Max-Planck-Institut
für
Astrophysik

Annual Report 2004

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. 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 250 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, 2 X-terminals, 4 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.

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 2003). 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 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 one IBM Power4 multiprocessor computer and one IBM blade center housed at RZG. In late 2004 a 64-bit OPTERON-cluster with 16 2.4 GHz processors and 32 GB of memory will be added to satisfy increasing needs for cheap, but effective CPU-resources for mid-range computing.

The MPA-computer centre consists of 8 powerful workstations (IBM, SUN, and INTEL-based PCs) providing computer resources both for interactive work (text processing, electronic communication, program development, data visualization) and for small to intermediate-scale numerical applications. In preparation of the above-mentioned new 16-processor OPTERON system, one two-way and one four-way OPTERON computer server have recently been added to the central installations and are already in use. All users have free access to all resources. One full-time and three part-time system administrators are responsible for the facilities; users have no administrative privileges or duties.

User access is mainly through desktop PCs (with Linux as the operating system and mostly modern TFT-screens), which are also administered by the system managers. The average age of the desktop equipment is below three years; older hardware, such as X-window terminals, are in use only in emergencies or for special purposes. At the end of 2004 more than 120 office places will provide 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.

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 manager in charge of the SDSS-project computer installations.

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 (which users sometimes feel to be too restrictive) 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 servers have been added to the central system. The total capacity is around 10 TB and will be doubled during 2004. All centrally stored data are saved daily by several and redundant backups. These, the hardware-redundancy of all components, and the Advanced File-System (AFS) guarantees 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, TByte 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 the managers are in close contact and have regular meetings with the MPA system managers.

For the future development we see 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 want 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 video-conferencing 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, which, so far, is available only, if at all, from other scientists. In view of these developments, more highly qualified personnel will be required in the future to maintain the high level of system support MPA is currently offering.

1.3 2004 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 2004 by Lars Bildsten from the University of California in Santa Barbara. Professor Bildsten have lecturs on three different subjects: *"X-Ray Binaries in Distant Elliptical Galaxies", "Neutron Stars and Black Holes: Advances in Relativistic Astrophysics"* and *"Accreting White Dwarfs: From Pulsations to Type Ia Progenitors"*. This series of excellent talks consistently filled the MPA lecture theatre to its limits.

Several workshops and conferences were organized by MPA scientists in 2004: "The 12th Workshop on Nuclear Astrophysics" (Ringberg Castle, March 22. - 27.); the Workshop "Protoplanetary Disks" (Ringberg Castle, April, 13 - 17); the MPA/ESO/MPE conference "Growing Black Holes: Accretion in a Cosmological Context" which was held in Garching (June 21. - 25.); the Mid-Term Review meeting of the RTN "The Physics of Type Ia Supernova Explosions" (Sept. 22 - 23), the EARA workshop "Black Holes, Stars and Galaxies:

Simulations and Observations" (December, 2. - 3.)

MPA's national and international cooperations and collaborations continued to flourish in 2004. 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 – the "Intergalactic Gas" led by Simon White – "Optical-Infrared Co-ordination Network for Astronomy" (OPTICON) led by Henk Spruit – "Multi-wavelength Analysis of Galaxy Populations" (MAGPOP) led by Guinevere Kauffmann – and the "Cosmic Microwave Background" Network led by Rashid Sunyaev.

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 2004.

The research quality at MPA was recognized in 2004 by international prizes at both senior and junior level. Benedetta Ciardi got the . Marie Curie Excellence Award, G. Diercksen got the Humboldt Reciprocity Research Award 2004 and V. Springel got the Heinz-Maier-Leibnitz-Prize 2004 of the DFG.

A much sadder event in 2004 was the tragic loss of one of our postdocs. Jatush Sheth came to the MPA in October, immediately after completing his PhD at the Inter-University Centre for Astronomy and Astrophysics in Pune. He arrived full of enthusiasm for his new life and full of plans for his astrophysics. Just a month after getting to Germany, Jatush decided to make a weekend trip to Italy with a group of Indian friends. After driving all night, their minibus was involved in an early morning accident in bad weather just outside Rome. Jatush and a friend were killed instantly and several others were injured. Although he was at the institute for only a few weeks, Jatush made a strong impression on all who came into contact with him. Unfailingly friendly and interested in all the scientific possibilities offered by the institute, he quickly made friends with his new colleagues. His warmth and his obvious love for his science were an inspiration for all of us. He has been sorely missed.

MPA Cosmology Group and the Shanghai Observatory

The Partner Group of the MPA at the Shanghai Astronomical Observatory (SHAO) was founded in May 2000 with Jing Yipeng as head and is 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. The Shanghai group now has thirteen members; four staff members including Jing, seven graduate students, and two students jointly supervised in Shanghai 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 this year 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 25 research papers have so far been published, mostly in the Astrophysical Journal, and about ten 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 .The joint supervision of the PhD students has continued. Six students of the Partner Group have been sent to MPA for PhD training. In addition lively contacts are maintained between the group and the MPA via the frequent short-term exchanges of scientists.

Public relations

Traditional public relations activities at MPA include articles written for popular science magazines and science sections of newspapers (see Section 4.4). MPA scientists are also often consulted by journalists for information or input to news reports and television programs.

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 4.5.3. 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.

MPA as the first institute in the Max Planck Society (MPG) adopted in 2002–2003 the new "Corporate Design" of the MPG internet pages which was developed by the MPG public relations office with the help of professional web designers. At the same time the information available electronically for external and internal access was expanded significantly and is usually provided in both English and German language (for our public relations pages, see (`http://www.mpa-garching.mpg.de/english/PR/`). Important information about MPA and its activities was integrated in the newly established global "Content Management System" of the MPG.

