observations by different X-ray observatories the GRXE peaks in the inner Galactic disk extending tens of degrees in longitude and a few degrees in latitude, and likely has a central bulge-like concentration. The presence in the energy spectrum of the GRXE of a number of emission lines of highly ionized atoms of heavy elements indicates its origin in a hot thermal plasma with temperatures reaching 5–10 keV. The total GRXE luminosity has been estimated at $\sim$1–2$\times 10^{38}$ erg s^{-1}. The GRXE is detectable at least up to 20–25 keV, and its spectrum above 3 keV consists of a power-law (photon index $\sim$ 2.1) continuum and strong emission lines at 6–7 keV.

Soon after its discovery some 30 years ago it was suggested that the GRXE might be composed of a large number of faint point X-ray sources such as quiescent low-mass and high-mass X-ray binaries, cataclysmic variables, coronally active binaries etc. However, it was not possible to critically test this hypothesis for lack of detailed information about the space densities and X-ray luminosity distributions of the classes of X-ray sources of interest. On the other hand, repeated attempts to directly resolve the GRXE into discrete sources have been unsuccessful despite the ever improving sensitivity of X-ray telescopes. Even in the recent deepest observations of some Galactic plane regions by the Chandra and XMM-Newton observatories reaching flux limits $\sim 3\times10^{-15}$ erg s^{-1} cm^{-2} only 10–15% of the GRXE was resolved, part of the resolved flux being actually due to extragalactic sources.

The small contribution of resolved Galactic sources to the GRXE was regarded by some as evidence that the GRXE is truly diffuse. However, the idea of a diffuse origin of the GRXE meets strong difficulties. The main problem is that the thermal spectrum of the GRXE implies that the emitting plasma is so hot ($\sim$5–10 keV) that it should be outflowing from the Galactic plane. An uncomfortably large energy supply is then required to persistently replenish the escaping plasma.

In an attempt to understand the GRXE origin we first studied in unprecedented detail its spatial distribution. Specifically, we constructed a high sensitivity map of the GRXE in the energy band 3–20 keV using archival observations with the PCA spectrometer of the RXTE observatory (see Fig. ??). The obtained map for the first time clearly reveals a disk-like and a bulge-like component of the GRXE which closely resemble the Galactic stellar disk and bulge/bar, respectively. Moreover, the inferred geometrical parameters of the GRXE disk and bulge components are fully compatible with those previously determined from near-infrared observations for the corresponding stellar components. This implies that the GRXE closely traces the stellar population of the Galaxy and suggests that the GRXE should be eventually resolvable into point X-ray sources associated with the stellar population.

The observed tight correlation between the GXRE and stellar emission allows one to estimate the X-ray emissivity (3–20 keV) per unit stellar mass in the Galaxy: $(3.5\pm0.5)\times10^{27}$ erg s$^{-1}M_\odot^{-1}$. If the GRXE is a superposition of faint X-ray sources, this value should represent their cumulative emissivity. The second part of our study was therefore aimed at evaluating the cumulative emissivity of faint X-ray sources directly from X-ray observations in order to compare it with the above prediction.

To construct the luminosity function of faint ($L_{\rm x} < 10^{34}$ erg s^{-1}) X-ray sources in the Solar neighborhood (within ∼1 kpc) we again used the RXTE/PCA all-sky survey (3–20 keV) and also the ROSAT all-sky survey (0.1–2.4 keV). Several classes of sources populate the luminosity range of interest. Cataclysmic variables (CVs), i.e. accreting white dwarfs in binaries, dominate at luminosities above $\sim 10^{31}$ erg s^{-1}, whereas at lower luminosities coronally active binaries (ABs, of RS CVn and other types) and single coronal stars prevail over CVs. The constructed luminosity function (see Fig. 2.21) covers a broad range from 10^{27} to 10^{34} erg s^{-1} and allows one to estimate the local cumulative 3–20 keV emissivity of CVs and ABs: $(5.3 \pm 1.5) \times 10^{27}$ erg s^{-1} $M_\odot^{-1}$. Given the excellent agreement of this locally determined value with the above prediction from the GRXE, we conclude that the bulk of the GRXE is likely a superposition of emission from thousands of CVs and millions of ABs. It is important to note that since both classes represent old stellar populations their luminosity function is not expected to vary significantly across the Galaxy. An additional non-negligible contribution to the GRXE may come from young coronal stars which produce locally $(1.0 \pm 0.2) \times 10^{27}$ erg s$^{-1}M_\odot^{-1}$ (but this estimate may not be representative of the Galaxy as a whole).

Having found a good agreement between the GRXE unit-stellar-mass emissivity and the local cumulative emissivity of faint X-ray sources, we can next check if also the observed spectrum of the GXRE is consistent with being a superposition of typical spectra of the contributing classes of sources. As shown in Fig. 2.22, CVs (polars, intermediate polars and dwarf novae) have much harder spectra than coronally active stars. A sum of the corresponding template spectra with weights determined by the relative contributions of these classes of sources to the local X-ray emissivity provides a good match to the GRXE spectrum in the energy band 3–20 keV, as expected.

It is also possible to predict the GRXE spectrum above 20 keV using the fact that stars are highly concentrated towards the Galactic Center. The infrared brightness of the Galaxy sharply rises within 10 arcmin of the Galactic Center reflecting the so-called nuclear stellar cluster. Since the GRXE closely traces near-infared surface brightness, one may anticipate a sharp rise of the GRXE in the inner 10 arcmin of the Galaxy. Such an X-ray intensity spike has indeed been observed with Chandra. If observed by a hard X-ray telescope with moderate angular resolution, such as IBIS aboard INTEGRAL (angular resolution 12 arcmin), the GRXE central cusp will be perceived as a point-like source at the Galactic Center. Since the innermost 30 pc (corresponding to 12 arcmin at the Galactic Center distance) of the Galaxy enclose $\sim 10^8 M_\odot$ of stars, this source is expected to have a 3–20 keV luminosity of $\sim 4 \times 10^{35}$ erg s^{-1}, or $\sim 2 \times 10^{35}$ erg s^{-1} in the 20–60 keV band. This estimate turns out to be in good agreement with the flux measured by INTEGRAL/IBIS from the Galactic Center "point" source IGR J17456−2901. The spectrum measured by INTEGRAL, which exhibits a significant softening above 20 keV, can thus be regarded as a prediction for the hard X-ray spectrum of the GRXE.

Finally, based on the luminosity function of faint X-ray sources it is possible to make the prediction that in order to resolve 90% of the GRXE a sensitivity limit of $\sim 10^{-16}$ erg s^{-1} cm^{-2} (2–10 keV) will need to be reached in future observations. This should be feasible to achieve with a ∼ 1 Msec observation of a Galactic plane region by Chandra. (Sergey Sazonov and Mike Revnivtsev).

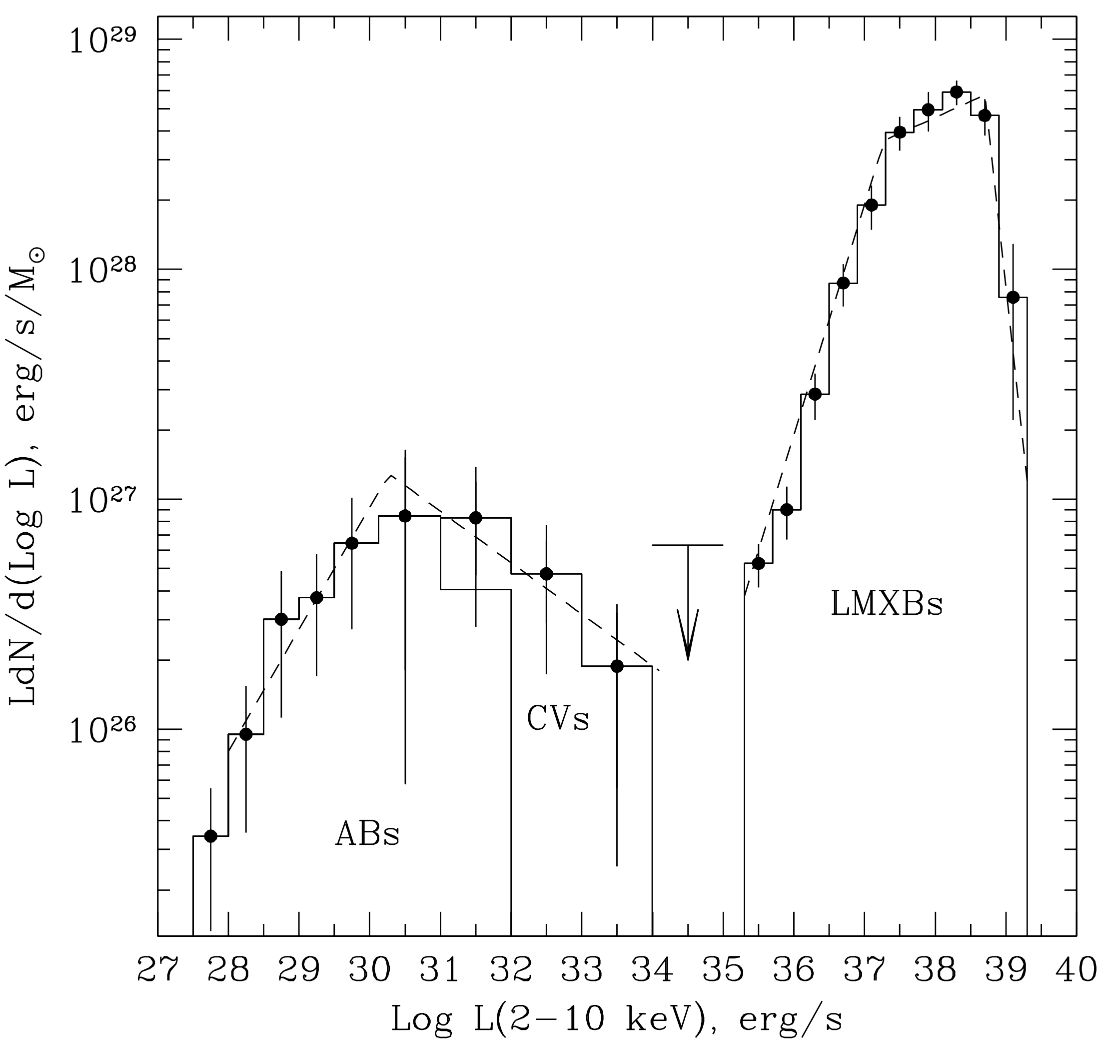

Figure 2.21: Differential luminosity distribution of the 2–10 keV emissivity of ABs, CVs and LMXBs. Also the contributions of these classes of sources are indicated and analytical approximations are presented (dashed lines).

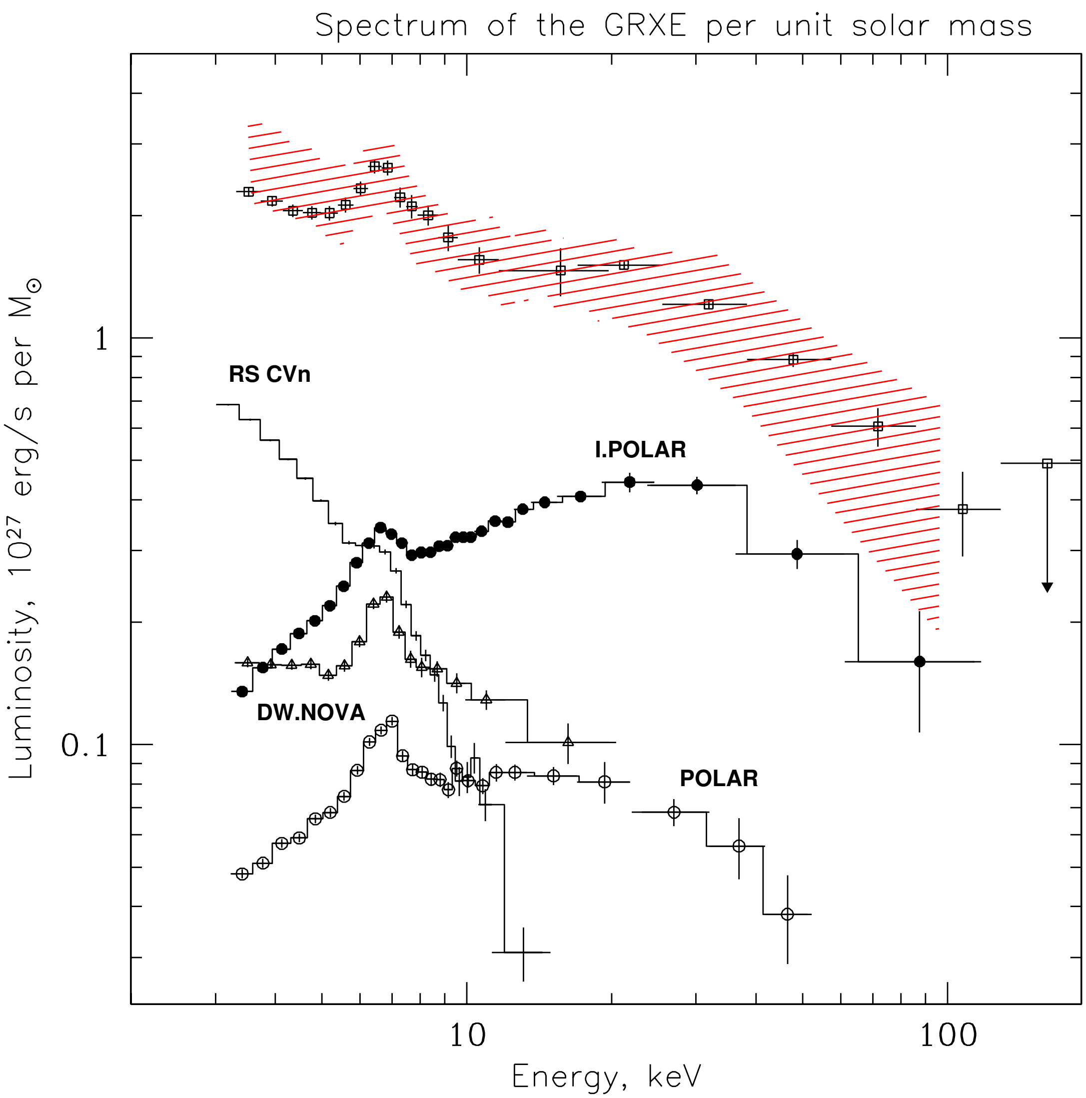

Figure 2.22: GRXE broad-band spectrum (squares). The data points in the 3–20 keV band (RXTE/PCA) were converted to unit-stellar-mass emissivity. The data points in the 20–100 keV band show the spectrum of the Galactic Center source IGR J17456−2901 measured by INTEGRAL/IBIS divided by the estimated total mass in stars ($\sim 10^8 M_\odot$) contained in the nuclear region. Also shown are typical spectra of X-ray source classes expected to significantly contribute to the GRXE: intermediate polars (V1223 Sgr, filled circles), polars (AM Her, open circles), dwarf novae (SU UMa, triangles), and coronally active binaries (V711 Tau). These spectra are plotted with normalizations corresponding to their expected relative contributions to the GRXE divided by 2. The shaded region shows a sum of these spectra.

2.8 The formation history of elliptical galaxies

Elliptical galaxies represent the most massive stellar systems in the local Universe and appear to define a homogeneous class of objects with uniformly old and red populations, little or no gas and dust, and very little star formation. Despite an enormous amount of work both on the theoretical and on the observational side in the last decades, understanding how these systems form and evolve remains essentially an open issue. Because ellipticals are so regular in appearance, it has been a long-standing hypothesis that they formed at very high redshifts in a single intense burst of star formation and that their stellar populations then evolved passively until the present day. This is often referred to as the *monolithic collapse* picture. Early simulations, however, showed that the merger of two spiral galaxies of comparable mass can produce a remnant with structural and photometric properties resembling those of elliptical galaxies. Such a *hierarchical* bottom-up formation scenario is naturally expected for the structure formation process in cosmologies dominated by cold dark matter and, in fact, the CDM model with the 'concordance' set of cosmological parameters (ΛCDM) has been so successful in the last decade, that it can now be considered a standard paradigm for the formation of structure in the Universe.

A number of observation results are, however, difficult to explain in a scenario in which larger spheroidals are assembled relatively late from the merger of late–type galaxies of comparable mass. One particularly controversial issue relates to the α-element enhancements observed in ellipticals. The so–called α-elements are released mainly by supernovae type-II, while the main contribution to the Fe-peak elements comes from supernovae type-Ia. For this reason, the $[\alpha/\mathrm{Fe}]$ ratio is believed to encode important information on the time–scale of star formation. It is now a well established result that massive ellipticals have super-solar $[\alpha/\mathrm{Fe}]$ ratios, suggesting that they formed on relatively short time–scales. This, together with a number of observational results (for example the evolution of the fundamental plane to high redshifts), confirms that star formation in elliptical galaxies has undergone 'down-sizing', i.e. the data suggest that less massive ellipticals have more extended star formation histories than their more massive counterparts, giving them a lower characteristic formation redshift. This is in marked contrast to naive expectations based on the growth of dark matter halos in hierarchical CDM cosmologies.

MPA scientists have investigated this problem by applying semi-analytic techniques that track dark matter halos and their embedded substructures to the largest high-resolution simulation of cosmic structure growth ever carried out. The Millennium Simulation combines high mass resolution with a very large number of particles, more than 10 billion. The simulation thus allows the evolution of all galaxies more massive than the Small Magellanic Cloud to be followed in a volume comparable to that of large modern redshift surveys. The semi-analytic model employed follows the transport of metals between the stars, the cold gas in galaxies, the hot gas in dark matter haloes, and the intergalactic gas outside virialized haloes, and it has been shown to reproduce the observed relations between stellar mass and gas-phase metallicity in local galaxies, luminosity and cold gas fraction and the observed decline in baryon fraction from rich clusters to galaxy groups.

A novel ingredient of the model is a prescription to describe central heating by AGN in massive groups and clusters and the associated suppression of cooling flows. In this model, gas condensation in massive systems is efficiently suppressed by 'radio mode' outflows that occur when a massive black hole finds itself at the centre of a static hot gas halo. MPA scientists have shown that, with physically plausible parameters, such a model is able to explain the apparent lack of gas condensation in cluster cooling flows and the observed cut-off at the bright end of the galaxy luminosity function. This additional mode of feedback does not require star formation to occur (in contrast to supernovae or starburst feedback) therefore naturally resulting in a trend for massive galaxies to have systematically older stellar populations than their lower mass counterparts.