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

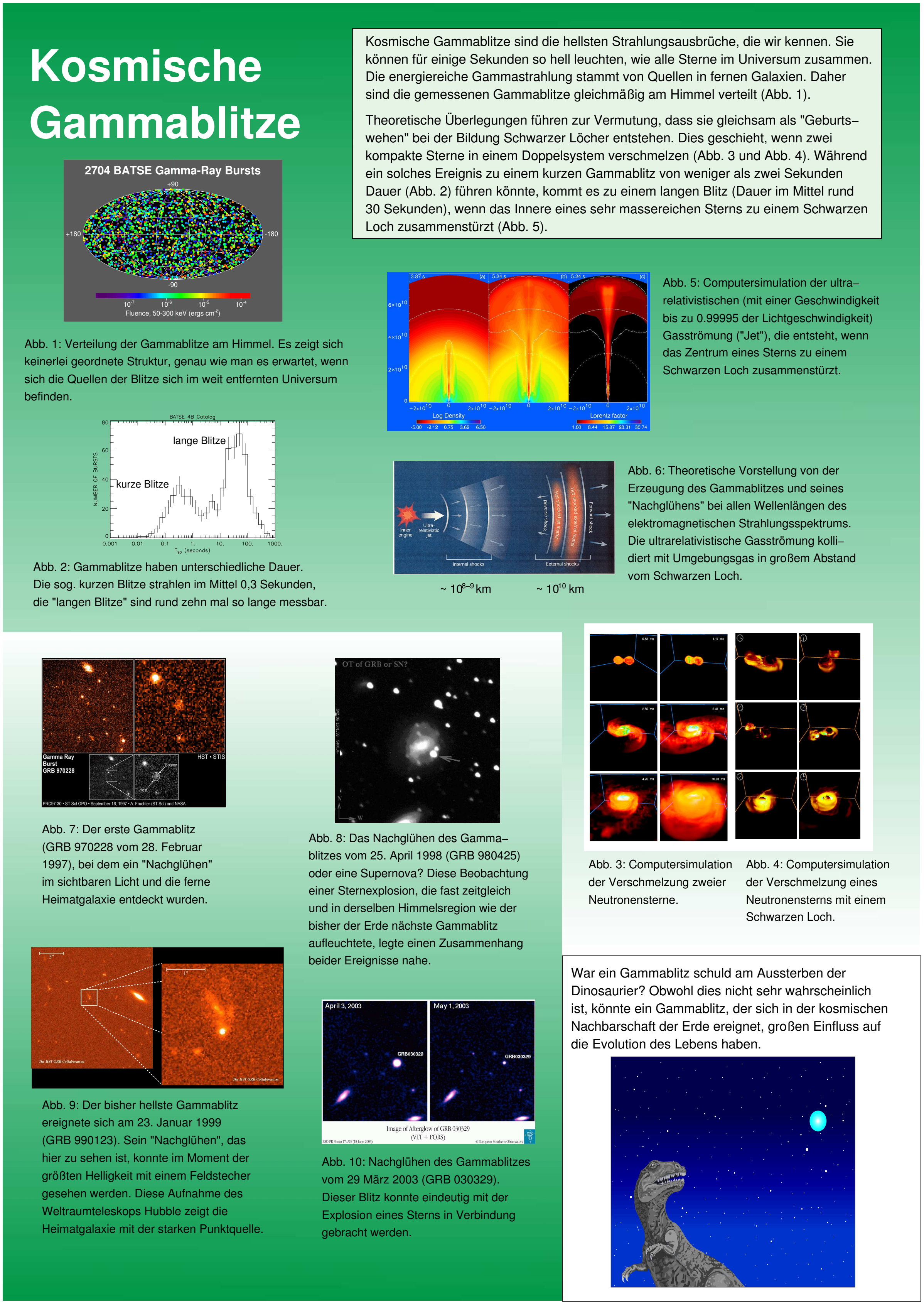

Figure 1.1: New poster on cosmic Gamma-Ray Bursts for the day of the "Open House" at MPA in 2003. The posters were developed by a young student, supervised by researchers, during her 3-week internship at MPA.

2 Scientific Highlights

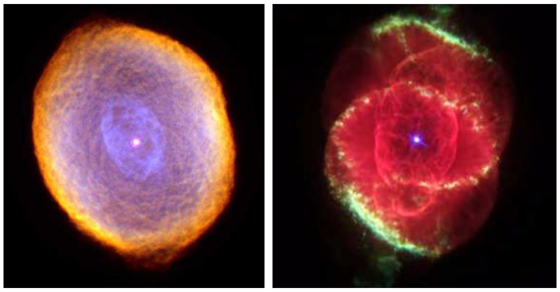

Figure 2.1: The *Spirograph* (IC 418) and *Cat's Eye (NGC 6543)* Planetary Nebulae Credit: Hubble Heritage Team (STScI/AURA)

2.1 Understanding the Planetary Nebulae Luminosity Function

Planetary Nebulae (PNe) are beautiful and interesting objects. The complexity seen in Fig. 2.1 reflects the complicated previous history of the objects. PNe are one end-product of stellar evolution, being the former envelope of stars of intermediate mass ($1 \lesssim M/M_\odot \lesssim 8$). Such stars pass through a sequence of nuclear burning phases until they reach the *Asymptotic Giant Branch* (AGB) during which their luminosity is created from an outer hydrogen and inner helium burning shell. In this phase they are very luminous (up to 1000 $L_\odot$) and cool ($T_{\rm eff} \lesssim 3500$ K), and therefore inflated to giant radii ($\approx 100\,R_\odot$). The interior shell structure is thermally unstable leading to regular *thermal pulses* of the helium shell on timescales of several thousand years. In addition, the envelope undergoes large radial oscillations with periods of several hundred days. As a consequence of the thermal pulses physical conditions in the envelope vary over wide ranges of temperature and density with the result of mixing events between photosphere and nuclear burning regions, neutron capture nuclear reactions and the generation of very heavy elements, and enrichment of the photosphere by carbon and other elements. Stars in this evolutionary stage are therefore very important for the chemical evolution of the Galaxy.

The interplay of pulses and pulsations, of carbon enrichment, high luminosity and very cool atmosphere also leads to extreme stellar winds of $10^{-4}\,M_\odot$/year, which is 10^{10} times larger than the present solar wind. The stars can therefore shed their envelopes within 10.000 years. Matter lost in this phase will later show up as a PN.

All effects mentioned depend on the initial stellar mass and composition. To investigate them with theoretical stellar models is one of the greatest challenges for the theory and even basic questions such as the effect of carbon enrichment are still debated and not uniquely reproducible. In addition, the stellar wind, which is due to radiation pressure on dust grains forming in the cool atmosphere, is not understood and requires the combination of chemistry, dust-formation processes, and radiation hydrodynamics.

As if this were not complicated enough, the evolution of the envelope after it has been blown from the star is influenced by the remains of the star, called the central star, which is quickly contracting, heating up to 100.000 K and exhibiting an extremely fast "hot" wind (velocities up to 1000 km/s, to be compared to the 10 km/s on the AGB). This fast wind and the hot UV photons from the central star heat up and ionize the expanding matter, which, depending on density, might absorb all energetic photons, reprocess and re-emit them: the circumstellar shell is lighting up, becomes an emission nebula, which we see as a PN. The central star will later evolve to a cooler and much fainter *White Dwarf* which cannot ionize its surrounding any longer. The phenomenon of a PN is therefore short-lived (some 10.000 years) and depends on a fine-tuning of post-AGB evolution and nebula expansion.

Having said all this, theorists are surprised by an undoubtable empirical finding, called the *Planetary Nebulae Luminosity Function* (PNLF). Looking at distant galaxies, one usually cannot resolve the individual stars. PNe, however, being rare, can be detected individually, because they re-emit at least 10% of all the stellar radiation in just one single emission line, which is that at 5007 Å of the double ionized oxygen atom OIII. Under laboratory conditions, the corresponding atomic level would not be populated, therefore it is a so-called

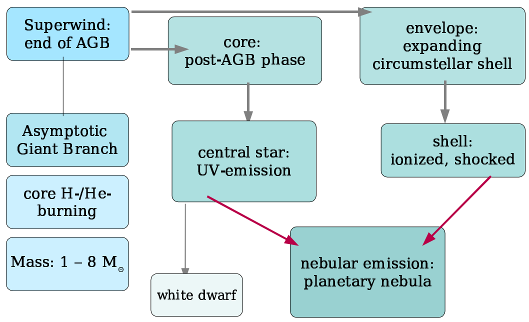

Figure 2.2: Sketch of the various steps of evolution from an intermediate mass star to a Planetary Nebula with an evolving central star.

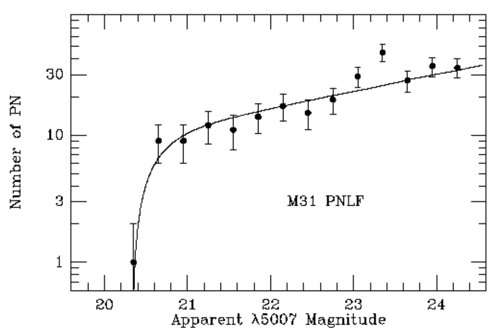

Figure 2.3: The PNLF for the Andromeda Galaxy M31. The known distance to Andromeda is used to determine the absolute brightness of the cut-off.

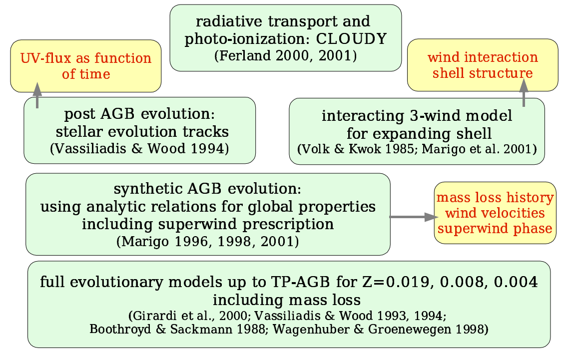

Figure 2.4: Building blocks of our theoretical model for a population of Planetary Nebulae, including a prediction of the PNLF.

forbidden line, labelled $[\mathrm{OIII}]_{5007}$. Very few objects emit this line. Observers therefore use filters that are transparent only in this wavelength range. Distant galaxies are very faint, when observed through such a filter, but the few PNe (of order 100) show up as very bright individual sources. As they are all at basically the same distances from us, their brightness in $[\mathrm{OIII}]_{5007}$ can directly be compared. The surprise now is that when counting the number of PNe in different brightness bins, it appears that the resulting distribution is (a) a universal function, and (b) has a universal cutoff, that is, there are no PNe brighter than about -4.5 mag in $[\mathrm{OIII}]_{5007}$ (Fig. 2.3 shows the PNLF of the Andromeda galaxy; since its distance is well-known, it serves as one calibrator for the PNLF cutoff brightness). This implies that populations of PNe in external galaxies can be used as a distance indicator, the distance resulting from the comparison of apparent to absolute magnitude of the cutoff luminosity. While this is a convenient empirical tool to determine galaxy distances, theorists would like to understand how the universality comes about. In view of the complexity discussed above, neither is the universality to be expected nor has it been managed to build a realistic theoretical model for the PNLF so far.

In a collaboration between P. Marigo, C. Chiosi (University of Padova), L. Girardi (Trieste Observatory), M.A.T. Groenewegen (Leuven), and A. Weiss (MPA) the so far most complete theoretical model has been developed to understand the PNLF. A schematic sketch of the building blocks is shown in Fig. 2.4: Starting from full stellar models, partially computed by J. Wagenhuber (MPA) for his thesis and partially from the literature, a model for synthetic AGB and post-AGB evolution is developed, which allows the calculation of many different populations of such stars without calculating the full models, since this would need prohibitively large amounts of computer resources. Next the expansion of the ejected envelope and its interaction with the radiation field of the central star and the hot post-AGB is modelled, and finally the radiation transport and the emission in $[\mathrm{OIII}]_{5007}$. At each step there are uncertainties, approximations, and parameters, which have to be adjusted to reproduce observations of individual galactic PNe (such as those in Fig. 2.1) or those of the PN population in the Magellanic Clouds, which are close enough to allow detailed observations. In spite of these limitations our model is the most advanced one and has many more applications than just the PNLF. It also allows to determine what PNe and central stars are those at the cutoff and from where they originate.

Fig. 2.5 shows a synthetic population of PNe in the Hertzsprung-Russell-Diagram of the central stars (see figure for more details). From this figure it is evident that the brightest PNe are located at the "knee" of the distribution, and that they are preferentially optically thick. Our model also yields what stars populate the bright end of the PNLF: we find that these are relatively young stars (a few Gyr) of initially $\approx 2.5\,M_\odot$, the exact value depending on composition. With our synthetic model we can explain why earlier and simpler model yielded discrepant answers about, for example, optical thickness or central star mass.

Finally, we modelled a typical spiral galaxy (Milky Way model) and an elliptical one. They differ in particular in their star formation history: while the spiral has ongoing star formation, the elliptical galaxy basically ceased to form stars some 5 billion years ago. The two PNLFs are shown in Fig. 2.6: the one for the spiral galaxy at the bright end resembles very much that of M31 (Fig. 2.2), and in particular reproduces very well the cutoff luminosity. On the other hand, the lack of young stars around $2 \cdots 3\,M_\odot$ results in a much too faint cutoff for the elliptical galaxy, a clear discrepancy with the observations.

Thus, we find that our model works very well for galaxies with recent star formation, but fails for galaxies with only old populations. We think that one shortcoming of the model is that the underlying stellar evolution models do not cover the whole age-metallicity range. At the same time our

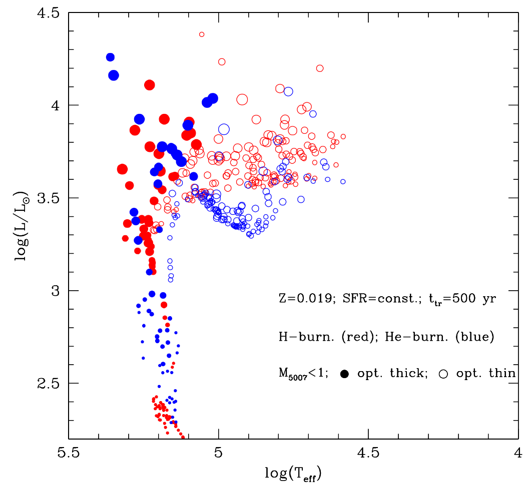

Figure 2.5: A synthetic population of PNe shown in the Hertzsprung-Russell-Diagram of their central stars. The size of the symbols indicates the $[\mathrm{OIII}]_{5007}$ brightness of the PN, the colour the main luminosity source of the central star. Filled circles designate optically thick nebulae, open circles optically thin ones. Solar metallicity, constant star formation rate and a transition time from the top of the AGB to the post-AGB of 500 years were assumed.