This is illustrated in Fig. 2.23 which shows the colour–mass relation for model galaxies with and without feedback from the 'radio mode'. A clear bimodality in colour is seen in both panels, but without a heating source the most massive galaxies are blue rather than red. The figure also shows that in presence of a heating source the most massive galaxies are morphologically classified as early–type, in agreement with observational results. This happens because the feedback from the 'radio mode' inhibits the formation of a new disk by suppressing the cooling in massive haloes.

Another way to look at the formation of the stars in the model galaxies is shown in the top

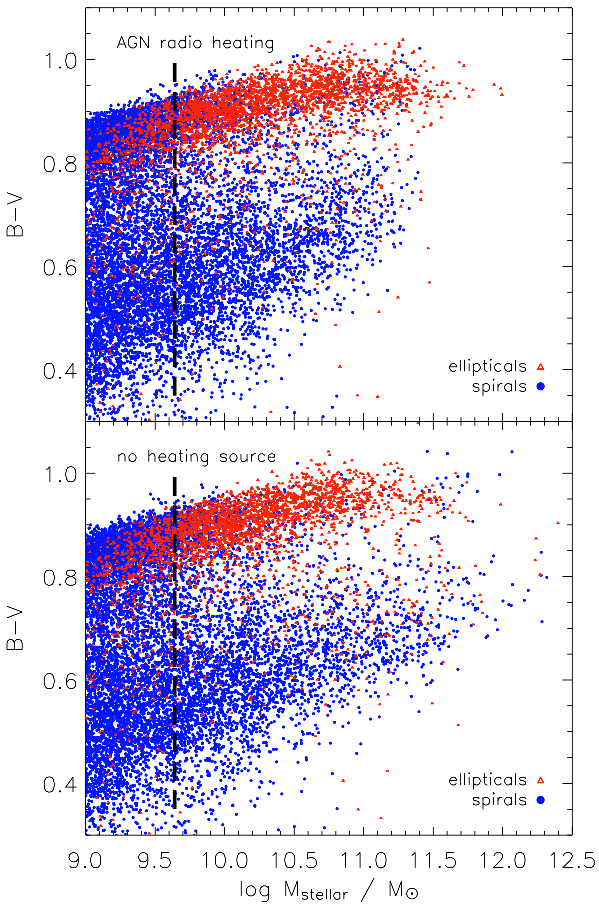

Figure 2.23: Colour–mass relation for model galaxies with (top) and without (bottom) 'radio mode' (see text for detail). Triangles (red) and circles (blue) correspond to early and late morphological types respectively. (From Croton et al. 2006).

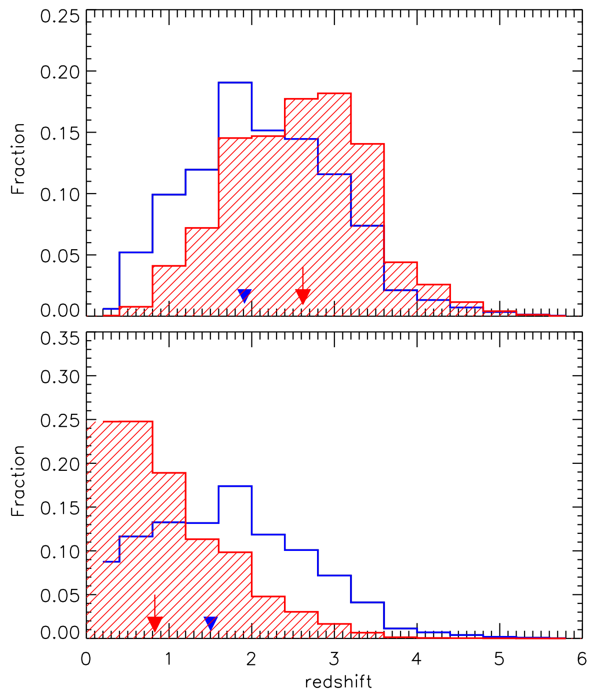

Figure 2.24: Top panel: distribution of the formation redshifts of model elliptical galaxies (see text for details). The shaded histogram is for elliptical galaxies with stellar mass larger than $10^{11}\,M_\odot$, while the open histogram is for all the galaxies with mass larger than $4 \times 10^9\,M_\odot$. Arrows indicate the medians of the distributions. Bottom panel: as in the top panel but for the assembly redshifts of model galaxies (see text for details). (From De Lucia et al. 2006).

panel of Fig. 2.24 that shows the distribution of the formation redshifts for model elliptical galaxies. The formation redshift is here defined as the redshift when 50 per cent of the stars that make up the final elliptical galaxy at redshift zero are already formed. The shaded histograms are for model elliptical galaxies with stellar mass larger than $10^{11}\,M_\odot$, while the open histogram is for all galaxies in the sample under investigation (that have stellar mass larger than $4 \times 10^9\,M_\odot$).

The figure clearly demonstrates that the stars in more massive ellipticals are on average older than those in their less massive counterparts, but the scatter of the distribution is rather large and there is a non-negligible fraction of model galaxies whose stars are formed relatively late. It is important, however, to distinguish the early *formation times* of the stars that make up the elliptical galaxy population (reflected in the 'down-sizing' scenario) from the *assembly time* of the more massive ellipticals. If massive ellipticals form a large fraction of their stars in a number of distinct progenitor systems before they coalesce, these two times may well be quite different. The bottom panel of Fig. 2.24 demonstrates that this is indeed the case in this model. This panel shows the distribution of the assembly redshifts for the same galaxies analysed in the top panel. The assembly time is defined as the redshift when 50 per cent of the final stellar mass is already contained in a single object. For galaxies more massive than $10^{11}\,\mathrm{M}_\odot$, the median redshift when half of the stars are formed is ~ 2.5 (upper panel), but for the same galaxies, half of their stars are typically assembled in a single object only at redshift ~ 0.8 (bottom panel). In addition, more massive galaxies assemble later than less massive ones, and only about half of the model elliptical galaxies have a progenitor with mass at least equal to half of their final mass at redshifts $\gtrsim 1.5$. The assembly history of ellipticals hence parallels the hierarchical growth of dark matter halos, in contrast to the formation history of the stars themselves. Fig. 2.24 implies that a significant fraction of present elliptical galaxies has assembled relatively recently through purely stellar mergers. This finding agrees with recent observational results.

These results demonstrate that an apparent ‘down-sizing’ in the formation of ellipticals is not in contradiction with the hierarchical paradigm. Modern semi-analytic models of galaxy formation do predict ‘anti-hierarchical’ star formation histories for ellipticals in a ΛCDM universe even though the *assembly* of these galaxies is indeed hierarchical. (Gabriella De Lucia)

3 Research Activities

3.1 Stellar Physics

U. Anzer together with P. Heinzel and S. Gunar (both Ondrejov, Czech Republic) performed a systematic investigation of the radiative properties of vertical 2D thread models for solar prominences. They found that the profiles of the Lyman lines can depend strongly on the angle between the line of sight and the magnetic field direction. U. Anzer and P. Heinzel also developped analytical models for extended EUV filaments on the basis of periodic magnetic arcades. U. Anzer, P. Heinzel and F. Farnik (also Ondrejov, Czech Republic) started an investigation of limb prominences using simultaneous SOHO/SUMER and YOHKOH/SXT data.

New insights into the nature of sunspots have been obtained by H. Spruit in a collaboration G. Scharmer (Institute for Solar Physics of the Royal Swedish Academy of Sciences). The level of detail revealed by recent movies at very high resolution (0.15 arc sec) from the 1-m swedish solar telescope on La Palma leads to a compelling theoretical picture that solves several long-standing problems about sunspots. See the highlight article on page 14.

A possible influence of sunspots on the Earth's climate has been a controversial theme over the past few decades, with a highly political dimension because of the possible connections with the global warming of the 20th century. In a review commissioned by Nature, P. Foukal (Heliophysics, Inc., Nahant, Massachusetts), H. Spruit, T. Wigley (National Center for Atmospheric Research, Boulder, Colorado) and C. Fröhlich, (World Radiation Center, Davos) investigate the current observational evidence, its interpretion in climate models, and theoretical understanding of solar brightness variability. They conclude that inferred small effects of solar activity on climate over the past 1000–10000 years are possibly real, that they are at a level consistent with the observed variations of the Sun's surface brightness due to solar activity, and insufficient to explain the global warming.

J. Braithwaite and H.C. Spruit continued their work on stellar magnetic fields. Using numerical magnetohydrodynamics, they simulated the instability in a toroidal magnetic field in a stably stratified stellar interior and investigated the behaviour of this instability including the effects of rotation and thermal diffusion. The non-linear development of this instability in the presence of differential rotation was studied, and was found to result in a self-sustained magnetic field (small scale dynamo process). In addition to this, the evolution of the magnetic field in a strongly magnetised neutron star was examined, and a model was made to describe the 'starquakes' and gamma-ray outbursts observed on these objects.

Together with collaborators from the Obs. de Paris-Meudon (R. Samadi, M.J. Goupil) F. Kupka investigated the capability of traditional, local convection models to predict solar p-mode excitation rates. The models were demonstrated to be insufficient for matching the observational data within their uncertainties. Non-local models which predict asymmetries in up- and downflows were suggested as a necessary alternative. Tests of such a model (together with F. Robinson, Yale Univ.) were extended from the solar case to low mass stars. An improvement over quasi-normal approximation models similar to the previously studied case of solar granulation convection was found. A variant of this new model (by K. Belkacem, Obs. de Paris-Meudon) is now being tested for its capability to predict solar p-mode frequencies and excitation rates (collaboration of F. Kupka with K. Belkacem, R. Samadi, and M.J. Goupil).

The study of F. Kupka performed in collaboration with C. Boisson, J. Frémaux, and M. Joly (Obs. de Paris-Meudon) on the prospects of population synthesis in the H band with current model atmospheres and spectrum synthesis codes has been continued. Insufficient atomic data was found to be the main limiting factor, more important than even molecular data, the detailed equation of state, the chosen set of light element abundances, or the particular model code when using identical input microphysics.

The determination of stellar ages has received continuing attention by A. Weiss and coworkers, who developed a new method for the simultaneous fitting of several age indicators in globular cluster colour-magnitude diagrams (with F. Meissner, MPA) and used data from the Sloan Digital Sky Server for colour-metallicity relations of metal-poor field stars (with M. Salaris, Liverpool John Moores University). In the first case it turned out that very few theoretical isochrones are able to fit globular cluster diagrams consistently, and that further investigations into the different results of various stellar evolution codes are needed. Other research projects concentrated on aspects of stellar evolution theory such as the influence of new nuclear reaction rates on low and intermediate mass models (with A. Serenelli, Princeton, USA, and H. Schlattl and A. Kitsikis, both MPA) and the accurate calculation of horizontal branch models (with A. Serenelli, Princeton, USA).

Four more new nearby Type Ia supernovae were observed in 2005 by the European Supernova Collaboration (ESC), led by W. Hillebrandt (SN 2005W, SN 2005bl, SN 2005cf, Sn 2005hk), and late-time observations of previous targets were continued. Comprehensive results on SN 2002dj and SN 2003er were published by the collaboration.

P.A. Mazzali modelled the spectra and light curves of nearby SNe Ia observed by the RTN on SNe Ia led by W.Hillebrandt in order to determine their properties. Together with postdocs M.Stehle and D.Sauer they used the "abundance Tomography" approach to study in detail the abundance distribution in some well observed, nearby Type Ia Supernovae, by means of modelling a closely spaced series of spectra. In particular, they concentrated on the presence of line absoprtion of very high velocities, that are observed in most SNe Ia that are observed within a few days of the explosion. These features may be the outer part of the explosion, and could potentially be used to shed light on the processes that govern the SN Ia phenomenon.

In collaboration with postdoc D. Sauer P. Mazzali worked on modelling the spectra and light curves of some Type Ic Supernovae in order to determine their properties in a quantitative way. In particular, the focused on SN 1994I and on SN 2004aw, a SN observed by the SN RTN collaboration. SN 1994I is considered a prototypical Ic, and determining its properties reliably is important in order to compare to the properties of the more energetic GRB-SNe and to understand whether there is a continuum of properties. SN2004aw has features that suggest it could be a highly energetic SN, but did not show an associated GRB. Our study aims at determining whether this may be a GRB-SN seen off axis or just a weaker manifestation of a SN Ic event.

In collaboration with K.Nomoto (U. Tokyo) and his group P. Mazzali worked on the properties curves Type Ic SNe, in particular on those objects that show exceptionally large explosion kinetic energy and luminosity. These objects may be related to the "hypernovae" observed in coincidence with long-duration GRBs. A particularly interesting result was the discovery of one such object, SN2003jd, which shows indications that it was a very aspherical explosion, such as those of the GRB-SNe, but viewed very far from the polar axis, as inferred from the double-peaked profile of the nebular emission lines of Oxygen. P. Mazzali and H.-T.Janka also worked on the properties of short-GRBs, which seem to be connected with the merging and collapse of binary NS or NS-BH systems.

With a number of collaborators P. Mazzali is involved in observational programmes to obtain data for new nearby SNe Ia (ESO, HST), follow up GRBs in the search for SNe (E. Pian, Trieste) (ESO, Subaru), and obtain late-time data of SNe Ic with the aim to understand the role of asymmetry, which may be a common feature of all SNe Ic, and possibly of all core-collapse SNe.

A. Pastorello contributed to the observational follow-up of a number of Type Ia SN targets, selected by the European Supernova Collaboration, and analysed the data of two typical SNe Ia (2004eo and 2005cf). Coordinating this work with that of other members of the European network, new impulse was provided in understanding the physical reasons for the observed diversity of the parameters of SNe Ia. This is a fundamental step for using these objects as powerful distance indicators.

With S. Taubenberger and in collaboration with people belonging to different Italian institutes and cooperating to the Italian Intensive Supernova Program (*http://web.oapd.inaf.it/supern/iisp/*), A. Pastorello led the study of the optical and near-infrared properties of one of the best observed core-collapse SNe so far, i.e. SN 2005cs (exploded in the famous, nearby Whirlpool Galaxy, M51). This is the first low-luminosity, ^{56}Ni-poor SN II-plateau having the progenitor star detected in pre-explosion archival images. Even if the apparent luminosity and colours of the progenitors do not provide unequivocal constraints on their initial masses, because these objects may explode in rather dusty environments, the combined analysis with synthetic spectra and light curve models should provide new clues on the nature of precursors of this rare group of core–collapse SNe. S. Taubenberger contributed to the data reduction of this fascinating object for which a first interpretation, a collapse of a star with a mass around 9 $M_\odot$, was provided by F.-S.. Kitaura, H.-Th. Janka and W. Hillebrandt.

In the course of his PhD work, supervised by W. Hillebrandt, S. Taubenberger carried on his studies on the unusual Type Ic SN 2004aw that provide further insight to a class of SNe that has not been well studied so far. Issues like the intrinsic heterogeneity within this class (both photometric and spectroscopic), the links between regular SNe Ic and hypernovae, and the presence or absence of He in the ejecta are addressed in this work. In the framework of the European Supernova Collaboration (ESC) he coordinated the observations and started the reduction and analysis of the data of the Type Ia SN 2005bl, which proved to be a representative of the underluminous, 1991bg-like subclass. This work will contribute to increase the variety of properties within the SN sample studied by the European network.

M. Stritzinger, a student of W. Hillebrandt and B. Leibundgut of the Euroopean Southern Observatory, completed his PhD entitled: "Type Ia Supernovae: Bolometric properties and new tools for photometric techniques." His dissertation work has led to three refereed publications. This includes a new method that provides a lower limit on the Hubble constant, an atlas of photometric standard stars, and constraints on the progenitor systems of type Ia supernovae.

W. Hillebrandt, F. Röpke and M. Reinecke, in collaboration with C. Kozma, C. Fransson, J. Sollerman (Stockholm Obs.), C. Travaglio (Turin Obs.) and J. Spyromilio (ESO) computed late time synthetic spectra of type Ia supernovae, based on three-dimensional deflagration models. The synthetic spectra were compared to observed late time spectra. They found that while the model spectra after 300 to 500 days show a good agreement with the observed Fe II-III features, they also show too strong O I and C I lines compared to the observed late time spectra. This may indicate a problem for pure deflagration models, although improved initial conditions, as well as higher resolution decrease the discrepancy.

C. Travaglio (Turin Obs.), W. Hillebrandt and M Reinecke investigated the metallicity effect (measured by the original ^{22}Ne content) on the detailed nucleosynthetic yields for 3D hydrodynamical simulations of the thermonuclear burning phase in type Ia supernovae (SNe Ia). They found a linear dependence of the ejected ^{56}Ni mass on the progenitor's metallicity, with a variation in the ^{56}Ni mass of 25% in the metallicity range explored. The largest variation occured at metallicities greater than solar. Implications for the observed scatter in the peak luminosities of SNe Ia were also discussed.

V. P. Utrobin (also ITEP, Moscow) and N. N. Chugai (Sternberg Inst., Moscow) studied time-dependent hydrogen ionization in the atmosphere of SN 1987A during the first month after the supernova explosion. The model included the kinetics of hydrogen ionization and excitation, molecular hydrogen, and a time-dependent energy balance. The primary strong effect of the time-dependent ionization is the enhanced hydrogen ionization compared to the steady-state model. The time-dependent ionization provides a sufficient population of excited hydrogen levels to account for the observed Hα without invoking the external ^{56}Ni. They found that the Ba II 6142 Å line in SN 1987A can be reproduced for the LMC barium abundance. This resolves the long-standing problem of the unacceptably high barium overabundance in SN 1987A. The key missing factor responsible for the "barium problem" is the time-dependent ionization. The modelling of the Hα profile on day 4.64 indicates the ratio of the kinetic energy to the ejected mass $\approx 0.83 \times 10^{50}$ erg $M_\odot^{-1}$.

V. P. Utrobin also studied the photometric and spectroscopic observations of SN 1987A on the basis of hydrodynamic modeling of the bolometric light curve and calculations of hydrogen lines during the photospheric phase using a time-dependent approach in hydrogen kinetics and energy balance. The study showed that only a ratio of the explosion energy to the ejected mass of $\approx 0.83 \times 10^{50}$ erg $M_\odot^{-1}$ gives a good agreement with the observations. At the same time the radius of the presupernova is $35.0 \pm 5R_\odot$ and the chemical composition of the surface layers with a relative mass fraction of $X = 0.743$ for hydrogen, $Y = 0.251$ for helium, and $Z = 0.006$ for heavy elements is characteristic of the LMC. He investigated the influence of the ejected envelope mass on the bolometric light curve with the above ratio of the explosion energy to the ejected mass and concluded that an optimal ejecta mass is $18.0M_\odot$ with the reasonable spread of $\pm 1.5M_\odot$ and, as a consequence, the explosion energy of SN 1987A is $(1.50 \pm 0.12) \times 10^{51}$ erg. If the gravitational collapse of the stellar iron core produced a neutron star with a mass of $\approx 1.6M_\odot$, just prior to the SN 1987A outburst the presupernova had the mass of $19.6 \pm 1.5M_\odot$.