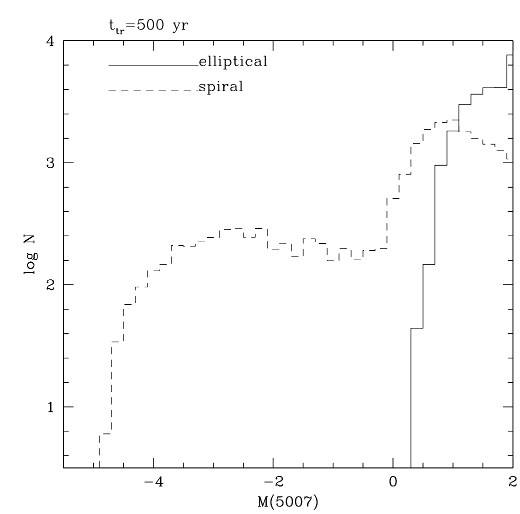

Figure 2.6: Building blocks of our theoretical model for a population of Planetary Nebulae, including a prediction of the PNLF.

model indicates that the PNLF could be a powerful population indicator, once it will be fully understood, because it may show substructure such as the local minimum at $M(5007) \approx -1$ in Fig. 2.6 which results from the star formation history. This project was the first steps towards this, and others will follow. *(Achim Weiss)*

2.2 Looking into the heart of a supernova

Based on the presently most detailed and most elaborate computer simulations of supernova explosions of massive stars researcher at the Max-Planck-Institut für Astrophysik in Garching by Munich have predicted the gravitational wave signal produced by these events.

Supernovae are dramatic explosions of red or blue giant stars which can be detected millions of light years away because for several weeks they shine as bright as a whole galaxy consisting of hundreds of billions of stars. This amazing optical outburst commences when the explosion wave, generated in the optically obscured stellar center, eventually reaches the surface layers of the star. As giant stars have very large radii (30 to 500 million km) in spite of the large speed of the explosion wave (about 10 000 km/sec), the spectacular optical outburst begins only hours after the actual onset of the catastrophe, which occurs in the very center of the star. There the burnt out stellar core containing a mass comparable to that of our sun collapses in a fraction of a second to a neutron star thereby liberating the binding energy of the compact remnant which causes the supernova explosion (Fig. 2.7).

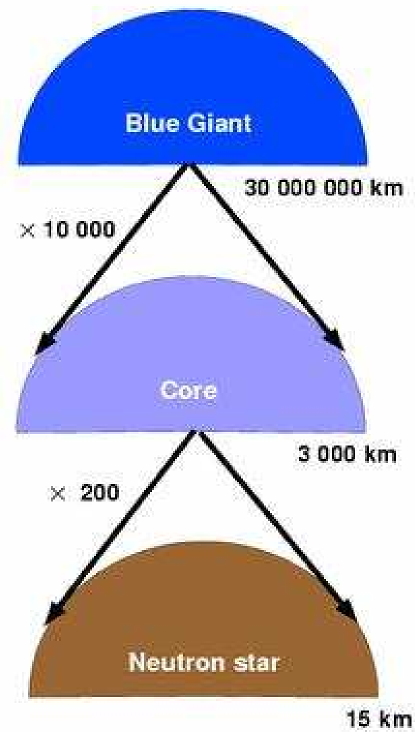

Figure 2.7: Radial scales in a blue giant star of about 20 solar masses. The star has radius of about 30 million kilometers, while the core is about ten thousand times smaller (radius of a few thousand kilometers) at the onset of its collapse. The neutron star formed by the collapse is still about 100 times smaller in size. At a scale of 1:1 000 000 the neutron would be the size of a marble, and if located at the Marienplatz in downtown Munich the surface of the star would have a radius of 30 km passing through the city of Freising (picture: E. Müller).

The only means to get direct and immediate information about the supernova "engine" is from observations of neutrinos emitted by the forming neutron star, and through gravitational waves which are emitted when the collapse does not proceed perfectly symmetrically. Neutrinos from a core collapse supernova have already been observed once, namely in case of the famous nearby Supernova 1987A which exploded in the Large Magellanic Cloud at a distance of only 160 000 light years. Gravitational waves, however, have not been observed directly up to now. Contrary to electromagnetic waves, which are oscillations of the electromagnetic field in spacetime, gravitational waves are oscillations of the fabric of spacetime itself. According to Albert Einstein, who first predicted their existence, gravitational waves are produced whenever matter (or equivalently energy) is accelerated aspherically. However, measurable signals are only produced by astrophysical sources involving very strong gravitational fields and velocities close to the speed of light, both of which are encountered, for example, in aspherical supernovae, or during the merger process of two neutron stars resulting in the formation of a black hole.

The researchers at the Max-Planck-Institut für Astrophysik could show that for a supernova exploding in our Galaxy or its neigbourhood (i.e. at a distance of less than about 100 000 light years), the gravitational wave signal should be detectable by gravitational wave detectors presently in operation or under construction. Such close super-

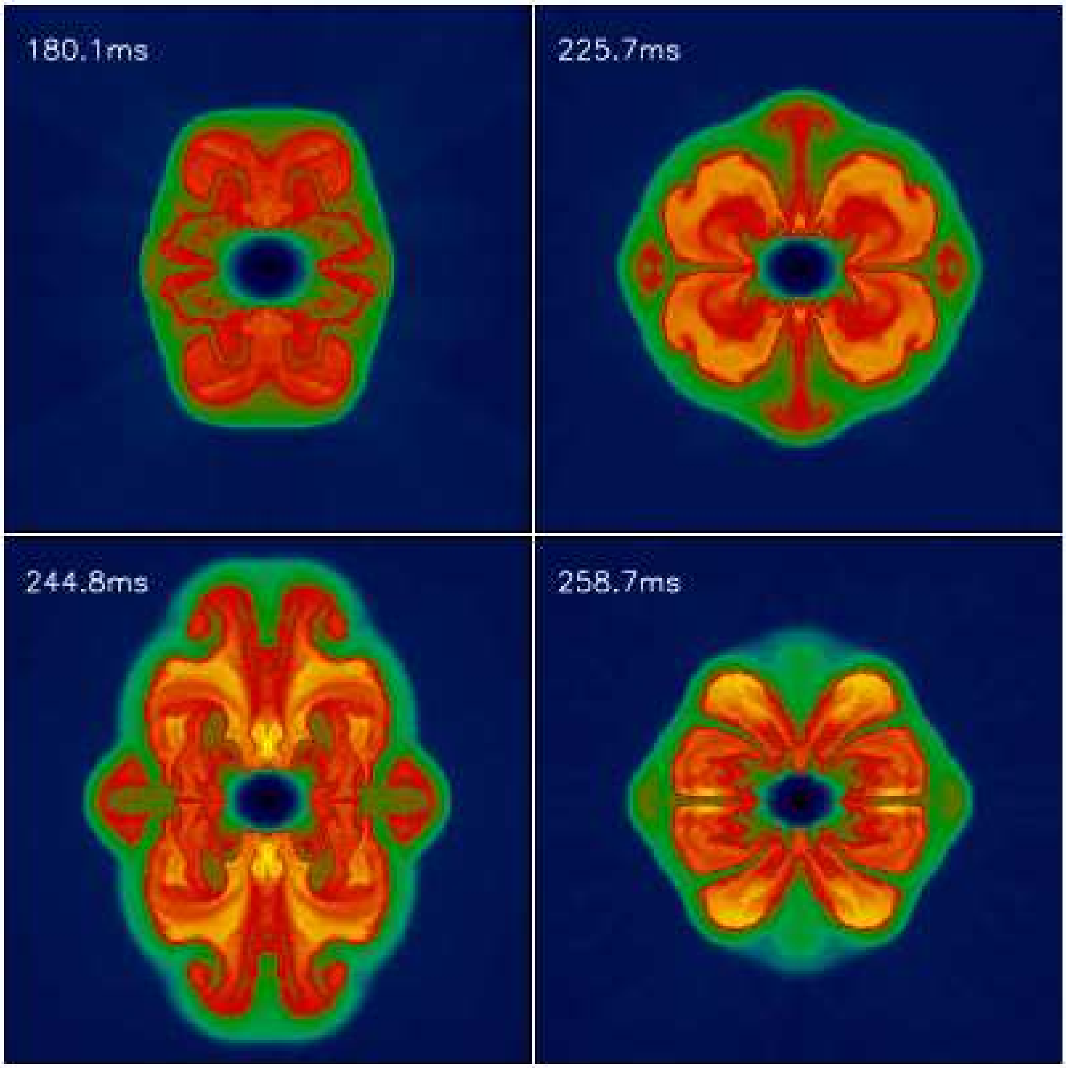

Figure 2.8: Four snapshots illustrating the violent mass motions in a rotating supernova model. The side length of the plots is 600 km, and the numbers in the top left corners give the times since maximum compression (bounce). The red-orange regions are rising bubbles of hot matter. The location of the explosion wave is visible as the sharp deformed green-blue discontinuity, and the oblate blue ellipse at the center indicates the forming neutron star which is flattened by centrifugal forces (picture: Müller et.al. 2004).

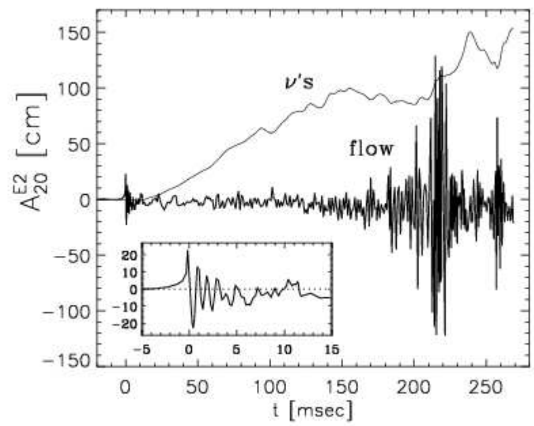

Figure 2.9: Gravitational wave signal due to violent mass flow (solid line) and asymmetric neutrino emission (thin line) predicted for a rotating supernova explosion model. The insert shows an enlargement of the bounce signal previously thought to be always the dominant contribution to the gravitation wave signal of a supernova explosion (picture: Müller etal., 2004).

nova events are unfortunately quite rare (statistically one event occurs in our galaxy about every 50 years), but when observed they could serve as a kind of Rosetta stone providing invaluable information about the supernova engine unaccessible deep inside the exploding star by classical astronomical observational techniques

They computed the gravitational wave signal using state-of-the-art progenitor models of rotating and non-rotating massive stars, and simulated the dynamics of their core collapse models by integrating the equations of axisymmetric hydrodynamics together with the Boltzmann equation for the neutrino transport including an elaborate description of neutrino interactions, and a realistic equation of state. From a detailed analysis of the simulation data they obtained the wave (quadrupole) amplitudes, the wave spectra, the amount of energy radiated in form of gravitational waves, and signal-to-noise ratios for the currently most sensitive gravitational wave detectors, which are part of the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the USA.

Contrary to what was common wisdom before, the Max-Planck researchers find that the dominant contribution to the gravitational wave signal is not necessarily produced when the collapse of a rotating stellar core is stopped at neutron star densities (the so-called bounce signal), but instead by violent turbulent mass motions (Fig. 2.8) which take place inside the forming neutron star and in its immediate neigbourhood independent of whether the star is rotating or not (Fig. 2.9). Because the mass motions stir up the whole center of the star the neutrinos produced during the event are emitted asymmetrically, and hence also cause a strong gravitational wave signal. According to the Max-Planck researchers a measurement of the gravitational wave signal of a galactic supernova together with a measurement of its neutrino signal would provide important insights about the working of the "heart" of a supernova.
(E. Müller, M. Rampp, R. Buras, H.-T. Janka)

2.3 Short Gamma-Ray Bursts — New Models Shed Light on Enigmatic Explosions

Researchers at the Max-Planck-Institute for Astrophysics have developed new relativistic models which allow predictions of so far unknown properties of short gamma-ray bursts. Their simulations will come under scrutiny by the Swift Gamma-Ray Burst Explorer, a NASA mission that was launched on November 20, 2004.

Gamma-ray bursts are among the most energetic and most luminous explosions in the Universe. They occur roughly once a day, last from a few thousandths of a second to a few hundred seconds, and come from all different directions of the sky. Their gamma radiation is more energetic than visible light and can be measured by satellites orbiting the Earth in space. The energy set free by the bursts in just one second is comparable to the energy production of the Sun during its whole life.

The more than 2700 observed bursts are grouped into two distinct classes, one of which are the so-called long bursts that emit gamma radiation for more than two seconds, and the other one are the short bursts with durations up to two seconds.