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 semi-annual 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, Milton Keynes), three releases (the latest as of 1 July 2005) of this catalogue have so far been issued (with the next release due 1 January 2006).

Also in the context of cataclysmic variables, H. Ritter and U. Kolb (Open University, Milton Keynes) have continued compiling the data for the semi-annual updates of the web-based living version and for the final edition of the Catalog and Atlas of Cataclysmic Variables which is provided in collaboration with R. Downes (Space Telescope Science Intitute, Baltimore), R. Webbink (MPA and Univeristy of Illinois, Urbana), M. Shara (American Museum of Natural History, New York), and H. Duerbeck (Free University Brussels, Brussels).

E. Meyer-Hofmeister and F. Meyer together with V. Burwitz and J.Greiner (MPE) and K. Reinsch (University of Göttingen) investigated new observational data for the binary supersoft source RX J0513.9-6954 to study the changes between the X-ray low and high states, which are related to a more or less extended surface of the white dwarf. Radius and temperature values found from the observations give constraints for the modeling of the variability cycles.

3.2 Nuclear and Neutrino Astrophysics

J. Pruet, R.D. Hoffman (both LLNL, California), S.E. Woosley (UCSC, Santa Cruz, California), in collaboration with H.-Thomas Janka and R. Buras, investigated the nucleosynthesis in proton-rich ejecta of core-collapse supernova models of the Garching group by a new process, the so-called rapid neutrino-p process. In this process, the interaction of neutrinos with free protons leads to the production of neutrons, whose instantaneous capture helps to bridge p-process waiting-point nuclei and thus enables the formation of p-process nuclei with mass numbers $A > 100$ in neutrino-processed supernova ejecta.

A. Marek as part of his PhD work, supervised by H.-Th. Janka, studied ion-ion correlations in neutrino-nuclei interactions during stellar core collapse. The project was performed in collaboration with M. Liebendörfer (CITA, Toronto) and aimed at clarifying the influence of a new, improved description of the correlations in the limit of low momentum transfer. In collaboration with K. Langanke and G. Martínez-Pinedo (GSI, Darmstadt), A. Marek also performed core-collapse simulations with an improved description of electron captures on heavy nuclei. The employed rates were based on shell model Monte Carlo calculations for a large number of nuclear species in nuclear statistical equilibrium.

In her PhD project, supervised by H.-Th. Janka and L. Scheck, A. Arcones performed hydrodynamic simulations of neutrino-driven winds from nascent neutron stars in core-collapse supernovae. The project aimed at studying the effects of the wind termination shock that forms when the fast wind collides with slower earlier supernovae ejecta. Also accretion-induced asymmetries and multiple shocks around the neutron star are investigated for their effects on the nucleosynthesis-relevant wind properties.

I. Panov (ITEP, Moscow) in collaboration with H.-Th. Janka performed r-process calculations for neutrino-driven winds from newly formed neutron stars. The project was intended to explore the possibility, pointed out by Japanese groups, that for suitable density and temperature decline during the neutron-capture phase, a strong r-processing is possible even at modest entropies. The Japanese results could not be confirmed.

Collapse and supernova explosion of 8–10 $M_\odot$ stars with O-Ne-Mg cores were simulated by F.S. Kitaura in a collaborative project with H.-Th. Janka and W. Hillebrandt. In this mass range of progenitor stars the viability of the neutrino-driven mechanism could be established and predictions of nucleosynthetic implications of this explosion scenario could be improved.

In his Diploma Thesis work R. Birkl, supervised by E. Müller in collaboration with M.-A. Aloy and H.-Th. Janka, performed ray-tracing calculations for neutrino-antineutrino annihilation in the vicinity of black-hole/accretion-torus systems. He explored the efficiency of energy deposition by this process for different geometries, taking into account relativistic effects as described by a Schwarzschild or Kerr metric.

A. Marek and L. Scheck, supervised during their PhD work by H.-Th. Janka, in collaboration with K. Kifonidis and E. Müller, continued simulations of stellar core collapse and post-bounce evolution in 2D with simplified neutrino treatment as well as spectral Boltzmann transport. Aim of the investigations was to clarify whether neutrino-driven explosions work and if so, what their consequences are for ejecta asymmetries and neutron star kicks.

3.3 Numerical Hydrodynamics

A. Mizuta studied ionization front instabilities by means of 2D hydrodynamic simulations. The calculations include radiation transport of ionizing incident photons from massive stars, and the detailed energy budget by radiative processes, such as photoionization of neutral hydrogen, recombination in HII region, and molecular cooling. A new type of instability which is triggered by a separation of the ionization front from the cloud surface is found. When the amplitude of the imposed perturbation is large, portions of the ionization front temporarily separate from the molecular cloud surface, locally decreasing the ablation pressure. The local variation in the ablation pressure causes the appearance of multi-mode perturbations which grow rapidly to large structures. Pillar like structures appear at later epochs. This work was done as a collaboration with B.A. Remington, D.D. Ryutov, J.O. Kane (all LLNL), M.W. Pound (Univ. of Maryland), and H. Takabe (ILE, Osaka Univ.).

N. J. Hammer has begun a PhD project supervised by E. Müller to investigate the prospects of axis-free methods with spherical polar grids for 3D hydrodynamic simulations. He has developed the necessary algorithms and program routines, and he has started to implement these into the latest version of the PROMETHEUS hydro-code. First tests have been performed and show very promising results.

M. Obergaulinger, in a PhD project advised jointly by M.A. Aloy and E. Müller, has continued his studies of multi-dimensional Newtonian magneto-rotational core collapse. Aiming towards a more comprehensive and detailed description of the magnetized flow during the collapse of a stellar core and its subsequent evolution, he extended his MHD code by modules including a more realistic nuclear equation of state, and the advection of different chemical species. Additionally, he has implemented in collaboration with H. Spruit different phenomenological models to describe the MHD turbulence expected in post-collapse accretion flows. These models include a Shakura-Sunyaev type of viscosity and resistivity, and a Maxwell-stress model based on H. Spruit's theory of stellar dynamos relying on the Taylor instability of a toroidal field.

P. Mimica, M.A. Aloy, E. Müller, and W. Brinkmann (MPE) have performed a detailed numerical study and theoretical analysis of the dynamics of internal shocks in relativistic jets and the non-thermal flares associated with these shocks. In their model internal shocks result from collisions of density inhomogeneities (shells) in relativistic jet flows. The merged shell resulting from the inelastic collision of shells has a complicated internal structure due to the non-linear dynamics of the interaction. Simple one-zone models are inadequate to extract physical parameters of the emitting region from the resulting light curves. In order to improve on these one-zone approximations, they propose a novel way of analyzing the space-time properties of the emission, and construct an analytic model of non-thermal flares which can be used to constrain some unobservable physical parameters of the internal shocks.

P. Mimica, M.A. Aloy and E. Müller have begun to extend the synchrotron radiation-hydrodynamics code "R-GENESIS" to relativistic MHD flows. Besides the multi-dimensional fluid flow the code also describes the injection of ultra-relativistic electrons at relativistic shock fronts, their synchrotron radiation and radiative losses (the back-reaction on the hydrodynamics is also considered), and their spatial advection by the thermal fluid. The extended code will be used to study relativistic collisions of density inhomogeneities (shells) within a magnetized blazar jet, and their impact on the characteristics of X-ray blazar flares.

M.A. Aloy and S. Heinz (Kavli Institute, MIT) have studied the interaction of microquasar jets with their environments by means of simulations of very high density shells or blobs of plasma that evolve in a diluted medium. The main goal of the work is to study the process of slowing down a relativistic outflow and to obtain estimates of the density of the medium surrounding Galactic mircroquasars. The authors conclude that the medium outside the Galactic radio sources GRS 1915+105 and XTE J1550-564 has very low density and that it is likely that fossil radio plasma is left behind by previous episodes of jet activity.

M.A. Aloy in collaboration with L. Rezzolla (Albert-Einstein-Institut, Golm) have discovered a new hydrodynamic mechanism to boost a jet flow to very high Lorentz factors. The hydrodynamic boosting acts when a hot jet is surrounded by a cold dense medium. Under these conditions, which are usually met in objects of astrophysical interest (gamma-ray bursts, parsec-scale jets, etc.), the external medium exerts a force on the jet surface which accelerates the fluid in the vicinity of the boundary between the jet and the external medium. Different from standard thermal acceleration mechanisms this boosting acts instantaneously on the jet. It modifies the commonly assumed structure of the contact layer between the jet and the ambient medium.

A. Mizuta investigated the dynamics of an injected outflow through a progenitor in the context of the collapsar model for GRBs and XRFs with S. Nagataki, S. Mineshige, and T. Yamasaki (YITP, Kyoto University). The power of the injected outflow is fixed, and the bulk Lorentz factor (Γ_0) and the specific internal energy (ϵ_0) of the injected outflow are varied in the range of $\Gamma_0 = 1.05 \sim 5$ and $\epsilon_0/c^2 = 0.1 \sim 5$, where c is speed of light. The character of the outflow dramatically changes from a collimated structure to an expanding one when the bulk Lorentz factor of injected outflow decreases. During the propagation in the progenitor, the bulk Lorentz factor increases. The maximum Lorentz factor depends on both initial Lorentz factor and specific internal energy, and follows a simple formula derived from energy conservation. The model can explain different events, such as GRBs, XRFs, and hypernovae.

M.A. Aloy, H.-T. Janka and E. Müller have performed a systematic parameter study of the conditions under which mergers of compact objects (i.e., systems formed by two neutron stars or a neutron star and a black hole) may yield ultra-relativistic outflows which will develop into short gamma-ray bursts (s-GRBs) at distances of $\sim 10^{13}$ cm. It turns out that such systems are able of producing s-GRBs when they are surrounded by a very low density medium. The outflow is collimated by the accretion disk which forms from the debris of the merger. It displays a highly inhomogeneous structure both longitudinally and transversally. The duration of the burst can be longer than the time during which the accretion of matter fuels the initial outflow. This is possible because the generated structure can be stretched longitudinally as a result of the faster propagation of its longitudinal front edge compared with its rear end.

A. Marek, H. Dimmelmeier, H.-Th. Janka, E. Müller, and R. Buras finished a project concerning the effects of using modified gravitational potentials in a Newtonian hydrodynamic code for simulations of configurations involving compact relativistic objects. They found that in many situations the complicated and computationally expensive relativistic approach can be replaced by various formulations of modified Newtonian gravity. This can be accomplished even for very rapidly rotating collapse models, for which B. Müller has derived and successfully applied an effective relativistic potential in his Diploma thesis supervised jointly by H. Dimmelmeier and E. Müller.

H. Dimmelmeier extended his previous research on astrophysical phenomena (e.g., core collapse supernovae) leading to the formation of compact objects like neutron stars and black holes using numerical hydrodynamic simulations. For this he used the well-tested and accurate 2d/3d relativistic hydrodynamics code CoCoNuT, which utilizes the conformal flatness approximation of spacetime. In 2005 he completed the previously started joint project with N. Stergioulas (Univ. Thessaloniki) and J.A. Font (Univ. of Valencia) on simulations of pulsations in rotating neutron stars. In this parameter study theoretically predicted nonlinear effects were observed, analyzed, and explained. The findings were recently published, with a particular focus on the implications of the results on gravitational wave detectability and asteroseismology.

H. Dimmelmeier, C. Ott (Albert-Einstein-Institut, Golm), I. Hawke (Univ. of Southampton), and E. Seidel (Louisiana State University, Baton Rouge) have continued their comparison study of supernova core collapse using the two codes CoCoNuT and Cactus/Whisky for general relativistic hydrodynamic simulations. Extending this work H. Dimmelmeier has supplemented the original simple treatment of the microphysics in the CoCoNuT code with a realistic equation of state by Shen et al., which was provided in an improved form by A. Marek and H.-T. Janka. Currently he investigates the influence of realistic stellar progenitor models and the realistic equation of state on the core collapse dynamics, again comparing his results with those of the Cactus/Whisky code. This comparison also encompasses the implementation of a promising new approximation method proposed by Liebendörfer which takes into account the effects of deleptonization and neutrino pressure during core collapse. This will provide more realistic templates of the gravitational wave signal from supernova core collapse.

As the current formulation of the gravitational field equations in the CoCoNuT code does not permit a time evolution beyond the formation of a black hole, H. Dimmelmeier has initiated a collaboration with A. Nagar (Politecnico di Torino) to use a perturbative code to simulate the continued accretion of matter onto a newly formed black hole. For this project results from computations with the CoCoNuT code are used as initial data for the perturbation code.

In the context of black hole formation, H. Dimmelmeier together with his collaborators J. Novak and L.-M. Min (Meudon Observatory, Paris) began extending the conformal flatness approximation of the CoCoNuT code to non-approximate formulations of the full general relativistic field equations by Bonazzola et al. As an important intermediate step towards a generic non-perturbative simulation of a nascent and accreting black hole they have successfully tested a method to find the apparent horizon in a non-symmetric spacetime. Such a method is required for the implementation of horizon excision schemes, which permit the long-term evolution of such spacetimes. First tests have been undertaken to consistently extract the gravitational radiation waveforms from the spacetime metric, instead of using the Newtonian quadrupole formula as done so far.

B. Zink has continued and almost finished his study of the process of black hole formation through fragmentation instabilities in toroidal polytropes. This PhD project supervised by E. Müller and done in collaboration with N. Stergioulas (Univ. of Thessaloniki), Ian Hawke (Univ. of Southampton), C.D. Ott, and E. Schnetter (both AEI) shows that differentially rotating toroids are unstable to nonaxisymmetric modes which lead to a fragmentation into self-gravitating, collapsing components. Using an adaptive mesh refinement technique and the Cactus computational framework the evolution of one such fragment was followed until the formation of an apparent horizon.

B. Zink also studied, during his seven-months visit to the Center of Computation and Technology (Louisiana State University, Baton Rouge), the application of methods from discrete analysis to the numerical treatment of black hole spacetimes. In collaboration with E. Pazos, P. Diener, and M. Tiglio (all Louisiana State University) he performed the first discrete evolution of a stellar-mass black hole accreting a Klein-Gordon field in spherical symmetry lasting several seconds in asymptotic time, with a solution error of less than one percent.

The collaboration of F. Kupka with H. Muthsam (Univ. of Vienna) on numerical simulations of stellar convection and on developing a semi-convection simulation code (also with H.C. Spruit) continued. Both applications are based on the Antares code (by H. Muthsam and coworkers), which is now sufficiently tested to allow for production runs.

F. Röpke and W. Hillebrandt performed numerical simulations of Type Ia supernova explosions. The MPA-approach of constructing a model without any tunable parameters raises the question of how the results of such simulations compare to observations. Consequently, effort was spent on linking the numerical models with observational results. Novel numerical techniques allowed to efficiently model the turbulent thermonuclear flame propagation in the exploding white dwarf star in great detail. In this way, effects of different ignition conditions could be studied. The chemical composition and central density of the white dwarf is believed to vary in different events and to contribute to the observed diversity of Type Ia supernovae – an important issue in the application of these objects in cosmological distance determination. The effects of the initial state of the white dwarf were tested in a series of numerical models in collaboration with M. Gieseler, and C. Travaglio (Observatory of Turin). While the initial carbon-to-oxygen ratio has little impact on the nucleosynthesis yields of the explosion, the central density and in particular the metallicity of the progenitor were found to affect it significantly. In collaboration with S. Blinnikov and E. Sorokina (ITEP, Moscow) light curves were derived from numerical models and showed reasonable agreement with observations. The new numerical techniques allowed to follow the explosion to a stage of homologous expansion, in combination with nucleosynthesis postprocessing facilitating the derivation of nebular spectra (in collaboration with C. Kozma, C. Fransson J. Sollerman (University of Stockholm) C. Travaglio (Observatory of Turin) and J. Spyromilio (ESO)). A comparison with observed nebular spectra pointed to a potential problem of the current model, namely a too large amount of unburnt material in the central parts of the ejecta. However, this problem was found to be alleviated in multi-spot flame ignition configurations were tested in yet another study in collaboration with J. Niemeyer (University of Würzburg) and S. Woosley (University of California Santa Cruz). The at present highest resolved Type Ia supernova simulation provided insight into the mechanism of turbulent burning and will serve as input for deriving observables. A comparison with well-observed nearby Type Ia supernovae will help to further test the validity and completeness of the explosion model.

A. Marek during his PhD work, supervised by H.-Th. Janka, and H. Dimmelmeier applied an effective relativistic potential in 1D and 2D stellar core-collapse simulations with and without neutrino transport, and tested the quality of such an approximative description of general relativistic effects against a more complete treatment of relativity.

K. Kifonidis in collaboration with H.-Th. Janka, E. Müller, and T. Plewa (Flash Center, Univ. of Chicago) performed adaptive mesh refinement simulations to study the development of hydrodynamic instabilities in the mantle and envelope of the exploding star as a consequence of dipolar and quadrupolar asymmetries produced in the innermost ejecta by convective overturn in the neutrino-heating layer and a newly discovered nonradial instability of the stalled accretion shock. The simulations revealed the importance of Richtmyer-Meshkov instabilities at the composition interfaces of the star after shock passage for triggering large-scale mixing of hydrogen deep into the stellar core and of metals far into the hydrogen layer, as required to explain the observational properties of SN 1987A.

3.4 High Energy Astrophysics

With the present generation of X-ray telescopes, types of X-ray sources so far seen only in our own galaxy have become observable in other nearby galaxies. The X-ray point source populations of such galaxies were studied by R. Voss, using archival observations by the Chandra satellite. In Centaurus A (NGC 5128) the spatial distribution of sources was found to be consistent with that oflow mass X-ray binaries (LMXBs). The distribution follows the K-band surface brightness of the galaxy. In the bulge of the M31 a significant excess of sources was found inside a radius of 1 arcmin from the center. This is most likely due to binaries created by dynamical captures in the dense stellar environment. Such capture is known in globular clusters, and extrapolation of the parameters showed a rough agreement with the observed excess.