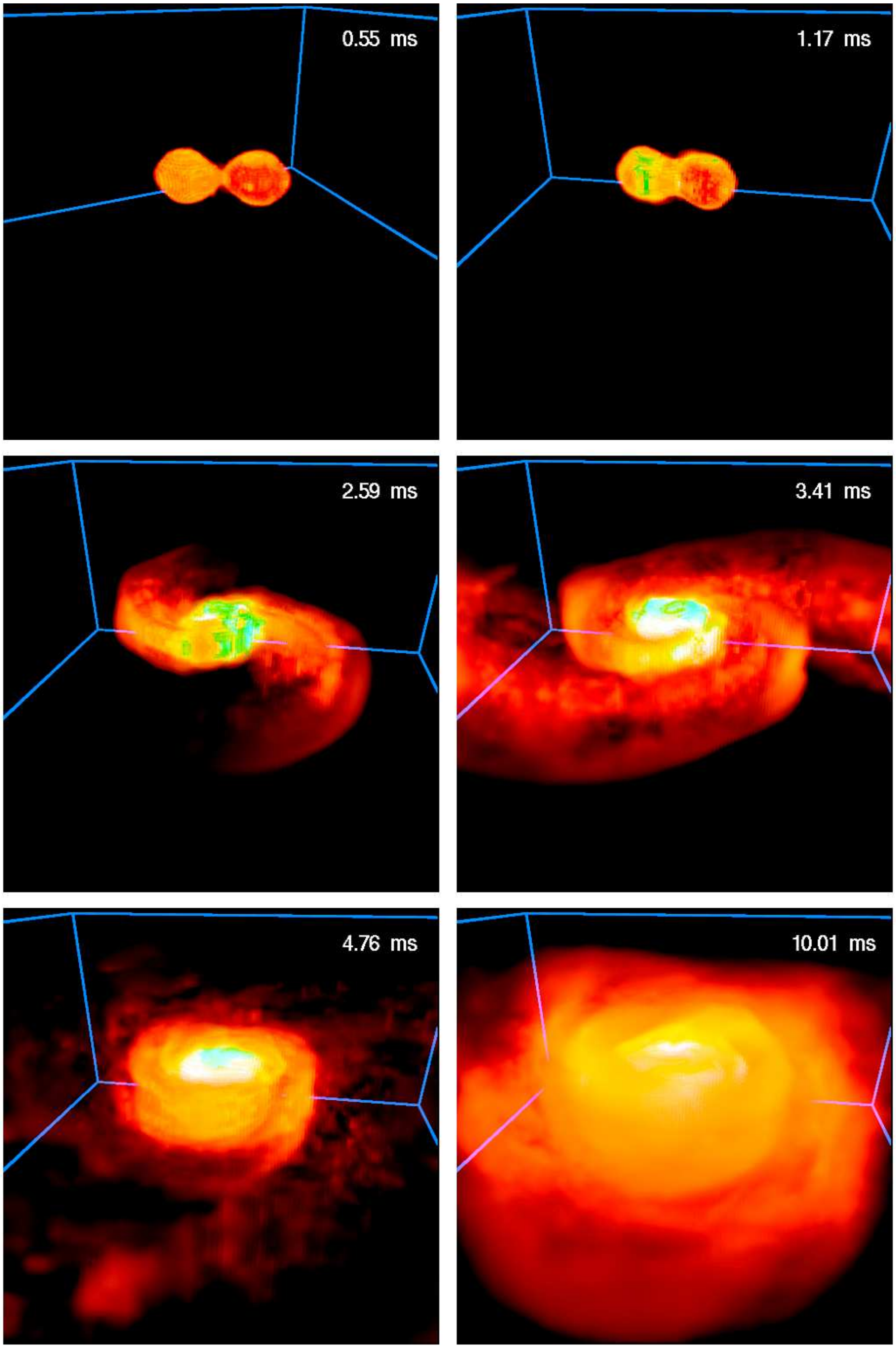

Figure 2.10: Snapshots of the merging of a binary neutron star (from top left to bottom right). The stars heat up when they plunge into each other and form a cloud of hot matter that surrounds a very dense, massive inner core. This core is likely to collapse to a black hole. The displayed evolution occurs in just a hundredth of a second (picture: Ruffert and Janka 2001).

So far only long bursts could be observed in much detail. The detection of associated afterglows in X-rays, visible light and at radio wavelengths allowed the determination of their distances and confirmed their origin from host galaxies at large redshifts, i.e., typically hundreds of millions to billions of light years away. Until recently the source of these bursts was a mystery. But evidence has accumulated that they are death throes that accompany the catastrophic explosions which end the lives of very massive stars. A final confirmation of this conjecture was provided by GRB030329, a gamma-ray burst which was detected on March 29, 2003, by HETE, NASA's High-Energy Transient Explorer satellite. For the first time this burst could unambiguously be identified as linked to a peculiar supernova named SN 2003dh at a distance of about two billion light years.

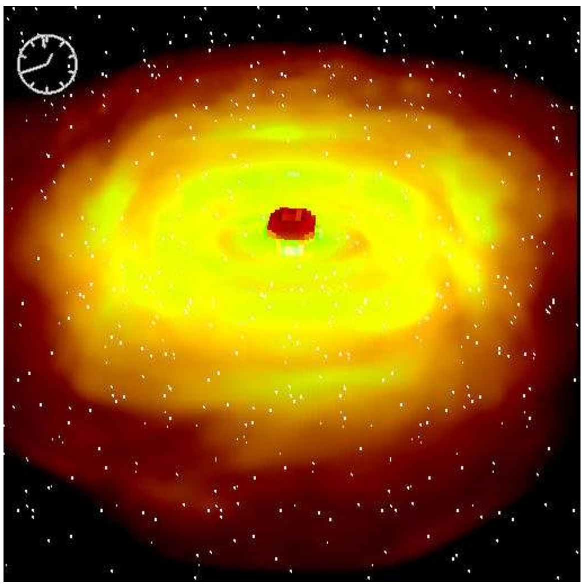

Figure 2.11: A hot, thick accretion torus girds the spinning black hole that has formed from the dense core of the merger remnant (picture: Setiawan, Ruffert, & Janka 2004).

But where does the gigantic energy come from which powers the gamma-ray burst? Scientists have coined the theory that the "engine" is a rapidly spinning black hole which forms when the central core of a dying star becomes unstable and collapses under its own gravity. This newly formed black hole then swallows much of the infalling stellar matter and thereby releases enormous amounts of energy in two jets. These expand highly relativistically, i.e. with almost the speed of light, along the rotation axis of the star. Before they break out from the stellar surface, they have to drill their way through thick layers of stellar material, thus getting collimated into very narrow beams with an opening half-angle of only a few degrees. Indeed, observations not only confirm the origin of long gamma-ray bursts from exploding massive stars, but also provide evidence that the gamma emission comes from narrowly collimated, ultrarelativistic jets with velocities of more than 99.995 per cent of the speed of light.