Rapid oscillations, the so-called burst oscillations, are seen in the X-rays bursts of the millisecond X-ray pulsars: neutron stars made visible in X-rays through the accretion of mass from a companion star. A. L. Watts and T. E. Strohmayer (NASA GSFC) found that the energy dependence of such oscillations in XTE J1814-338 differs from that observed from bursters in which the rotation period is not seen in X-rays; this rules out existing surface oscillation mode models as their cause. Rapid oscillations, probably of a very different origin, have recently been detected in the 2004 giant flare from the magnetar SGR 1806-20, in this case a neutron star without a comnpanion, but with a very strong magnetic field. Data from the RHESSI satellite are presently analyzed by A. L. Watts and T. E. Strohmayer to test the theory that these oscillations are due seismic vibrations of the neutron star.

Gamma-ray bursts have become a topic of intensive research at MPA. Problems with the standard model for the observed gamma rays motivate the development of magnetic models for powering the relativistic outflow and spectra of GRBs. D. Giannios in collaboration with H. C. Spruit studied the production of the electromagnetic spectrum in such a Poynting-flux dominated outflow. The very high magnetic field strengths in such a flow (energy density above the rest-mass energy density) lead to very efficient synchrotron emission. In contrast with the standard internal shock model, dissipation of magnetic energy by reconnection is gradual and does not produce the spectrum of cooling electrons associated with shock acceleration. A spectrum with a break in the BATSE energy range is produced, instead, if the magnetic dissipation heats a small ($\sim 10^{-4}$) population of electrons. A very different spectral component is poduced by Compton scattering near the photosphere of a magnetic flow; it is expected to produce a highly nonthermal looking spectrum. Calculations of this process are in progress. A new method for quantifying the time-variablity of GRBs was developed by L.-X. Li and B. Paczyński (Princeton), and used to obtain a tight correlation between the variability and peak luminosity of GRBs. Compared to previous results, the new method reduces the data scatter by a factor of about 3. If this correlation is confirmed by future observations, it will provide a convenient calibration for GRB luminosity and distance.

Fitting of theoretical disk models to the X-ray spectra of accreting compact objects is a standard excercise in observational X-ray astronomy, and implemented in data analysis packages such as XPEC. It is motivated in particular by the expectation of extracting properties of the central object. In a collaboration with R. Narayan, J. McClintock and E.R. Zimmerman (CfA), L.-X. Li has written a series of efficient computer codes (implemented as the KERRB tool in XSPEC) for computing the blackbody radiation spectrum from a thin Keplerian disk around a Kerr black hole. These codes take into account all general relativistic effects, including frame-dragging, Doppler boosting, gravitational redshift, and bending of light by the gravity of the black hole. R. Shafee, J. McClintock, R. Narayan (CfA), S.W. Davis (UC Santa Barbara), L.-X. Li (MPA) and R.A. Remillard (MIT) have combined the KERRBB tool with Davis et al.'s (2005) disk atmosphere model, to get a most reliable fit to the blackbody spectra observed in a black hole-accretion disk system. With this combination, the thermal dominant or high soft state of two dynamically confirmed black hole systems, GRO J1655-40 and 4U 1543-47, has been analyzed, using the data from ASCA and RXTE. The resulst indicate the spin parameter of the black hole to be 0.7-0.8, and 0.85-0.9, respectively.

The 'fundamental plane' of black hole activity is a non-linear correlation among radio core luminosity, X-ray luminosity and mass of all accreting black holes, both of stellar mass and supermassive, found by A. Merloni et al. in 2003. In collaboration with S. Heinz (MIT, USA), T. Di Matteo (Carnegie Mellon University, USA), E. Körding (Univ. of Southampton, UK), S. Markoff (Univ. of Amsterdam, The Netherlands) and H. Falcke (Univ. of Nijmegen, The Netherlands), Merloni has studied the issue of sample selection and the bias introduced by the effect of distance in two of the correlated quantities. The results demonstrate that the fundamental plane relation cannot be a distance artifact, and that its non-linearity must represent an intrinsic characteristic of accreting black holes, which may hold the key for understanding the nature of the coupling between accretion and jet acceleration in these objects.

E. Churazov in collaboration with S. Heinz (MIT) considered the dissipation of sound waves and shocks in the intercluster medium containing bubbles of reletivistic plasma. Using hydrodynamic simulations and a technique to extract the rotational component of the velocity field, they show how bubbles of relativistic gas inflated by AGN jets in galaxy clusters act as a catalyst, transforming the energy carried by sound and shock waves into heat. The energy is stored in a vortex field around the bubbles, which can subsequently be dissipated. The efficiency of this process is set mainly by the fraction of the cluster volume filled by (sub-) kiloparsec-scale filaments and bubbles of relativistic plasma.

E. Churazov, S. Sazonov, R. Sunyaev, W. Forman (CfA), C. Jones (CfA) and H. Böhringer (MPE) studied a simple model of supermassive black hole growth in ellipical galaxies. Relativistic outflows (mainly observed in the radio) are a characteristic feature of both Galactic stellar-mass black holes and supermassive black holes (SMBHs). Simultaneous radio and X-ray observations of Galactic sources have shown that the outflow is strong at low accretion rates, but it weakens dramatically or disappears completely at high accretion rates, manifesting structural changes in the accretion flow. It is reasonable to assume that SMBHs follow the same trend. For low-luminosity SMBHs in nearby elliptical galaxies and clusters, recent observations strongly suggest that the outflows play the central role in keeping the gas hot (mechanical feedback). If the outflow is quenched in SMBHs at high accretion rates similarly to the behaviour of Galactic sources, then the straightforward consequence is a relatively weak feedback of rapidly accreting SMBHs. We argue that elliptical galaxies and their central engines should then evolve through two stages. Early on, the central SMBH rapidly grows by accreting cooling gas at a near-Eddington rate with high radiative efficiency but with weak feedback on the infalling gas. This stage terminates when the black hole has grown to a sufficiently large mass that its feedback (radiative and/or mechanical), despite the low gas heating efficiency, is able to suppress gas cooling. After that the system switches to a stable state corresponding to passively evolving ellipticals, when the accretion rate and radiative efficiency are very low, but the gas heating efficiency is high and energy input from the relativistic outflow keeps the gas hot.

P. Shtykovskiy (Space Research Institute, Moscow) and M. Gilfanov studied populations of compact sources in the Small Magellanic Cloud (SMC) using the XMM-Newton data. In the focus of their study was the number and luminosity distribution of high-mass X-ray binaries, as well as their time dependence. The observed number of HMXBs is consistent with the prediction based on star formation rate (SFR) estimates derived from the SN frequency and analysis of stellar colour-magnitude diagrams (CMD). If, on the contrary, the true value of the SFR is better represented by FIR, Hα or UV-based estimators, then the abundance of HMXBs in the SMC may significantly (by a factor of as much as 10) exceed the value typical for the Milky Way and other nearby galaxies. Studying the shape of the XLF they found a deficit of faint sources which may be a result of the "propeller" effect. Based on the analysis of the stellar CMDs they derived the spatially-resolved star-formation history of SMC and studied the dependence of the HMXB population on the time passed after the star-formation event.

P. Shtykovskiy, A. Lutovinov (Space Research Institute, Moscow, Russia), M. Gilfanov and R. Sunyaev searched for X/γ-ray emission from the stellar remnant in SNR1987A in LMC. As the envelope is still opaque in the standard X-ray band but begins to become transparent above ~ 20 keV, the optimal for this purpose is the IBIS telescope aboard the INTEGRAL observatory. No statistically significant emission has been detected in the 20-60 keV band with the upper limit on the luminosity of the central source of 10^{36} erg/s. This implies an upper limit on the mass of radioactive Ti-44 of 10^{-3} $M_{\odot}$.

P. Rebusco and E. Churazov in collaboration with H. Böhringer (MPE, Garching) and W. Forman (Harvard-Smithsonian Center for Astrophysics) studied an impact of stochastic gas motions on the metals distribution in the galaxy cluster cores. Peaked abundance profile is a characteristic feature of the clusters with cool cores and they are likely associated with the metals ejection from the brightest cluster galaxy. The width of the observed abundance peaks is significantly broader than the central galaxy light distribution, suggesting that gas motions are transporting the metals ejected from the galaxy. Treating this process in a diffusion approximation the constraints on the characteristic velocities and spatial scales of stochastic gas motions have been derived for a sample of cool core clusters and groups.

M. Revnivtsev, A. Lutovinov, S. Molkov, R. Krivonos, S. Grebenev and R. Sunyaev used ongoing observations of INTEGRAL orbital observatory to trace the population of Galactic X-ray transients. In the course of this study several new X-ray sources were discovered. S. Molkov, R. Sunyaev, P. Shtykovsky and M. Revnivtsev used a large set of INTEGRAL observations of the Galactic Center region in order to study the properties of persistent and bursting hard X-ray emission of soft gamma repeater SGR 1806-20. It is shown for the first time that the persistent high energy emission of this source continues up to at least 200 keV having a simple power law shape with very flat slope. It demonstrates that the majority of energy of SGR 1806-20 is emitted in hard X-rays or even in gamma rays. Flat powerlaw shape of the energy spectrum of the source indicates that it might have non thermal origin and might be connected with ultra-high strength of the magnetic field of the neutron star in this system. M. Revnivtsev, S. Sazonov, S. Molkov, A. Lutovinov, E. Churazov and R. Sunyaev used specially organized observations of the INTEGRAL satellite to obtain deep image of the Crux spiral arm tangent region. This region of the Galactic plane was practically missed in previous observations of the INTEGRAL satellite and the performed new study allowed to increase significantly the number of known Galactic X-ray sources. Relatively accurate positions of a number of detected sources will allow to perform follow up observations in different wavelengths. M. Revnivtsev and M. Gilfanov studied the properties of the accretion disk and the boundary/spreading layer in accreting neutron star binary systems. Key feature of the used approach is the possibility to separate relatively confidently the contribution of the boundary layer and the accretion disk to the total X-ray emission of the X-ray binary system. Having analyzed all available data of the RXTE observatory on bright accreting neutron star binary systems, made with needed spectral and timing resolution, they have shown that independently on the mass accretion rate in the binary system the emission of the accretion disk boundary layer might be well described by a diluted blackbody model, which parameters are determined practically only by the gravity of the neutron star. The measured spectral parameters of the neutron star boundary layer emission allowed them to put constrains on the ratio of mass to radius of the studied neutron stars. Assuming masses of the neutron stars approximately $1.4M_{\odot}$ the constrains on the radii are $\sim 9 - 14$ km. Analysis of a large number of observations of different systems at different instant mass accretion rate allowed to trace the behavior of the accretion disk in the binary system. It was shown that approximately at the Eddington mass accretion rate the structure of the accretion disk strongly changes, it is likely that the accretion flow near the neutron star becomes puffed up. Proposed model of the behavior of the whole accretion flow in the systems reasonably well describes the so-called "Z-track" of the bright neutron star X-ray binaries. M. Revnivtsev, S. Sazonov, M. Gilfanov, E. Churazov and R. Sunyaev utilized data of the scanning and slewing observations of the RXTE observatory and showed that the origin of the Galactic ridge X-ray emission, which was a long standing problem in Galactic X-ray astronomy since the discovery of this emission in late seventies, is a superposition of a large number of known type of Galactic X-ray sources. First of all it was shown that the intensity distribution of the Galactic ridge X-ray emission very closely follows the intensity distribution of the near infrared emission of the Galaxy which is in turn very closely traces the Galactic stellar mass distribution. Then, analyzing the results of all sky surveys performed by the RXTE and ROSAT observatories the luminosity function of weak Galactic X-ray sources was constructed which covered very broad luminosity range $10^{27} - 10^{34}$ erg/s. Comparison of the unit stellar mass X-ray emissivity obtained from the constructed luminosity function with that obtained from the Galactic ridge X-ray emission showed that they give compatible values. It confirms that the majority of the Galactic ridge X-ray emission consists of known type of Galactic X-ray point sources and not of truly diffuse emission. Comparison of composite spectrum of weak X-ray point sources which make contribution to the unit stellar mass Galactic emissivity with that of the Galactic ridge emission also confirmed the abovementioned conclusion. M. Revnivtsev and R. Sunyaev in collaboration with Space Research Institute (Moscow, Russia) and Kazan State Univ. (Kazan, Russia) performed optical follow up observations of newly discovered active galactic nuclei (AGN) candidates. Analysis of a number of observations allowed them to identify six nearby ($z < 0.1$) AGNs. Parameters of the brightest emission lines are measured, which allowed to classify discovered AGNs. Importance of this result is underlined by the fact that such bright nearby AGNs are not numerous. In total only $\sim 30 - 40$ nearby ($z < 0.1$) AGNs with such luminosities are known to date. M. Revnivtsev and R. Sunyaev in collaboration with Special Astrophysical Observatory (Nizhnij Arkhyz, Russia), Sternberg Astronomical Institute (Moscow, Russia), Univ. of Oulu (Oulu, Finland), Kazan State Univ. (Kazan, Russia) and TUBITAK National Observatory (Turkey) studied the different time scale variability of supercritically accreting Galactic X-ray binary system SS433 and in particular the broad band power spectra of its flux variability in X-rays, optical and radio energy bands. It was shown that the power spectra of its flux variability in different energy bands are practically identical and can be represented by a power law with flattening at frequencies lower than 10^{-7} Hz. Such a flattening means that on time scales longer than $\sim 10^7$ sec the source variability becomes uncorrelated. This naturally leads to the appearance of quasi-poissonian flares in the source light curve, which have been regularly observed in radio and optical spectral bands. The broad band power spectrum of SS433 can be interpreted in terms of self-similar accretion rate modulations in the accretion disk proposed by Lyubarskii (1997) and elaborated by Churazov et al. (2001). There was also found a correlation of the radio and optical fluxes of SS433 and the radio flux is delayed by about ~ 2 days with respect to the optical one. This is an anticipated time scale for a transportation of perturbations from regions where optical emission originate to the regions of creation of radio emission of SS433.

The INTEGRAL observatory continues to survey the hard X-ray sky and will eventually provide an unbiased sample of active galactic nuclei (AGN), including those whose optical and soft X-ray emission is obscured by dust and gas. S. Sazonov, E. Churazov, M. Revnivtsev, and R. Sunyaev in collaboration with A. Vikhlinin (Harvard-Smithsonian Center for Astrophysics, Cambridge, USA) observed with the Chandra X-ray telescope 8 hard X-ray sources discovered by INTEGRAL during the all-sky survey. In 6 cases a bright X-ray source was found within the INTEGRAL localization region, which permitted to unambiguously identify 5 of the objects with nearby galaxies, implying that they have an active galactic nucleus, whereas one source is likely an X-ray binary in LMC. 4 of the 5 newly discovered AGN have measured redshifts in the range 0.025–0.055. The X-ray spectra reveal the presence of significant amounts of absorbing gas ($N_{\rm H}$ in the range 10^{22}–10^{24} cm^{-2}) in all 5 AGN, demonstrating that INTEGRAL is starting to fill in the sample of nearby obscured AGN.

Further, M. Revnivtsev, S. Sazonov, E. Churazov in collaboration with S. Trudolyubov (Institute for Geophysics and Planetary Physics, Univ. of California) used observations with RXTE, INTEGRAL, and the XRT telescope on SWIFT to identify four X-ray sources discovered during the recent RXTE Slew Survey (XSS) of the $|b| > 10°$ sky with nearby ($z \sim$0.017–0.098) luminous ($L_{\rm X} \sim 5 \times 10^{42}$–$10^{44}$ erg s^{-1}) AGN. Two of the objects exhibit heavily intrinsically absorbed X-ray spectra ($N_{\rm H}10^{23}$ cm^{-2}). This study fills some of the remaining gaps in the XSS catalog. The final XSS catalog will consist of up to $\sim$ 130 X-ray bright ($\gtrsim$0.5–1 mCrab), mostly nearby ($z < 0.1$) AGN, and serve as a useful input sample for detailed studies of the local AGN population, complementing the information provided by the continuing INTEGRAL and SWIFT hard X-ray all-sky surveys.

3.5 Accretion

Black Hole systems, either in X-ray binaries or in active galactic nuclei, when shining at luminosities close to the Eddington limit are thought to be powered by accretion through geometrically thin, optically thick discs. However, according to the widely adopted standard accretion disc solutions, highly luminous accretion discs close to the Eddington rate should be radiation pressure dominated and therefore unstable to perturbations of both mass flow and heating rate, under the commonly adopted assumption that viscous stresses within the disc are proportional to the total (gas+radiation) pressure (Shakura and Sunyaev 1973). Thus, it is not clear yet to what extent these standard solutions represent a realistic description of the observed systems. A. Merloni has been interested in the X-ray spectral properties of the most extreme Seyfert galaxies and Narrow Line Seyfert 1s, which exhibit the strongest relativistic effects, the most peculiar spectral features, and, possibly, the most powerful outflows, comparable to BAL QSOs. In particular, a new, self-consistent model has been recently proposed to explain these observational properties in terms of radiation pressure dominated accretion flows which are subject to strong clumping instabilities. The research was carried out in collaboration with J. Malzac (CESR, Toulouse, France), A.C. Fabian (University of Cambridge, UK) and R.R. Ross (College of the Holy Cross, USA). They have used a sophisticated radiative transfer code (the only one existing so far in literature) capable of self-consistently calculating the radiative equilibrium between the two phases present in the innermost region of an accretion disc so that mutual radiative feedback is fully taken into account. With such a code, we were able to demonstrate that for very inhomogeneous configurations, i.e. those which have both a large covering fraction in clouds and very concentrated dissipation, the emerging radiation can be dominated by ionized reflection and that the observed spectra are very complex, with prominent signatures of ionized reflection dominated by a plethora of UV and soft X-ray emission lines.

A. Merloni has also been carrying out numerical simulations of coupled accretion disc/jet systems in collaboration with S. Nayakshin (University of Leicester, UK). They have built a numerical, 1-D code that includes a detailed, physically motivated, and fully self-consistent dynamical treatment of a viscous disc within which magnetic field is amplified by the Magneto Rotational Instability and buoyantly escapes in the vertical direction. This allows to study both the generation of a X-ray emitting corona and the launching of a MHD driven jet/outflow. The model is time-dependent and couples the angular momentum equation (including both the turbulent and the jet induced torque) with the disc energy equation, in such a way that the disc instability can be studied in the presence of both jet and corona.

J. Cuadra, S. Nayakshin (Leicester), V. Springel and T. Di Matteo (CMU) developed a 3-dimensional numerical scheme to model the hydrodynamics of gas originated by stellar winds in galactic nuclei. They applied it to the Galactic centre and found that radiative cooling produces cold clumps of gas that coexist with the hot gas observed in X-rays. As a consequence, the accretion rate onto the central black hole is expected to be strongly variable on time-scales of tens to hundreds of years, probably making Sgr A* an important energy source for the Galactic centre.