Rotating, growing stellar mass black holes are also born in other cosmic events, for example in the violent mergers encountered by binary neutron stars (Fig. 2.10) or by a neutron star and a black hole after hundreds of millions of years of inspiral, driven by the emission of gravitational waves. The remnant of such a catastrophy is a stellar-mass black hole sucking matter from a girding, thick torus of gas (Fig. 2.11). Such events have long been considered as possible sources of gamma-ray bursts, and they are still hot candidates for bursts of the short type, which so far could not be studied by observations in the same way as bursts from dying stars.

Researchers at the Max-Planck-Institute for Astrophysics have now developed better computer models that take into account effects due to Einstein's theory of relativity. Their simulations can follow the highly relativistic ejection of matter that is caused by energy release (e.g., due to particle reactions) in the close vicinity of the black hole. The calculations confirm that short bursts have properties that are distinctively different from those of long bursts. Since the black hole–torus system is not buried inside of many solar masses of stellar material as in case of dying stars, the polar jets do not have to make their ways through dense stellar layers and quickly reach extremely high velocities (Fig. 2.12). As a consequence, they are strongly collimated by the presence of the accretion torus, but their opening half-angles are not very different from those determined for long bursts, typically around 5 to 10 degrees (Fig. 2.12). The models predict that outside of these polar cones gamma emission should become very weak (Fig. 2.13) so that a gamma-ray burst will be observable only from one out of hundred mergers when the ultrarelativistic jet is sent towards Earth. The models also suggest that short bursts can be nearly as bright as long bursts, although their total energy release is 100 times lower.

Previous gamma-ray satellites were unable to make precise measurements for short bursts, but there is hope that these predictions can be tested

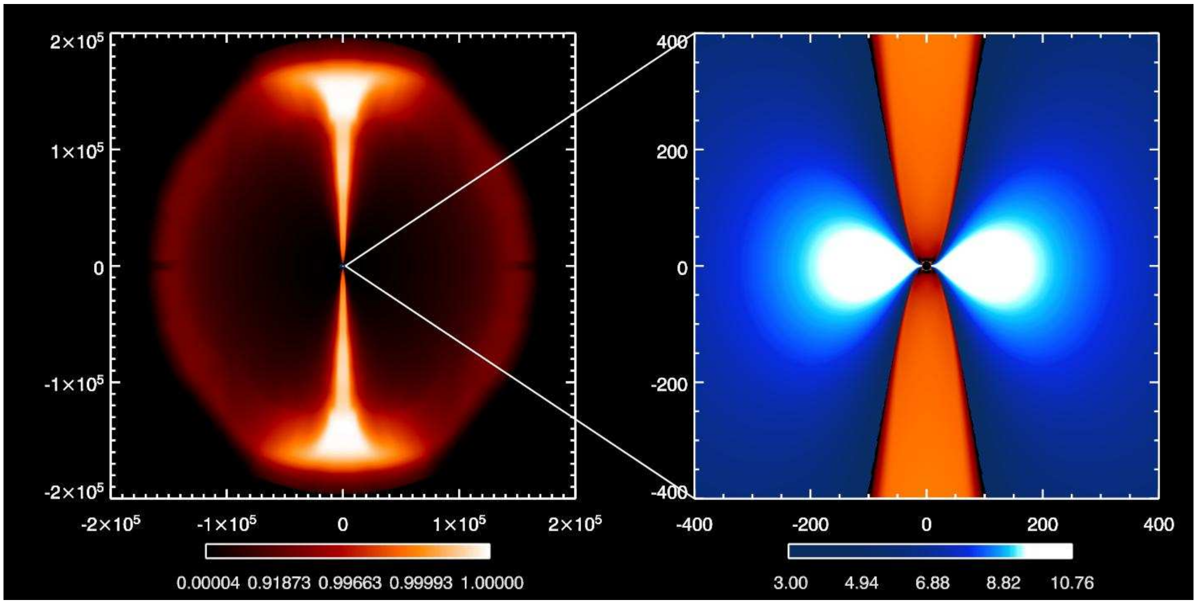

Figure 2.12: Gas outflow from the accretion torus more than half a second after the onset of the energy release at the black hole. The axial jets (bright white regions) with velocities above 99.995 per cent of the speed of light have reached a distance of more than 150000 kilometers. These ultrarelativistic outflows cause gamma-ray bursts at much larger distances. The gas ejected off axis is much less energetic and slower; it has a velocity of typically less than 98 per cent of the speed of light (red regions). The right panel shows a zoom of the close vicinity of the central black hole (out to a radius of about 400 km) with the base of the jets and the extended accretion torus. Whitish regions indicate gas densities above about 1000 tons per cubic centimeter.

soon. The Swift Gamma-Ray Burst Explorer, a NASA mission with international participation, was launched on November 20, 2004. One of its prime goals is to unravel the mysteries of the short bursts.
(H.-Thomas Janka, M.A. Aloy, E. Müller)

2.4 Low surface brightness photometry with the SDSS: galaxy haloes and intracluster light

Our current picture of the formation and evolution of galaxies emphasises the role of interactions both with other galaxies and with the environment. Kant idealised galaxies as island-universes, but it now seems that they build up their own identity not only through internal processes, but also (and perhaps primarily) through mergers with other systems, through the capture and disruption of satellites, through the tidal effects of the clusters in which they live, and through the complex hydrodynamical interaction between internal and external gas components. Understanding the detailed balance between these mechanisms remains an unsolved problem.

Gravitational interactions naturally produce a population of stars which is loosely bound or even unbound to the galaxies in which they formed. These stars are observed as diffuse, low-surface-brightness optical emission in the *haloes* of galaxies and in the intergalactic space within galaxy clusters, the so-called *intracluster light*. Study of these components can allow us to quantify the tidal damage suffered by galaxies in various environments. Unfortunately their surface brightness is so low (less than 1/1,000 that of the dark night sky, or $\mu_r > 28$ mag arcsec^{-2}) that they are very difficult to measure. Not only are the required sensitivity and calibration accuracy extremely challenging, but also severe problems due to stray light and to contamination from superposed bright sources must be overcome. For this reason we still lack direct observations of these structure for large, statistically representative samples.