J. Dunkel performed numerical simulations and analytical studies of disk models for the accretion of matter onto neutron stars and black holes. A main objective has been to implement more realistic opacity functions into the standard accretion disk model of Shakura and Sunyaev. Furthermore, the effects of unusual element abundances on the disk structure as well as the influence of advection and radial radiation heat diffusion have been investigated. This work was done in collaboration with R. Sunyaev and J. Chluba.

A range of observed phenomena in accreting X-ray sources does not fit easily in standard accretion disk theory: the presence of powerful jets, and the evidence that a 'second parameter' (in addition to the accretion rate) must be present to explain the X-ray behavior. H. Spruit and D. Uzdensky (Princeton) have developed a model which relates these two puzzles. The second parameter involved is the variable amount of net magnetic flux accumulated in the form of a strong flux bundle around the compact object.

F. Meyer, E. Meyer-Hofmeister together with L.B. Liu (Yunnan Observatory, Chinese Academy of Sciences) investigated the physics of spectral state transitions of low-mass X-ray binaries. The luminosities at which, during an outburst, the hard-soft and the soft-hard transitions occur differ from each other. Understanding this hysteresis is an important requirement for modeling of the interaction of corona and disk. It could be shown that it is caused by the different amount of Compton cooling and heating resulting from the irradiation of the accretion disk corona by the radiation emanating from the center at the time of the transition, in one case from an inner disk, in the other case from a hot coronal flow. A relation between hardness of the radiation and amplitude of the hysteresis was deduced. In further work F. Meyer and E. Meyer-Hofmeister evaluated how heat conduction influences the change-over from disk accretion to a hot coronal flow.

F. Meyer, E. Meyer-Hofmeister and L.B. Liu (Yunnan Observatory) analysed the "intermediate state" of black hole accretion for which the spectrum signals the presence of a hot advection-dominated accretion flow while at the same time an iron K-alpha line and reflection signatures indicate cool material within the same region. Such features can result from re-condensation of part of the hot flow into a cool inner disk.

U. Anzer, G. Börner, I. Kryukov (Moscow, Russia) and N. Pogorelov (Riverside, USA) extended their modelling of accretion flows to fully 3D calculations. They included the radiative cooling, and also the Compton heating and cooling which is produced by the radiation emitted from the central X-ray pulsar. These calculations will provide information on the stability of the accretion process.

P. Rebusco continued her work following the model of Kluźniak and Abramowicz to explain the twin peak high frequency QPOs in LMXRBs. For a fixed source and event, the twin peak QPOs frequecies f_1, f_2 resulted to be linearly correlated, $f_1 = Af_2 + B$. It was now proved that the resonance model predicts that for different sources the coefficients A and B should be nearly linearly anticorrelated. The previous predictions agree with the QPOs observations. After P. Rebusco had already proved that a small forcing may excite the parametric $3:2$ resonance in epicyclic oscillations of a nearly Keplerian accretion flow in strong gravity she now together R. Vio (Chip Computers Consulting s.r.l, Italy), P. Andreani (INAF-Osservatorio Astronomico di Trieste, Italy) and H.Madsen (Technical University of Denmark), integrated the same equations numerically, dropping the ad hoc forcing, but adding instead a stochastic term to mimic the action of the MRI turbulence. They found the stochastic term triggers the resonance and influences its pattern.

U. Anzer, G. Börner, I. Kryukov (Moscow, Russia) and N. Pogorelov (Riverside, USA) extended their modelling of accretion flows to fully 3D calculations. They included the radiative cooling, and also the Compton heating and cooling which is produced by the radiation emitted from the central X-ray pulsar. These calculations will provide information on the stability of the accretion process.

R. Oechslin and H.-Th. Janka performed relativistic hydrodynamic simulations of neutron star mergers with different microphysical equations of state in order to predict the gravitational-wave signals from such events and the torus masses which will survive the collapse of the central, compact merger remnant to a black hole. The computations revealed that between $0.05M_\odot$ and $0.25M_\odot$ can remain around the black hole for secular timescales. These torus masses were estimated to be sufficient for providing the energy that is needed to explain the recently observed, well-localized short gamma-ray bursts by ultrarelativistic, collimated outflows that are powered by neutrino-antineutrino annihilation. Such outflows were simulated by M.-A. Aloy, H.-Th. Janka, and E. Müller. The jet profiles for the computed set of models were used to make predictions for the redshift, fluence, and energy distributions of short-hard bursts. These theoretical predictions were compared with the current data of short-hard gamma-ray bursts with known redshifts (H.-Th. Janka, M.-A. Aloy, P. Mazzali, and E. Pian (Istituto Naz. di Astrofisica, Trieste)).

3.6 Interaction of radiation with matter

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 dimension 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 based on a variety of schemes and approximations. However, few analytical solutions exist that can be used to test the codes. B. Ciardi, in collaboration with I. T. Iliev (CITA, Toronto), A. Maselli (MPA, Garching) and others, has set up a number of numerical tests to compare different approaches.

B. Groves, using his radiative transfer and ionization program MAPPINGS, has modelled the infrared emission from the Narrow Line Regions (NLR) of active galaxies. The resulting models give insight into the general shape of the NLR IR emission, but also have resulted in diagnostic diagrams enabling the possible determination of NLR parameters in heavily obscured objects. These models also enable the NLR fractional contribution to the overall IR emission of active galaxies and IR luminous galaxies to be estimated.

3.7 Galaxy and AGN evolution

S. Charlot, in collaboration with A. Gallazzi (MPA), G. Kauffmann (MPA), H. Mathis (Oxford) and S. White (MPA), exploited his most recent population synthesis code to constrain stellar metallicities and star formation histories from the high-resolution SDSS spectra of over 10^5 nearby galaxies. The models were also used in collaboration with F. Lamareille, T. Contini (Toulouse) and O. Le Fèvre (Marseille) to interpret in a similar way the galaxy spectra gathered by higher-redshift surveys, such as the VLT-Vimos Deep Survey (VVDS). Finally, in collaboration with S. Salim (UCLA), G. Kauffmann (MPA), T. Heckman (JHU) and C. Martin (Caltech), S. Charlot exploited a physically motivated treatment of attenuation by dust to interpret simultaneously the ultraviolet and optical emission from over 6000 nearby galaxies for which both GALEX and SDSS photometry was available.

B. Panter continued the development of the MOPED algorithm and improved the resolution of the code to 3 Å, the limit of the current state of the art models. The improved algorithm has been applied to the third data release of the Sloan Digital Sky Survey in collaboration with Rita Tojeiro and Alan Heavens of the Royal Observatory in Edinburgh and Raul Jimenez of the University of Pennsylvania. In addition, B. Panter has worked with G Lemson of the MPE and Alex Szalay of the John Hopkins University to deploy the MPA version of the SDSS-SQL database and provide Virtual Observatory support to members of the MPA wishing to implement their data in the SQL environment.

In the last years a lot of effort has been made by several groups to include the effect of the α-enhancement (overabundance of α elements relative to iron when compared to solar values) in stellar population models, in order to better understand massive galaxies. In the evolutionary stellar population models, all ingredients should consistently consider the α-enhancement. A stellar library was computed by P. Coelho and published in Coelho et al. (2005). Stellar evolution tracks were computed by A. Weiss (MPA, Weiss et al., in preparation), and both ingredients are being included by P. Coelho, S. Charlot (IAP) and G. Bruzual in the stellar population code by Bruzual & Charlot (2003). This work will produce the first fully consistent high-resolution spectralmodels for α-enhanced stellar populations (Coelho et al, in preparation).

A. Gallazzi, under the supervision of S. Charlot (MPA) and S. White (MPA), and in collaboration with J. Brinchmann (Porto), developed a new method, based on a recent, high-resolution population synthesis code, to derive simultaneous estimates of stellar metallicities, ages and stellar masses from galaxy optical spectra. The method has been applied to a sample of over 10^5 SDSS galaxies, including both quiescent early-types and star-forming galaxies. The new stellar metallicity and age estimates and the large statistical power of the SDSS, allowed to explore in great detail the dependence of age and stellar metallicity on stellar mass for different classes of galaxies and to re-investigate the physical origin of well-known observational relations for early-type galaxies. They exploited these physical parameters estimates to derive the total metal content in stars in the local Universe and to study the distribution of metals as a function of galaxy properties.

B. Groves studied the the distinctions between three classes of emission line galaxies in the SDSS DR4 sample: Starbursts or star-forming galaxies, Seyfert 2 galaxies and low ionization narrow line emission region galaxies or LINERs. In collaboration with L. Kewley (IoA, Hawaii), G. Kauffmann and T. Heckman (John Hopkins University, MD), he has shown that LINERs and Seyferts are distinct objects with clear separations between their emission line properties and the properties of their host galaxies. Also revealed is the continuum of host galaxy and emission line properties that exist between the star formation dominated starbursts and AGN dominated Seyferts.

G. Kauffmann studied the recent star formation histories of local galaxies in the Sloan Digital Sky Survey by analyzing the scatter in their colours an spectral properties. The work was carried out in collaboration with T. Heckman (JHU), G. de Lucia, J. Brinchmann (Porto), C. Tremonti (Steward Observatory) and S. White. The conclusion of the study was that galaxy subpopulations of all stellar masses form their stars at the same average rate per unit stellar mass. However, the scatter in galaxy colours and emission line strengths is larger for more compact galaxies of a given mass. This suggests that star formation occurs in shorter, higher amplitude events in galaxies with smaller sizes. Above a characteristic density, galaxy growth through star formation shuts down. A model was developed in which star formation events are triggered when cold gas is accreted onto a galaxy and the new high resolution Millennium Simulation of V. Springel and collaborators was used to quantify the incidence of these accretion events.

G. Kauffmann continued her work analyzing the properties of galaxies with actively accreting black holes. In collaboration with A. Pasquali (Zurich) and T. Heckman (JHU), the far-infrared properties of galaxies with and without active nuclei (AGN) were compared using a matched catalogue of galaxies from the Sloan survey that were detected in the IRAS satellite data. In collaboration with T. Heckman , A. Ptak and A. Hornschemeier (JHU), the relationship of hard x-ray and optical line emission was studied using data from Chandra and XMM. In collaboration with A. Moretti (Padova), the Lick indices of galaxies with AGN were compared with control samples on non-AGN. The far ultraviolet properties of nearby active galaxies are now being investigated using data from the Galaxy Evolution Explorer (GALEX) satellite.

S. Sazonov and R. Sunyaev in collaboration with J. Ostriker (Princeton University) and L. Ciotti (University of Bologna) explored the possible role of feedback via photoionization and Compton heating in the co-evolution of SMBHs at the center of spheroidal galaxies and their stellar and gaseous components. It was found that the observed black-hole-mass/stellar-velocity-dispersion relation could be established following the conversion of most of the gas of an elliptical progenitor into stars, specifically when the gas-to-stars mass ratio in the central regions has dropped to a low level $\sim$0.01 or less, so that gas cooling is not able to keep up with the radiative heating by the growing central SMBH. A considerable amount of the remaining gas will be expelled and both SMBH accretion and star formation will proceed at significantly reduced rates thereafter, in agreement with observations of present day ellipticals.

D. Croton, in collaboration with 10 other authors from the MPA and elsewhere, elaborated his implementation of the formation of galaxies and their central black holes within the Millennium Simulation. This was the galaxy formation model used in the original Nature article on the simulation published in May 2006. This work demonstrated clearly that the observed luminosity function of galaxies cannot be reproduced in the context of the "concordance" ΛCDM cosmology without invoking at least two independent feedback mechanisms. One, plausibly a combination of radiative heating of the IGM by quasars and young galaxies and ejection of material in galactic winds, is required to suppress star formation in low mass halos. This is necessary to produce a relatively flat luminosity function at low luminosity. A separate process is required to suppress late-time cooling and star formation in massive halos which otherwise produce galaxies which are much brighter, bluer and more massive than those actually observed in the centres of groups and clusters. This feedback is plausibly associated with radio galaxy activity and simple models reproduce not only the observed galaxy luminosity function, but also the clustering of galaxies as a function of luminosity, colour and morphology.

G. De Lucia, in collaboration with V. Springel, S. D. M. White, D. Croton and G. Kauffmann, studied the formation and the evolution of elliptical galaxies within this same semi-analytic model which tracks dark matter halos and their embedded substructures within the *Millennium Simulation*. Massive ellipticals in this model have higher metal abundances, older luminosity–weighted ages, shorter star formation timescales, but lower assembly redshifts than less massive systems. Within clusters the typical masses, ages and metal abundances of ellipticals are predicted to decrease, on average, with increasing distance from the cluster centre. These findings are consistent with recent observational results that suggest "down-sizing" or "anti-hierarchical" behaviour for the star formation history of the elliptical galaxy population, despite the fact that the model includes all the standard elements of hierarchical galaxy formation and is implemented on the standard, ΛCDM cosmogony.

M. G. Kitzbichler in collaboration with D. Croton and S.D.M. White made use of these same Millennium Simulation, semi-analytic models, incorporating a new mode of AGN feedback, dubbed radio mode. Studying the evolution of the population out to higher redshifts, one finds good agreement between high-redshift predictions from the simulations and the available data already with the default model, calibrated using local data only. Improving the recipe for gas cooling in low mass systems brings the simulations into agreement with observations even better. In order to facilitate the comparison between simulations and recent intermediate and high-redshift surveys, a computer program has been devised that produces a number of independent mock observations of the simulated galaxies out to arbitrarily high redshifts. Utilizing this tool it is also possible to make predictions for future galaxy surveys, deeper in magnitude and redshift than current ones.

D. Sijacki, in collaboration with V. Springel, studied feedback by active galactic nuclei (AGN) in clusters of galaxies, using hydrodynamical simulations of structure formation. Besides self-gravity of dark matter and baryons, their numerical models incorporated radiative cooling and heating of the gas, as well as star formation and supernova feedback. D. Sijacki extended the numerical code with new models that explore AGN heating in the cores of galaxy clusters and groups. She analyzed how the properties of intracluster gas and stars are affected over cosmic time by recurrent heating events provided by AGN-driven bubbles. She explored a variety of different assumptions for the spatial configuration of hot bubbles, for their duty cycles, and the energy injection mechanism. Moreover, she studied the occurrence of sound waves generated by the buoyantly rising bubbles in the atmospheres of clusters. She also analyzed the efficiency and spatial spreading of AGN bubbles during the merging episodes of clusters, and determined the dependence of these processes on cluster mass. As a result, D. Sijacki could show that AGN feedback is likely an essential ingredient of galaxy cluster physics and provides a promising solution to a number of open questions: it can in principle account for the low star formation rates and red colors of central cluster galaxies, for the mismatch between simulated and observed metallicity gradients, for the X-ray scaling relations of clusters, and for the long-standing problem of the absence of strong cooling flows in clusters.

D. Sijacki, together with V. Springel and S. White, implemented a novel self-consistent treatment of fluids with physical viscosity in the parallel TreeSPH code GADGET-2. To this end, she derived a formulation of the Navier-Stokes and general heat transfer equations for the smoothed-particle hydrodynamics method that ties in consistently with the entropy and energy conserving framework used by the code. Both shear and bulk viscosity stress tensors have been considered. A Braginskii-Spitzer parameterization of the shear viscosity coefficient has been introduced as well, taking into account a possible suppression of the viscosity by magnetic fields. The implementation has been extensively tested on standard hydrodynamical problems and provides a very useful tool for the analysis of the properties of intracluster gas in the presence of some level of physical viscosity. In particular, with the new code it will be possible to estimate the amount of viscous damping of sound waves produced by AGN-driven bubbles during the active phases of black hole activity.

V. Springel, together with T. Di Matteo (Carnegie-Mellon University, Pittsburgh) and L. Hernquist (Harvard University, Cambridge), used hydrodynamical simulations to study the influence of supermassive black holes on colliding and merging galaxies. During the first encounter in the merger of two spiral galaxies, strong gravitational tidal forces trigger a nuclear gas inflow, which leads to a starburst and strong accretion onto the embedded supermassive black holes at the galaxies' centres. This accretion fuels quasar activity, and allows a central black hole to reach a period of exponential mass growth. In simulations of major mergers, it was found that this quasar activity has a significant impact on the star formation activity in the final stages of a merger and in the elliptical remnant that forms. The energy output by the growing black hole(s) can eventually become strong enough to truncate the star formation, and to expel much of the remaining gas. As a result, the forming elliptical galaxy quickly develops a very red spectral colour, as observed. On the other hand, in simulations without black hole activity, the remnants showed comparatively high levels of residual star formation, leading to spectrophotometric colours much bluer than observed. Quasar activity may therefore play an important role for establishing the observed bimodality in the colour distribution of galaxies.

The implications of feedback by supermassive black holes in galaxy merger simulations were further analysed in a collaboration of V. Springel, T. Di Matteo (Carnegie-Mellon University, Pittsburgh), P.F. Hopkins, L. Hernquist, B. Robertson and T.J. Cox (all four Harvard University, Cambridge). They showed that the simulations predict a relation between the quasar lifetime and the peak luminosity attained during the accretion activity, and hence with the final black hole mass. This allowed the construction of a novel theoretical model for the quasar luminosity function, based on a calibration of the relation between lifetime and peak luminosity obtained from a large sample of hydrodynamical merger simulations. Unlike in previous studies that used very simple models for quasar lifetimes, the new interpretation associates the faint-end of the quasar luminosity function with quasars that are in sub-Eddington quiescent states, or are going into or are coming out of a period of peak activity, while the bright end directly traces the intrinsic peak quasar activity. This model provides a stunningly good match to observational data over a very wide range of passbands. In addition, an identification of quasar activity with formation events of elliptical galaxies can at the same time explain many properties of the population of luminous red elliptical galaxies.

E. Hayashi studied the kinematics of disk galaxies in triaxial halos using the solutions for closed loop orbits in nonaxisymmetric potentials. He found that deviations from circular motion caused by a nonspherical potential can obscure the structure of the dark matter halo as inferred from simple analyses of the inner shape of observed disk galaxy rotation curves. He also investigated the shapes of dark matter halos in cosmological simulations in collaboration with J. Navarro (University of Victoria). The lensing properties of galaxy clusters in the Millennium simulation were also studied using ray tracing software developed by M. Bartelmann and M. Meneghetti (University of Heidelberg).

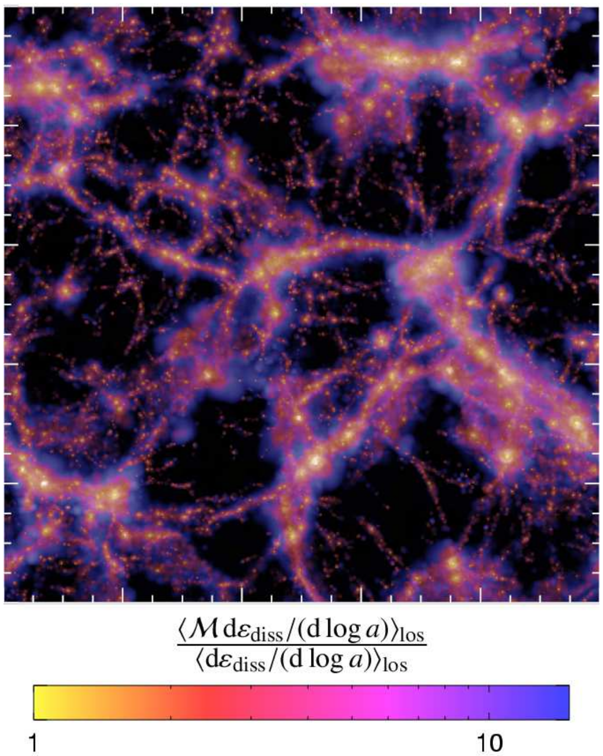

Figure 3.1: Distribution of shock waves in a simulated Universe, identified with the new SPH-shock capturing code. The Mach number of the shocks is colour-coded, and the energy dissipation rate is brightness-coded. Strong shocks with high Mach numbers (blue) enclose structures like galaxy clusters, in which weak (low Mach number) shocks dominate.

One of the most debated issues in the theoretical modeling of cosmic reionization is the impact of small-mass gravitationally-bound structures. B. Ciardi, in collaboration with E. Scannapieco (Kavli Institute for Theoretical Physics, Santa Barbara), F. Stoehr (IAP, Paris), A. Ferrara (SISSA, Trieste), I. T. Iliev (CITA, Toronto) and P. R. Shapiro (U. Texas, Austin), has carried out the first numerical investigation of the role of such minihaloes, which serve as self-shielding screens of ionizing photons. She finds that, depending on the details of the minihalo formation process, their effect on the overall progress of reionization can range from modest to significant.

Another debated issue is the role of very massive, metal-free stars in the first stages of reionization. B. Ciardi, in collaboration with R. Schneider (Centro Enrico Fermi, Roma), R. Salvaterra (U. Insubria, Como) and A. Ferrara (SISSA, Trieste), has investigated the physics of the transition from an early epoch dominated by massive Pop III stars to a later epoch dominated by familiar low-mass Pop II/I stars and their impact on reionization.

3.8 Large scale structure, galaxy clusters and the Intergalactic Medium

Gao Liang, in collaboration with Volker Springel and Simon White, used the statistical power provided by the very large Millennium Simulation to explore the clustering properties of dark matter halos as a function of further parameters in addition to halo mass. This uncovered the unexpected result that the clustering of low-mass halos of given mass is a strong function of halo formation time. Halos which formed early are much more strongly clustered than halos of the same mass which formed more recently. This formation time dependence disappears at halo masses much larger than that of the Milky Way. It is inconsistent with the standard excursion set theory for the build-up of nonlinear structures which predicts that the formation of an object of given mass should be independent of its environment. The galaxy population of a dark halo plausibly depends significantly on its formation history. In consequence, the halo occupation distribution models often used to derive cosmological parameters from observations may give systematically incorrect results since they assume that the galaxy content of dark halos depends on halo mass alone.

T. Enßlin, C. Pfrommer, V. Springel, and M. Jubelgas developed a mathematical formalism which allows to include the effect of relativistic particle populations (cosmic rays) in hydrodynamic simulations. The formalism is a compromise between the complexity of cosmic ray physics and the requirement of computational efficiency. It encloses descriptions for cosmic ray injection at shock waves and supernova remnants, cooling due to Coulomb and hadronic interactions with the background gas, adiabatic energy changes, re-acceleration, and momentum dependent and anisotropic diffusion. The cosmic ray pressure force was formulated in a way which allows an implementation into energy and entropy conserving smoothed particle hydrodynamics (SPH) simulations. Comparisons with the extact solution in a situation of balance between supernova injection and cosmic ray dissipation have shown that the simplified model can reproduce the CR pressure to an accurate of $\tilde{5}\%$. The formalism can serve in a large number of projects, including from analytical investigations to cosmological simulations.

The formalism was implemented by M. Jubelgas and V. Springel into the GADGET SPH simulation code. Extensive tests were performed to demonstrate e.g. the stability of the code and that energy is conserved in the simulation. In addition, C. Pfrommer developed a shock wave capturing algorithm permitting to measure shock strength in-situ during a SPH simulation run for the first time. This shock strength measurement is required for the description of cosmic ray injection at shock waves. The resulting GADGET extension is suitable to simulate many cosmological interesting scenarios, ranging from the effect of cosmic rays on galaxy formations to the cosmic ray distribution injected into galaxy clusters due to structure formation shock waves.

First results in galaxy formation simulations indicate that the cosmic ray pressure can play an important role in regulating star formation in galaxies: In smaller galaxies star formation seems to be suppressed due to a relatively high cosmic ray pressure, compared to the thermal one. Whereas in large galaxies the cosmic ray pressure stays negligible. This is a very important finding, since it can be the key to understand the apparent low star formation efficiency of low mass galaxies, a riddle of our current understanding of galaxy formation.

The shock capturing scheme allowed to build up a statistic of the strength of shock waves in cosmological simulations. This statistic is in agreement with results of previous publications by other workers. However the new statistic has a range which is increased by several orders of magnitude. This statistic shows that the shock waves with strongest Mach numbers occur in the periphery of galaxy clusters (see Fig. 3.1). This has important consequences for our understanding of the spatial distribution of relativistic particles in the cosmic large-scale structure, since it suggests that the ratio of the energy density of cosmic ray proton population to the thermal gas within galaxy clusters increases with the cluster radius. Just such an increase is required to explain the huge extended radio synchrotron halos of galaxy clusters by the injection of relativistic electrons through hadronic interactions of the cosmic ray protons with the background gas.

K. Dolag, together with F. Vazza (Dip. Astro., Padova), G. Tormen (Dip. Astro., Padova) and G. Brunetti (INAF IRA, Bologna) studied the build up of turbulence in galaxy clusters by means of hydrodynamical simulations. We implemented - in the parallel TREESPH-code GADGET2 - a novel scheme to handle artificial viscosity. This new scheme reduces the artificial viscosity of SPH outside of shocks significant and therefore for the first time allows to study turbulent gas motions in high resolution simulations of galaxy clusters. Furthermore, a novel filtering technique was used to separated the turbulent velocity pattern from the large scale cosmological velocity field. We find that turbulent motions in the cluster center can carry up to 30% of the thermal energy budget. Thereby this none thermal pressure support leads to a flatter density profile within the core and reduced the predicted X-ray luminosity by about a factor of 2. Applying a model for accelerating relativistic electrons by ICM turbulence we find that galaxy clusters simulated with reduced viscosity scheme may develop sufficient turbulence to account for the radio emission that is observed in many galaxy clusters, provided that a non–negligible fraction of the turbulent energy in the real ICM is associated with Fast Modes.

K. Dolag, together with M. Meneghetti (ITA, Heidelberg), L. Moscardini (Dip. Astro., Bologna), E. Rasia (Dip. Astro., Padova) and A. Bonaldi (Dip. Astro., Padova) studied the physical properties of the matter inside the cosmic web by means of a high resolution, hydrodynamical simulation of filaments embedded in a super cluster region. The typical, orthogonal extent found for such filaments is 5 Mpc before the roundisch shape of the filaments fades into the structure of sheets. The density profile is found to scale flatter than in bound structures like galaxy clusters. Analyzing synthetic maps of observational quantities like galaxy distribution, X-ray surface brightness, SZ maps or gravitational lensing maps we found - with the exception of the galaxy over density - a direct detection to be quite challenging, also for future missions.

K. Dolag, together with S. Ettori (INAF, Obs., Bologna), S. Borgani (Dip. Astro. Trieste) and G. Murante (INAF, Pino Torinese) studied the baryon mass fraction by means of hydrodynamic simulations of galaxy clusters. Main emphasis was taken on the prediction of simulations carried out with different complexity of modeling the ICM as well as on the time evolution of the baryonic mass fraction. Both are crucial if once want to calibrate the systematic effects which are limiting the use of the X-ray gas mass fraction as a cosmological tool. In general, at z=0 the cosmic baryon fraction is reached at about 3 times the virial radius, independent on the details in the treatment of the physical processes within the ICM. However, at radii smaller than the virial radius, where the baryon fraction shows significant evolution with cosmic time. For the set of simulations with different complexity of modeling the ICM we computed redshift dependent corrections for the baryonic mass fraction.

A wealth of information on the reionization history is likely to be obtained by the next generation of radio telescopes. In fact, it has long been known that neutral hydrogen in the IGM may be directly detectable in emission or absorption against the CMB radiation at the frequency corresponding to the redshifted 21 cm line. B. Ciardi, in collaboration with M. Valdes (SISSA, Trieste), A. Ferrara (SISSA, Trieste), M. Johnston-Hollit (University of Tasmania) and H. Röttgering (Sterrewacht Leiden), has used numerical simulations of cosmic reionization and 21 cm emission line to produce synthetic radio maps as seen by LOFAR, finding that, if reionization occurs relatively late, the telescope will be able to detect HI structures on arcmin scales.

Additional information on the structures in the early universe can be obtained by observations of spectroscopic measurements of molecular and atomic absorption lines in the afterglow of high-redshift gamma-ray bursts. B. Ciardi, in collaboration with S. Inoue (MPI, Heidelberg) and K. Omukai (NAOJ, Tokyo), finds that such lines might be detected by ALMA and/or SKA, offering a unique probe of the physical conditions in individually Pop III and early Pop II star forming regions.

Visiting graduate stuent Li Cheng (Hefei) in collaboration with G. Kauffmann, Y.P. Jing (Shanghai), G. Börner, F. Cheng (Hefei), and S. White studied how galaxy clustering (as measured by the projected two-point correlation function and the pairwise velocity dispersion in Fourier space) depends on galaxy properties such as stellar mass, colour, concentration, and stellar surface mass density for a sample of 200,000 galaxies in the Sloan Digital Sky Survey. Galaxies with redder colours, higher concentration and density were found to cluster more strongly. The clustering differences were largest on small scales and for low mass galaxies. One interesting result was that the dependence of the correlation function of colour extended out to physical scales significantly larger than those of individual dark matter haloes (> 5 Mpc/h). This large-scale clustering dependence was not seen for the structural parameters. On small scales (< 1 Mpc/h), the amplitude of the correlation function also exhibited strikingly different dependences on galaxy age and on structural parameters, demonstrating that different processes are required to explain environmental trends in the structure and in star formation history of galaxies. Visiting graduate student L. Wang (Beijing) is currently interpreting these results using mock catalogues from the Millennium Run Simulation.

G. Hütsi studied the clustering of SZ-selected galaxy clusters on a past light-cone, particularly paying attention to the possibility of constraining properties of dark energy. The prospects of detecting baryonic features in the cluster power spectrum for a wide and shallow survey like PLANCK, and for an SPT-like narrow and deep survey were investigated. It was demonstrated that on largest scales these future blank sky SZ surveys will have the capability to improve over the recently announced detection of baryonic oscillations based on the SDSS Luminous Red Galaxy sample. Cosmological parameter forecasting was carried out using a Fisher matrix approach, including the treatment for the anisotropic nature of the power spectrum due to redshift space and cosmological distortions. It was shown that together with the complementary observational constraints from the CMB studies interesting limits for the dark energy equation of state parameter can be expected.

G. Hütsi carried out a full analysis of the SDSS DR4 Luminous Red Galaxy sample power spectrum, finding evidence for a series of acoustic features down to the scales of $\sim 0.2\,h\,\mathrm{Mpc}^{-1}$. This corresponds up to the 7th peak in the CMB angular power spectrum. The derived acoustic scale, $(105.4 \pm 2.3)\,h^{-1}\,\mathrm{Mpc}$, was found to agree very well with the "concordance" model prediction and also with the one determined via the analysis of the spatial two-point correlation function by D. Eisenstein (Univ. of Arizona) and collaborators. The models with baryonic features turned out to be favored by 3.3σ over their "smoothed-out" counterparts without any oscillatory behavior.

J. Blaizot studied the clustering properties of SDSS galaxies using the GALICS semi-analytic model (SAM) for galaxy formation. He found that this model is able to reproduce the observed 2- to 5-point correlation functions provided that galaxies are distributed as dark matter substructures. This work was done in collaboration with S. Colombi, F. Bouchet (IAP, France), I. Szapudi, J. Pan (Univ. of Hawaii), A. Szalay, T. Budavari (Johns Hopkins Univ.), B. Guiderdoni, J. Devriendt (Obs. de Lyon, France). J. Blaizot also participated in the development of a model for Lyman- alpha emission of Lyman break galaxies (in collaboration with J.-M. Rozas, from Barcelona University) and to the development of a new model for the joint evolution of AGNs and galaxies within the GALICS model (in collaboration with A. Cattaneo (Astro. Inst. of Potsdam), J. Devriendt and B. Guiderdoni).

J. Blaizot worked in analysing the Millennium simulation both with the GALICS model and the Munich model (in collaboration with G. De Lucia, MPA). He adapted the MOMAF code to run on this simulation so that simulated light-cones can be made, either filled with DM particles, DM haloes, or galaxies. An web interface was made in collaboration with G. Lemson (MPE) so that light-cones can be built on-line.

A. von der Linden constructed a sample of local galaxy clusters from the Sloan Digital Sky Survey, placing particular emphasis on the identification of the central dominant galaxy and accurate velocity dispersions. This sample of central cluster galaxies has been used by her, Philip Best (Edinburgh), and Guinevere Kauffmann to show that the fraction of these galaxies that are radio-loud is about twice as high as for other galaxies of the same mass. This implies that a cluster supplies its central galaxy with more gas to feed the central supermassive black hole than the other galaxies.

A. von der Linden, G. de Lucia, and S. White collaborated with Bianca Poggianti (Padova) and other members of the EDisCS science team to investigate the evolution of star formation activity in galaxies, depending on the environment. They used the [OII] emission line as a diagnostic for ongoing star formation, and measured the fraction of star-forming galaxies in galaxy clusters at intermediate to high redshifts (0.4 to 1) and in a sample of local clusters, drawn from the Sloan Digital Sky Survey. In the high redshift sample, the star-forming fraction anti-correlates with the velocity dispersion of the system (used as a prior for the cluster mass), whereas in the local clusters, star formation activity is generally low in the most massive systems, and varies in low-mass systems. The strongest evolution is thus seen in intermediate-mass systems. By comparison with the Millenium Simulation, they developed a scenario to link the star formation activity with the growth of dark matter halos.

An alternative to the standard dark matter cosmological paradigm is that of Modified Newtonian Dynamics or MOND according to which Newtonian gravity fails on large scales. Recently, a phenomenologically successful, relativistic generalisation for MOND has been proposed by Bekenstein (2004). The theory consists of three dynamical gravitation fields and succeeds in explaining a large part of extragalactic and gravitational lensing phenomenology without invoking dark matter. D. Giannios studied the strong gravity regime of this theory. More specifically, he studied spherically symmetric static and vacuum spacetimes relevant for a non-rotating black hole or the exterior of a star. Two branches of solutions are identified and is shown that in the first one the β and γ PPN coefficients in TeVeS are identical to these of general relativity (GR) while in the second the β PPN coefficient differs from unity violating observational determinations of it. For the first branch of solutions, exact analytic expressions for the physical metric are derived and their implications are discussed. Applying these solutions to the case of black holes, it is shown that they violate causality (since they allow for superluminal propagation of metric, vector and scalar waves) in the vicinity of the event horizon and that they are characterized by negative energy density carried by the vector field.

3.9 Gravitational lensing

R. B. Metcalf worked on simulations of gravitational lensing using a combination of N-body simulations and analytic modeling of the lenses. A. Amara (CEA Saclay, France) visited for one week to collaborate on these simulations. This is also in collaboration with P. Madau a long term visitor to the MPA. The CDM model predicts a large amount of substructure in dark matter halos which has not been observed directly. The goal of these studies is to determine what effects the substructure has on the lensing properties and compare them with observations of strong gravitational lenses. R.B.

Metcalf also worked on constraining the density of primordial black holes in the universe using the gravitational lensing of type Ia supernovae and has been able to rule them out as the primary constituent of dark matter if there masses are above 0.01 solar masses.

O. Möller developed a code to fit cluster mass models to the full structure of gravitationally lensed arcs, using the information from individual arc-pixels as well as the empty, "null-spaces" in observed lens clusters. This code was applied to extend the study of the kinematical structures of gravitationally lensed arcs (in collaboration with E. Nordermeer, Groningen). It was shown that the kinematic properties of the source can in principle be reconstructed from IFU observations with current and future instruments. Such observations would enable determination of rotation curves of high redshift galaxies with an accuracy of 20% out to 2-3 scale lengths. Lensing cluster mass models can also be improved in this way.

S. Hilbert developed in collaboration with V. Springel a software program for ray-tracing the Millennium Run simulation in order to study various gravitational-lensing effects. In collaboration with O. Möller, S. Hilbert studied the influence of the use of different fixed and adaptive smoothing lengths for projecting the particles of N-body simulations on the strong-lensing cross section of galaxies and galaxy clusters.

K. Dolag, together with E. Puchwein (ITA, Heidelberg), M. Bartelmann (ITA, Heidelberg) and M. Meneghetti (ITA, Heidelberg) studied the impact of the ICM for the strong gravitational lensing signal of galaxy clusters. Using hydrodynamical simulations of galaxy clusters it was demonstrated that such cluster simulations - specially when strong turbulence is present in the core - predict a smaller strong lensing cross section then the pure dark matter n-body simulations. In contrary, simulations which allow the ICM to cool and to form stars, predict a steeper central density profile and thereby increase the strong lensing cross section significantly.

H. Sandvik, together with J. Diego and M. Tegmark(MIT) and P. Protopapas (CfA), further developed a model-independent method for cluster lens mass reconstruction from strong gravitational lensing data. The method was used on the giant arc system A1689(Broadhurst et.al. 2004). A total mass of $0.25\times10^{15}h^{-1}M_{\odot}$ within a 70" circle radius from the central peak was recovered. The result was tested using simulated data mimicking the observations, confirming that the reconstructed mass between 25" and 70" is an unbiased estimate of the true mass distribution of the cluster, however a bias was identified in outer regions. The method was thus further improved by including weak lensing data which was shown to significantly reduce this bias, as well as reduce the need for priors and/or regularization schemes. In a further attempt at increasing the signal to noise in model-independent reconstruction schemes the group have also investigated use of extended basis functions with particular, favourable symmetries. One such set of basis functions has been shown to allow for optimisation in the "image plane" as opposed to the "source plane" optimisation previously employed. P. Protopapas (CfA) spent one week at the MPA as H.Sandvik's guest working on this issue.

3.10 Cosmic Microwave Background Studies

The MPA is participating in the Planck Surveyor Mission of the European Space Agency, which aims at sensitive and high-resolution measurements of the Cosmic Microwave Background in order to study Cosmology with an unprecedented precision. S. White and R. Sunyaev are Co-Principal Investigators of the mission. T. Enßlin is managing the Planck Surveyor team at MPA. Due to their engagement in the project, several institute members acquired the official status of a Planck scientist with Planck data rights within 2005: A.J. Banday, R. Hell, W. Hovest, and S. White.

In December 2005, the Planck team delivered important software infrastructure to the Planck project. As part of the Planck Integrated Document and Information System (IDIS) release 2.0 two software components were distributed:

1. The *Process Coordinator* (ProC) is a scientific workflow engine with graphical user interface, which will be used to build and execute the Planck software pipelines (see Fig. 3.2). These consist of software modules written in a variety of native computer languages like Fortran, C, C++, or IDL. The ProC provides a framework for controlled execution of very complex pipelines within local and remote networks and guarantees the reproducibility and automatic documentation of any data product. The ProC is developed by W. Hovest, T. Riller, and U. Dörl.

2. A *Data Management Component* (DMC). The modules in the ProC-pipelines need to ex-

change data. This will be accomplished through the Planck DMC, which allows the definition and population of data structures, which can be stored, queried, and accessed in database management systems. To non-specialists (like astronomers) the DMC provides database functionality including data integrity due to transaction safety. The DMC is developed by R. Hell and T. Matthai.

The ProC and DMC will be the framework in which the data analysis pipelines of the Planck mission will be executed. The design of this software is so generic that it is usable in other projects. The software has become a part of the AstroGrid-D project, an astronomical community contribution to the construction of a German computational Grid, the *D-Grid* project of the *Bundesministerium für Bildung und Forschung*. As part of the AstroGrid-D activities, the ProC and DMC will be grid-enabled, permitting the deployment and execution of computations on a distributed network of computer farms. In the short period since the start of the Grid project in September 2005 H.-M. Adorf, who has taken over the responsibility for this task, together with U. Dörl and W. Hovest already managed to interface the ProC to a cluster scheduling system in a grid compatible way.

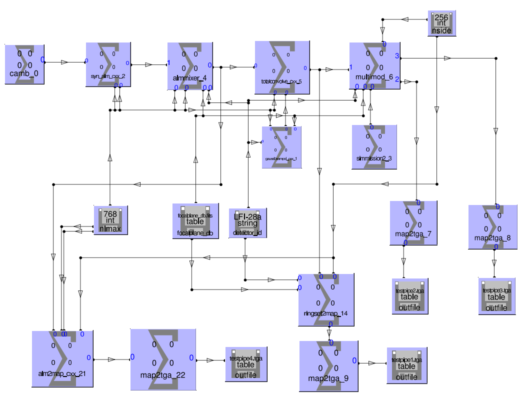

Figure 3.2: The pipeline editor of the Planck Process Coordinator. Shown is the simulation pipeline of the Planck mission. Each box represents a software module or data object, and the lines indicate the data flows between the different programs and objects.

M. Reinecke, M. Bartelmann (ITA, Heidelberg), K. Dolag, R. Hell, and T. Enßlin developed a simulation pipeline permitting to generate synthetic observations of the Cosmic Microwave Background with the Planck Surveyor instrument. The pipeline permits to simulate different cosmological models. It includes a variety of foreground emitters ranging from extra galactic over galactic to solar-system objects. It takes into account Planck-instrumental effects like noise, beam shapes and the satellite scanning strategy. The pipeline is an integral part of the Planck data analysis system developed by the international Planck collaboration. The pipeline is operating with the Planck data processing framework provided by the ProC and DMC packages (Fig. 3.2). The simulation package serves to develop, test, calibrate, and statistically characterize the official Planck data analysis pipeline. The description of the simulation pipeline is published and the functionality is provided to the scientific community through a web service[1], which was set up by G. Lemson of the German Astronomical Virtual Observatory group (MPE, Garching). As part of the simulation package development, the scientific software package HEALPix[2], to store and manipulate spherical maps in real and spherical harmonics space, was translated to C++ by M. Reinecke.

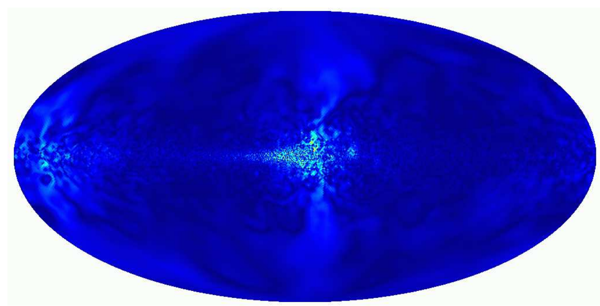

Figure 3.3: Simulated polarised synchrotron emission of the Galaxy. Note the depolarisation channels permeating the galactic disk.

A. Waelkens and T. Enßlin developed a computer code which allows to treat the radiative transfer of polarised radio-synchrotron emission within three-dimensional models of our galaxy including Faraday rotation along the radiation path. This can be used to generate consistent sets of artificial observations at all frequencies, required for the Planck Surveyor mission to test polarisation data analysis algorithms. Furthermore, the code allows detailed tests of models of the large scale galactic fields. Surprisingly, even simple versions of such models reproduced the mysterious *depolarisation channels* observed in high resolution radio maps of the galactic plane (Fig. 3.3).

[1]`http://www.g-vo.org/portal/tile/products/services/planck/index.jsp`
[2]`http://healpix.jpl.nasa.gov`

A.J. Banday in collaboration with T. Jaffe, K.M. Górski (JPL/CalTech, USA), H.K.E. Eriksen, F. Hansen, P. Lilje (Oslo, Norway) and P. Bielewicz (Warsaw University, Poland) has continued a comprehensive analysis of the statistical nature of the CMB anisotropy data collected by NASA's *WMAP* satellite.

A remarkable result was the apparent correlation of the observed large angular scale structure with a particular anisotropic model, specifically a Bianchi VIIh model. Detailed study indicated that this could not be caused by foreground residuals. The result remains provocative, not least because it provides a ready explanation of the asymmetry in the distribution of temperature fluctuations measured between two hemispheres, for the planar structure and alignment between the quadrupole and octopole, and for an anomalously large temperature decrement in the southern sky. Unfortunately, since the model corresponds to an open cosmology with a density parameter $\Omega \sim 0.5$ it is inconsistent with the acoustic peak structure which favours a critical density universe. An attempt to remedy this contradiction by including dark energy and searching for those models which are also consistent with the peak structure has not been successful. However, a pragmatic approach should still be taken in the interpretation of the results. In particular, i) the Bianchi model provides a means to statistically quantify deviations from isotropy, and ii) the best-fit model provides a template temperature pattern which other models may need to reproduce in order to explain the observed anomalies.

A power equalization filter has been applied to the high-latitude *WMAP* data in order to reconstruct the low-l multipoles (quadrupole, octopole etc.) free from the largest Galactic foreground modelling uncertainties in the Galactic plane which plague other analyses. A re-assessment of a set of earlier claims of both cosmological and non-cosmological low-l correlations based on multipole vectors has then been performed. The well-known quadrupole-octopole correlation is confirmed at the 99% confidence level, and shown to be robust with respect to frequency and sky cut. Additionally, a putative low-l alignment with respect to the ecliptic is nominally confirmed, but also shown to be very dependent on severe a-posteriori choices. In fact, given the peculiar quadrupole-octopole arrangement, finding such a strong alignment with the ecliptic should not be considered unusual.

K. Dolag, together with F.K. Hansen (Inst. of Theo. Astro., Oslo), L. Moscardini (Dip. Astro., Bologna) and M. Roncarelli (Dip. Astro., Bologna) used a constrained, hydrodynamical simulation of the local universe to investigate the thermal and kinetic SZ effect of the local large scale structure. Analysis of synthetic full sky maps showed that the prominent local super clusters dominate the SZ signal at $l < 100$. Their signal can be even on order of magnitude above expectation from an unconstrained simulation at $l < 20$. Although the amplitude of the signal (as well as the alignment of the low multipoles) is to small to explain the anomalies observed in the WMAP data, it was demonstrated that the PLANCK sattelite will be able to estimate the predicted SZ power spectra. The full sky maps produced are now also part of the template foregrounds for the PLANCK satellite simulation pipeline.

A solution to the CMB component separation problem has been proposed based on standard parameter estimation techniques. A parametric spectral model is assumed for each signal component, and the parameters fitted on a pixel by pixel basis. This approach has many advantages. The fitted model may be chosen freely, and the method is therefore completely general; all assumptions are transparent; no restrictions on spatial variations of foreground properties are imposed; the results may be rigorously monitored by goodness-of-fit tests; and, most importantly, we obtain reliable error estimates on all estimated quantities. Ultimately, the method should allow the foreground uncertainties to be rigorously propagated through to CMB power spectrum estimation and cosmological parameter inference. Such a component separation strategy will be of great importance for Planck and high-sensitivity polarisation measurements, especially given the spatial variations in foreground spectral properties that have been suggested by analysis of the *WMAP* data in a collaboration with C. Dickinson (Caltech, USA) and R.D. Davies (Manchester, UK).

A. J. Banday in collaboration with K. M. Górski (JPL/Caltech, USA), E. Hivon (NASA-IPAC, USA), and M. Reinecke continue to maintain and develop the HEALPix software package for the simulation and analysis of CMB anisotropy maps. Version 2 was publicly released in late 2005, including for the first time toolkits in C++ and Java. The code has also now been released under the GNU general public license. Studies are also continuing in the utilisation of HEALPix as a standard spatial database scheme for Virtual Observatory applications, in collaboration with G. Lemson (MPE, Garching) and the German Astrophysical

Virtual Observatory (GAVO).

J. Chluba in collaboration with R.A. Sunyaev studied the effect of induced two-photon decay of the hydrogen 2s-level on the cosmological recombination. Due to induced two-photon decays hydrogen recombination is faster on the level of percent. Correspondingly this leads to changes of the ionization fraction, visibility function and angular temperature and polarisation power spectra of the CMB on the same level.

3.11 Quantum mechanics of atoms and molecules, astrochemistry

In a series of studies quantum-chemical models of atoms and molecules have been applied to investigate the effects of spatial confinement on the properties and reactions of quantum systems. The confined object is described by the Hartree-Fock (HF), the configuration interaction (CI) and the coupled cluster methods, respectively. The spatial confinement is defined by an external one-particle potential introduced to the N-electron Hamiltonian. Among others, the following topics have been investigated: The spectrum and the electron density distribution of two, three, and four electrons confined by a weak, strongly anisotropic oblate-type harmonic oscillator potential have been studied for all spin states. Large electron correlation prevails for the low-lying states of the studied systems particularly for the states with low spin multiplicity. (G. H. F. Diercksen and T. Sako) Static dipole polarizabilities of two-electron systems confined by a spherical harmonic-oscillator potential ω have been calculated. The polarizability α of the 2-electron quantum dot for $\omega = 0.01$ is calculated to be 19 996 au, in perfect agreement with the exact value of 20 000 au. Already medium confinement, $\omega = 1.0$, reduces it to 2.00 au. The decrease of the polarizability is smaller for H^- and much smaller for He and Li^+. (F Holka, P Neogrády, V Kellö, M Urban and G H F Diercksen) The low-lying excited states of the hydrogen molecule confined in a harmonic potential have been studied. The effect of the confinement on the geometry and spectroscopic constants has been analyzed (G. H. F. Diercksen, J. H. M. Lo and M. Klobukowski). Potential energy curves of the NeH Rydberg molecule in the presence of cylindrical spatial confinement have been computed. The influence of the applied potential on the structures and spectra of the ground and excited states of NeH has been analyzed. In addition, the phenomenon of field-induced ionization has been discussed. (J M H Lo, M Klobukowski, D Bielińska-Wąż, E W S Schreiner, and G H F Diercksen) Spectral properties of the low-lying singlet and doublet states of a lithium atom in a laser plasma have been calculated by using a Debye shielding model Hamiltonian. A large spherical Gaussian basis set has been adopted to describe the wavefunctions of the electrons bound in a non-Coulombic Yukawa-type potential with high accuracy. The relative energies and the first ionization potential have been found to decrease as the shielding parameter μ increases and the number of bound states to decrease gradually as μ increases. (Hiroshi Okutsu, Tokuei Sako, Kaoru Yamanouchi, and and Geerd H.F. Diercksen)

Studies of the basic exothermic binary reactions of potentially astrophysical relevance are continued investigating the radiative charge-transfer reaction $He^+ + H_2 \rightarrow He + H_2^+ + h\nu$. This study is essentially based on the results of previous calculations on the rigorous quantummechanical state-to-state level of the single-state and the two-states radiative association formation processes of the HeH_2^+ ion. The charge-transfer reaction proceeds such that in $He^+ + H_2$ collisions initially long-lived resonances of the excited HeH_2^+ ion are formed which in a second step undergo spontaneous radiative transitions to appropriate continuum states of the ground state HeH_2^+ ion dissociating finally to He + H_2^+. Other than the single-state and the two-states formation processes of HeH_2^+, the charge-transfer reaction is much faster with a reaction rate constant of the order of 10^{-14} cm^{3}s^{-1} (W.P. Kraemer together with F. Mrugala (Torun)). Whereas in HeH_2^+ the ground electronic state can be characterized as a He...H_2^+ complex and the first excited electronic state as a loosely bound He^+...H_2 associate, the situation is reversed for the LiH_2^+ ion. Calculations are performed to evaluate all bound ro-vibrational levels of the weakly bound electronic ground state Li^+...H_2 complex (W.P. Kraemer together with V. Špirko (Prague)).

Previous studies of the spectroscopy of interacting electronic states in triatomic molecular systems such as the Renner-Teller states of CH_2 and SiH_2 are now extended to include also higher excited electronic states ($SiH_2(\tilde{B}\ ^1A_1)$ and $SiH_2(\tilde{a}\ ^3B_1)$) and to investigate the Renner-Teller effect for the ionic analogues, especially the SiH_2^+ $\tilde{X}$ and $\tilde{A}$ states (W.P. Kraemer together with P. Jensen (Wuppertal) and P.R. Bunker (Ottawa)). As a first application of a recently developed generalized two-determinant coupled-cluster approach (P. Neogrady (Bratislava)) the potentials and spectroscopic constants for a series of alkali metal diatomics in their ground and lower $^1\Sigma^+$ and $^1\Pi$ excited states are calculated and their accuracy is discussed in comparison to corresponding results obtained from standard CASSSCF/MR-CISD calculations (W.P. Kraemer together with P. Neogrady (Bratislava)).

4 Publications and Invited Talks

4.1 Publications in Journals

4.1.1 Publications that appeared in 2005

Acke, B., M. E.van den Ancker and C. P. Dullemond: [O I]6300 emission in Herbig Ae/Be systems: Signature of Keplerian rotation. Astron. Astrophys. **436**, 209–230 (2005).

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4.2.1 Publications in proceedings appeared in 2005

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4.2.2 Publications available as electronic file only

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Arp, H. and E.M. Burbidge: X-ray Bright QSO's around NGC 3079. astro-ph/0504237.

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http://www-int.stsci.edu/ downes/cvcat

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4.3 Books and popular articles

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Wegmann, R.: Methods for numerical conformal mapping : Handbook of complex analysis: Geometric function theory, Vol. 2, Ed. R. Kühnau, Elsevier 2005, 351–477.

4.4 Invited-, and Public talks

4.4.1 Invited and review talks

M.A. Aloy: JGRG15 Workshop “Progenitors of gamma-ray bursts” (Tokyo, 28.11.–02.12.)

G. Börner: Sophia University, Tokyo, Japan (13.1.)

G. Börner: Tokyo University, Japan (17.1.)

G. Börner: Kyoto University, Japan (27.1.)

G. Börner: Tohoku University, Sendai (22.2.)

G. Börner: Universität Magdeburg (3.5.)

G. Börner: Max-von Laue Kolloquium, Physikalische Gesellschaft Berlin (23.6.)

G. Börner: Technische Universität, Darmstadt (9.12.)

S. Charlot: XXVth Rencontres de Moriond “When UV Meets IR: a History of Star Formation” (La Thuile, 7.3.–11.3.)

S. Charlot: International Workshop on “Stellar Populations: a Rosetta Stone for Galaxy Formation” (Schloss Ringberg, 4.8.–8.8.)

E. Churazov: GLAST Mini-symposium on the Galactic Center Region, (Stanford, USA, 1.09)

E. Churazov: ”The X-ray Universe 2005” Symposium, (El Escorial, Spain, 26.09-30.09)

B. Ciardi: “Conference on Computational Cosmology” (Trieste, 31.5.–4.6.)

B. Ciardi: “Reionizing the Universe: the Epoch of Reionization and the Physics of the IGM” (Groningen, 27.6.–1.7.)

B. Ciardi: “Stellar Evolution at Low Metallicity: Mass Loss, Explosion, Cosmology” (Tartu, 15.8.–19.8.)

B. Ciardi: “Carbon-Rich Ultra Metal Poor Stars in the Galactic Halo” (Ringberg, 28.11.–2.12.)

G. De Lucia: “The role of wide and deep multi-wavelength surveys in understanding galaxy evolution” (Ringberg Castle, 29.3.-1.4.)

G. De Lucia: “The Origin of the Hubble Sequence” (Vulcano Island, 6.6.-12.6.)

G. De Lucia: “From Simulations to Surveys” (Ringberg Castle, 26.6.-1.7.)

G. De Lucia: “Distant clusters of galaxies” (Ringberg Castle, 24.10.-28.10.)

G. De Lucia: “Workshop on Dark Matter Substructures” (Massachusetts Institute of Technology, 6.-9.10.; 5.-9.12.)

G. De Lucia: Osservatorio Astronomico di Capodimonte (Naples, 7.4.)

G. De Lucia: University of Sussex (Brighton, 28.4.)

G. De Lucia: Osservatorio Astronomico di Padova (Padova, 4.5.)

G. De Lucia: Yale University (New Haven CT, 30.9.)

T.A. Enßlin: International Conference on 'The Origin and Evolution of Cosmic Magnetism' "Future magnetic fields studies using the Planck Surveyor experiment" (Bologna, 29.8.– 2.9.)

M. Gilfanov: A meeting in honor of Ed van den Heuvel "A Life with stars", (Amsterdam, 22.08.–26.08.)

M. Gilfanov: International conference "High Energy in the Highlands", (Fort William, Scotland, 27.06–01.07.)

M. Gilfanov: Nordita Workdays on QPOs (Nordita, Copenhagen, Denmark, 24.02.–01.03.)

M. Gilfanov: COSPAR Colloquium on Spectra and Timing of Compact X-ray Binaries, (Mumbai, India, 17.01.–21.01.)

W. Hillebrandt: Ringberg Workshop on "Current Topics in Astroparticle Physics" (Ringberg Castle, 25.4.–29.4.)

W. Hillebrandt: 206th Meeting of the American Astronomical Society (Minneapolis, USA, 29.5.–2.6.)

W. Hillebrandt: 59th Yamada Conference '1Inflating horizon of particle astrophysics and cosmology" (Tokyo, Japan, 20.6.–24.6.)

W. Hillebrandt: 'A Life with Stars", Conference in Honor of Ed van den Heuvel (Amsterdam, The Netherlands, 22.8.–26.8.)

H.-Th. Janka: International Conference "Neutron Stars at the Crossroads of Fundamental Physics" (Vancouver, 9.8.–13.8.)

H.-Th. Janka: University of Barcelona (Barcelona, 20.4.)

H.-Th. Janka: MPI für Astrophysik, SFB-TR7 (Garching, 6.6.).

H.-Th. Janka: TU München (Garching, 10.11.)

G. Kauffmann: STScI Workshop on "The Galaxy IGM Ecosystem" (Baltimore, 7.3.–9.3.)

G. Kauffmann: "Superunification of active galactic nuclei: Black Hole Mass, Spin and Accretion Rate"(Elba, 25.5.–28.5.)

G. Kauffmann: "The Fabulous Destiny of Galaxies", (Marseille, 20.6.–24.6.)

G. Kauffmann: "Nearly Normal Galaxies", (Santa Cruz, 7.8.–13.8.)

G. Kauffmann: " QSO Host Galaxies: Evolution and Environment", (Leiden, 22.8.–26.8.)

F. Kupka: MONS 2005 "Element Stratification in stars: 40 Years of Atomic Diffusion", (Chateau de Mons, France, 6.6.–10.6.)

P. Mazzali: "Hypernovae and Gamma-Ray bursts" at the meeting "Triggering Relativistic Jets" (Cozumel, 2.4.–5.4.)

P. Mazzali: "Asphericity in Supernova Explosions" at the semiannual Meeting of the American Astron. Soc. (Minneapolis, 1.6.–4.6.)

A. Merloni: "Superunification of Active Galactic Nuclei: Black Hole Mass, Spin and Accretion Rate" (Elba Island, Italy, 25.5-28.5)

A. Merloni: "High Energy in the Highlands" (Fort William, Scotland, UK, 27.6-1.7)

A. Merloni: Colloquium at Physics Department, University Rome 3 (Rome, Italy, 18.5)

E. Müller: Third Tapas Workshop on "Jet physics", (Granada, Spain 21.4.–23.4.)

E. Müller: 59th Yamada conference on “Inflating horizon of particle astrophysics and cosmology”, (Tokyo, Japan 20.6.–25.6.)

E. Müller: International Conference on “General relativity”, (Jena, Germany 26.9.-29.9.)

E. Müller: IOP meeting on “Supernovae”, (Edinburgh, UK, 26.10.)

E. Müller: Albert-Einstein-Institut, Institute colloquium, (Golm, Germany 9.11.)

V. Springel: IPAM Conference “N-Body problems in Astrophysics” (Los Angeles, 18.-22.4.)

V. Springel: Conference on “Computational Cosmology” (Trieste, 31.05.-5.6.)

V. Springel: Conference on “Nearly Normal Galaxies” (Santa Cruz, 8.-12.8.)

V. Springel: Workshop on “Dark Matter Substructure” (MIT, 17.10.)

V. Springel: ESO/MPA Workshop on “Carbon Rich Ultra Metal-Poor Stars in the Galactic Halo” (Ringberg, 28.11.-2.12.)

V. Springel: Astrophysical Colloquium (Harvard-ITC, 19.10.)

V. Springel: Astrophysical Colloquium (Harvard-CfA, 25.10.)

V. Springel: Astrophysical Colloquium (Princeton University, 26.10.)

V. Springel: Astrophysical Colloquium (Bonn, 2.12.)

R. Sunyaev: XXVIIIth Spanish Relativity Meeting “A Century of Relativity Physics” (Oviedo, 4.9.–11.9.)

R. Sunyaev: “A Life with stars”, Meeting in honor of Ed van den Heuvel, (Amsterdam 20.8.–25.8.)

R. Sunyaev: 40 Years of Cosmic Mirowave Background, (Villa Montragone, Rome, 18.10.–19.10.)

R. Sunyaev: Joint Astrophysical Colloqium, (ESO Garching, 10.03)

R. Sunyaev: Institute for Advanced Study, (Princeton, April)

R. Sunyaev: National Radioastronomical Observatorty, (Charlottesville, Va, October)

R. Sunyaev: National Radioastronomical Observatorty, (Socorro, NM, November)

R. Sunyaev: Univeristy of Pennsylvania, (Philadelphia, November)

R. Sunyaev: Invited lecture, Academy of Sciences of Uzbekistan, (Tashkent, 8.6.)

R. Sunyaev: Invited lecture, Kazan State University, (Kazan. Russia, 1.9.)

R. Sunyaev: “High Energy Astrophysics, 2005”, Space Research Institute, (Moscow, 26.12.)

S.D.M. White: IAP Colloquium on Dark Matter Structures (Paris 4.7.–9.7.)

S.D.M. White: Summary talk, IAU Colloquium 199 (Shanghai, 14.3.–18.3.)

S.D.M. White: Invited Plenary Talk, National Astronomy Meeting (Birmingham, UK, 8.4.)

S.D.M. White: ICTP workshop on Computational Cosmology (Trieste, 31.5.–3.6.)

S.D.M. White: “Mass and Mystery in the Local Group” (Cambridge, 18.7.–22.7.)

S.D.M. White: Nearly Normal Galaxies 2005 (Santa Cruz, 8.8.–12.8.)

S.D.M. White: Open Questions in Cosmology (Garching 22.8.–26.8.)

S.D.M. White: MIT/Kavli workshop on dark matter substructures (Cambridge, USA, 1.10.–2.10.)

S.D.M. White: Introduction, Ringberg workshop on galaxy clusters (Schloss Ringberg, 24.10.–28.10)

4.4.2 public talks

G. Börner: Katholisches Bildungszentrum, Regenstauf (5.10.)

G. Börner: Nixdorf Forum Paderborn (27.10.)

G. Börner: Volkssternwarte München (16.12.)

5 Personnel

5.1 Scientific staff members

Directors

W. Hillebrandt, R. Sunyaev (managing director until 31.12.2005), S.D.M. White (managing director since 1.1.2006)

External Scientific Members

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

Staff

M.A. Aloy, A.J. Banday, J. Ballot (since 1.10.), J. Blaizot, G. Börner, S. Charlot (till 31.8.), J. Chluba (since 1.7.) B. Ciardi, E. Churazov, L. Dessart (till 28.2.), T. Di Matteo (till 31.1.), H. Dimmelmeier, K. Dolag, T. Enßlin, D. Gadotti (since 15.9.), L. Gao (till 30.9.), M. Gilfanov, B. Groves, E. Hayashi, H.–T. Janka, G. Kauffmann, K. Kifonidis, C. Kobayashi (till 30.9.), F. Kupka, L.X. Li, A. Maselli (since 1.8.), Z. Meliani (since 15.9.), B. Metcalf (since 15.9.), A. Mizuta (since 1.8.) A. Merloni, O. Möller, T. Morris (since 1.12.) E. Müller, S. Nayakshin (till 31.7.), R. Oechslin, P. Popowski (till 14.10.), M. Revnivtsev, H. Ritter, F. Röpke, H. Sandvik, S. Sazonov, B. Schäfer (till 30.9.), S. Sim (since 1.9.), V. Springel, M. Stehle (till 31.10.), H.C. Spruit, A. Watts (since 1.10.), A. Weiss, V. Wild (since 17.10.).

Emeriti

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

Scientists associated:

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

Sofja Kovalevskaja Program

S. Charlot (awardee, until 31.8.), G. De Lucia, B. Panter.

Alexander von Humboldt fellowships

P. Madau (1.6.–31.7. and 1.-31.12.), J. Navarro (till 28.2.), A. Szalay (1.3.–31.7.)

EC–fellowships

A. Ferguson (till 31.1.), D. Giannios, C. Hernandez-Monteagudo (till 14.3.), Z. Meliani (since 15.9.), A. Moretti, T. Morris (since 15.8.), E. Rasia (15.1.–14.4.), E. M. Rossi (till 31.10.), A. Pastorello, D. Sauer, M. Topinka (since 1.3.), V. Wild (since 17.10.).

Ph.D. Students

R. Buras (till 30.6.), J. Dunkel, M. Gieseler, N. Hammer (since 15.1.), S. Hilbert, L. Iapichino (till 31.8.), M. Jubelgas (Ende Okt. gegangen - noch keine Pruefung), M. Obergaulinger, C. Pfrommer (till 31.10.), D. Sauer (till 30.4.), B. M. Schäfer (till 30.5.), L. Scheck, S. Taubenberger, L. Wang, B. Zink.

IMPRS Ph.D. Students

A. Arcones, M. Baldi (since 1.9.), J. Chluba (till 30.6.), D. Croton (till 30.10.), J. Cuadra, D. Docenko, A. Gallazzi, G. Hütsi, T. Jaffe, F. Kitaura, A. Kitsikis, M. Kitzbichler, U. Maio (since 1.9.) A. Marek, M. Mocak (since 1.9.), P. Rebusco, M. Righi, D. Sijacki, M. Stritzinger (till 30.11.), A. von der Linden, R. Voss, J. Wang, F. Xiang,

Diploma students

R. Birkl (since 15.3.), M. Fink (since 1.12.), Q. Guo (since 15.8.), J. Jasche (since 5.9.), F. Meissner (till 30.6.), B. Müller (till 31.12.), R. Pakmor (since 15.10.) A. Waelkens (till 31.12.).

Staff news

M.A. Aloy: Ramón y Cajal fellow at the Departamento de Astronomía y Astrofísica of the Universidad de Valencia.

B. Ciardi: Tenure track position at Max-Planck-Institute für Astrophysic.

B. Ciardi: DFG (Deutsche Forschungsgemeinschaft) Priority Program 1177 grant for a two year Postdoctoral position.

J. Dunkel: SCOR Actuarial Prize (2nd prize) of the SCOR Group/Universität Ulm.

G. Kauffmann: DFG (Deutsche Forschungsgemeinschaft) Priority Program 1177 grant for a two year Postdoctoral position.

A. Moretti: Honourable mention for the best PhD thesis from the Italian Astronomical Society (2.5).

V. Springel: Nano Special-Award 2005 for Scientific Visualization.

R. Sunyaev: Karl Jansky Lecturership from National Radio Astronomy Observatory

R. Sunyaev: Sackler Lecture on Astrophysics at Harvard-Smithsonian Center for Astrophysics

R. Sunyaev: Bisho Lecture on Astrophysics, Columbia University

S.D.M. White: Max-Planck Research Prize for international Cooperation.

S.D.M. White: Blauuw Professor, University of Groningen.

S.D.M. White: elected to the Akademie deutscher Naturforscher, Leopoldina.

S.D.M. White: Dannie Heineman Prize of the American Astronomical Society.

S.D.M. White: Gold Medal of the Royal Astronomical Society.

Ph.D. theses 2005

Robert Buras: "Multi-dimensional simulations of core-collapse supernovae with a variable Eddington factor technique for energy-dependent neutrino transport", Technische Universität München.

Jens Chluba: "Spectral Distortions of the Cosmic Microwave Background", Ludwig-Maximilians-Universität München.

Darren Croton: "Galaxy Formation and Evolution: the local galaxy population as a cosmological probe", Ludwig-Maximilians-Universität München.

Alessia Moretti: "Extragalactic globular cluster systems: M104 and M33" University of Padua.

Christoph Pfrommer: "On the role of cosmic rays in glusters of galaxies", Ludwig-Maximilians-Universität München.

Daniel Sauer: "Steps toward a consistent NLTE treatment of the radiative transfer in Type Ia Supernovae", Technische Universität München.

Bjoern Malte Schaefer: "Methods for detecting and characterising clusters of galaxies", Ludwig-Maximilians-Universität München.

Max Stritzinger: "Type Ia Supernovae: Bolometric properties and new tools for photometric techniques." Technische Universität München.

Diploma theses 2005

F. Meissner: "Modeling of Color-Magnitude-Diagrams of Galactic Globular Clusters" Ludwig-Maximilians-Universität München.

B. Müller: "Core Collapse Supernovae and Supermassive Stars: Improved Approximations to General Relativity" Technische Universität München.

A. Waelkens: "Models of polarized Synchrotron emission as a CMB foreground" Ludwig-Maximilians-Universität München.

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
Vadim Arefiev	(IKI Moscow)	8.11.–20.12.
Dominique Aubert	(Univ. Strasbourg)	1.5.–30.9.
Petr Baklanov	(Sternberg Inst. Moscow)	29.4.–31.5.
Eduardo Beffermann	(Univ. Catolica de Chile)	10.1.–9.6.
Vasily Belokurov	(IOA Cambridge, U.K.)	26.6.–11.7.
Sergey Blinnikov	(Sternberg Inst. Moscow)	1.3.–30.11.
M. Boylan-Kolchin	(Berkeley, USA)	29.5–18.6
Jonathan Braithwaite		since 1.10.
Jarle Brinchmann	(Univ. de Porto, Portugal)	18.5.–30.5.
Tamas Budavari	(John Hopkins Univ. USA)	24.4.–23.5.
Michael Busha	(Univ. of Michigan, USA)	
Paula Coelho	(Sao Paulo, Brazil)	1.1–31.12.
Tiziana Di Matteo	(CMU Pittsburgh, USA)	2.5.–23.5.
Ekatarina Filippova	(IKI, Moscow)	1.7.–1.9.
Sergey Grebenev	(IKI, Moscow)	25.11.–25.12.
Petr Heinzel	(Ondrejov, Czech Republic)	25.4.– 9.5.
Carlos Hernandez-Monteagudo	(Univ. of Pennsylvania, US)	11.5.–1.6.
Yonghui Hou	(Shanghai Obs. China)	until 28.2.
Nail Inogamov	(Landau Inst. Moscow)	15.10.–15.12.
Patrik Jonsson	(UC Santa Cruz, USA)	10.11.–15.12.
Roman Krivonos	(IKI Moscow)	7.2.–6.5.
		16.6.–16.10.
Igor Kryukov	(Moscow, Russia)	5.9. - 5.10.
Shri Kulkarni	(Caltech, USA)	5.7.–4.8.
Fabrice Lamareille	(Toulouse Observatory)	1.03.–31.05.
Marcelo Lares	(IATE Cordoba, Argentina)	16.8.–16.11.
Yang-Shyang Li	(Shanghai Obs. China)	104.–28.5.
Cheng Li	(Hefei, China)	since 19.8.
Alexander Lutovinov	(IKI Moscow)	25.9.–25.11.
Chung-Pei Ma	(Berkeley, USA)	30.5.–18.6.
Kenichi Maeda	(Univ. of Tokyo, Japan)	1.8.–19.8.
Matteo Maturi	(Padova, Italy)	1.2.–30.4.
Paolo Mazzali	(Trieste, Italy)	1.1.–31.12.
Attila Meszaros	(CESNET, Praha, Czech Republic)	24.1.–31.3.
		1.6.–11.7.
Petar Mimica	(Mimice, Croatia)	1.9.–31.10.
Sergei Molkov	(IKI Moscow)	12.1.–11.6.
Dimitri Nadezhin	(ITEP Moscow)	14.4.–16.5.
Josef Paldus	(Waterloo, Canada)	01.05.–30.06.
Igor Panov	(ITEP, Moscow, Russia)	1.10.–30.11.
Ary Rodriguez	(INAOEP, Pueblo, Mexico)	12.2.– 11.5.
Alberto Rubino-Martin	(Tenerife, Spain)	25.1.–24.2.
		5.5.–19.5.
		13.7.–31.7.

Name	home institution	Duration of stay at MPA
Cecilia Scanapieco	(Buenos Aires, Argentina)	10.5.–9.9.
Alex Schekochihin	(Cambridge, UK)	22.7.–30.7.
Aldo Serenelli	(Princeton, USA)	10.7.–14.8.
Nicolai Shakura	(Sternberg Inst. Moscow)	1.9.–30.9.
Shiyin Shen	(Shanghai Obs., China)	1.10.–31.12.
Pavel Shtykovskii	(IKI, Moscow, Russia)	22.03.–29.04.
		20.09.–16.12.
Analia Smith Castelli	(Buenos Aires, Argentina)	1.3.–30.4.
Elena Sorokina	(Sternberg Inst. Moscow)	25.8.–24.9.
Linda Sparke	(Univ. of Wisconsin, USA)	3.1.–31.5.
Masaomi Tanaka	(Univ. of Tokyo, Japan)	1.8.–19.8.
Alexei Tolstov	(ITEP Moscow)	1.6.–26.7.
Luca Tonatore	(SISSA Trieste, Italy)	1.7.–31.7.
Sergei Tsygankov	(IKI Moscow)	20.5.–20.11.
Victor Utrobin	(ITEP Moscow)	since 1.12.
Oscar Ventura	(Montevideo, Uruguay)	08.06.–29.08.
Corina Vogt	(Dwingaloo, NL)	16.4.–13.5.
Rolf Walder	(Zürich, Switzerland)	since 15.09.
Huiyuan Wang	(Hefei, China)	since 19.8.
Ronald Webbink	(Urbana, IL, USA)	1.1–30.6.
Stanford Woosley	(UCOLICK, Santa Cruz)	1.8.–31.8.
Xiaohu Yang	(Shanghai Obs. China)	17.10.–17.11.