We have tackled this problem using a completely different philosophy. A prime goal is to understand the systematic variation of the mean photometric properties of these diffuse stellar components with the properties of the parent galaxies or

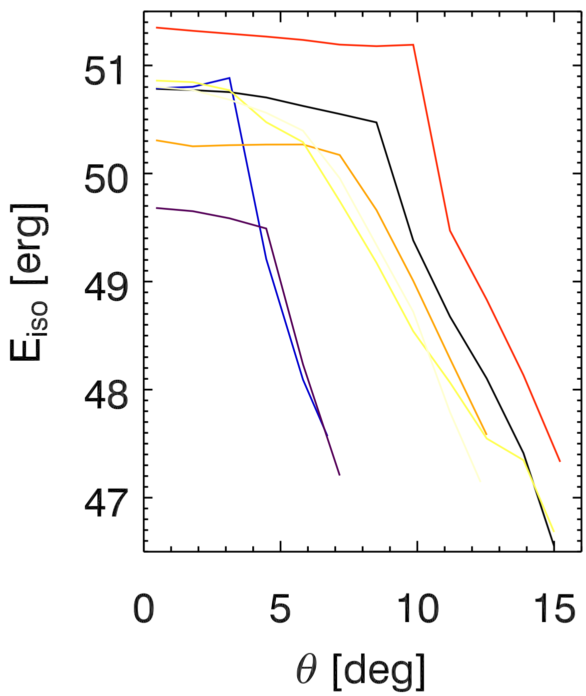

Figure 2.13: The energy of the jet flow with velocities larger than 99.995 per cent of the speed of light as measured by a distant observer from different viewing angles relative to the jet axis. It is assumed that the observer does not know that the jet is narrowly collimated to opening half-angles θ between 5 and 10 degrees, and therefore interprets the explosion as isotropic. The displayed lines correspond to a sample of computed models.

galaxy clusters. One can reach the required sensitivity and accuracy to measure the "average" properties of a population of objects by properly combining the images of a large number of individual systems, each of which is individually much too shallow to reach the required depth. The combination or *stacking* scheme must ensure: i) that a sufficiently long exposure time is obtained for the stack as a whole; ii) that fore- and background sources are masked out as far as possible before the images are combined; iii) that residual sources of pollution average to a uniform background in the stack; and iv) that spatial inhomogeneities in the response of the detector are averaged out.

The Sloan Digital Sky Survey is perfectly suited for such stacking. Its sky coverage already extended over 1,500 deg^2 at the time when the objects discussed here were selected, and when complete it will provide by far the largest database of CCD imaging ever compiled. Its 5 photometric bands cover the full optical spectrum. The typical sensitivity of an individual image is ~24.5 mag arcsec^{-2} per pixel in the r band. For our purposes an additional advantage of the SDSS imaging is its drift-scan acquisition mode, which strongly suppresses sensitivity variations in the scan direction by integrating the signal along the CCD columns. As a result, the stacking of 500 to 1000 images allows us to reach 31 mag arcsec^{-2} in r on scales of a few tens of arcseconds. This spectacular sensitivity is roughly a factor 10 better than the best performance achievable in images of individual fields.

A first application targeted a sample of 1047 edge-on disk galaxies, and aimed to detect and characterise their stellar haloes. Late-type (bulgeless), edge-on galaxies were chosen to minimize contamination by bright regions of the galaxies. As one can see in Figure 2.14, although the overall emission is dominated by the very flat disk component, at the faintest levels some light is contributed by a rounder component: the halo. By studying the surface brightness as a function of distance and direction from the centre of the stack, the observed light distribution can be separated into a flattened spheroidal halo in which the space density of stars declines as R^{-3}, and the disk emission itself, which falls exponentially with radius. A similar structure is observed in the Milky Way and in M31, the only two galaxies for which a direct and detailed study of the halo has been possible. A careful statistical analsis shows that these properties are typical for the galaxy sample studied; most disk-dominated galaxies are surrounded by a low luminosity but extended stellar halo.

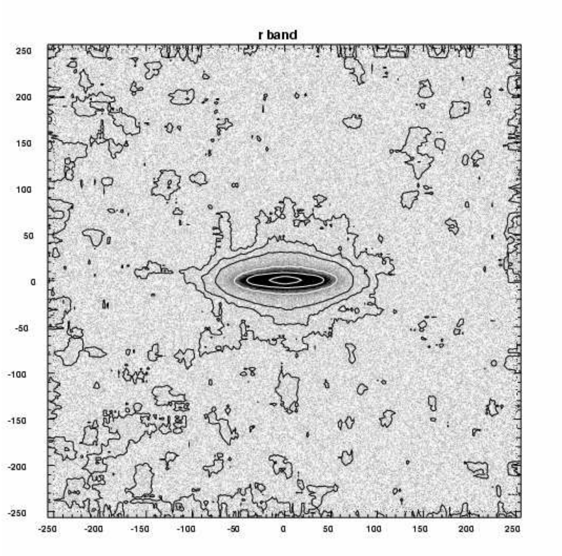

Figure 2.14: Map of the r-band emission from the stacking of 1047 galaxies. Contours indicate different surface brightness levels, from 22 to 30 mag arcsec^{-2}. The rounder shape of the outer contours reveals the presence of diffuse halo emission.

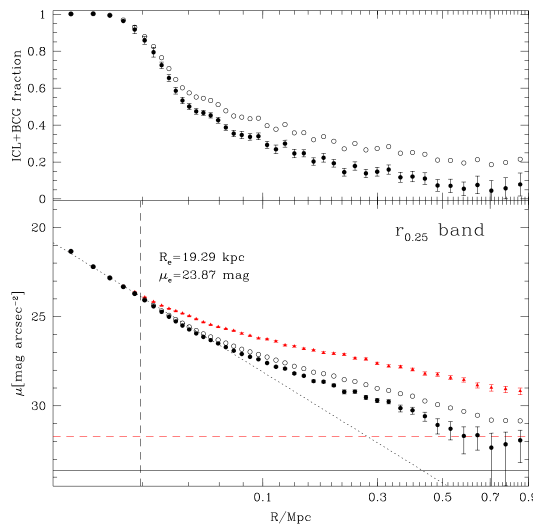

Figure 2.15: The radial variation of the mean light fraction in intergalactic stars and of the surface brightness of the various luminous components for a stacked image of 683 galaxy clusters. In the lower plot, red triangles with error bars represent the mean cluster light, open circles the diffuse light (including the BCG) after masking out all detected non-central galaxies. Filled circles with error-bars show the result of correcting for undetected galaxies and the unmasked outer parts of detected galaxies. The upper plot shows the ratio at each radius of mean surface brightness after masking of detected galaxies to mean surface brightness before such masking. (From Zibetti et al. 2005).

The colour of the halo light and the fact that its luminosity grows with the luminosity of the parent galaxy both support the general idea that it is made primarily of old stars stripped from accreted satellites. However, the observed colours are marginally inconsistent with those of standard old stellar populations: perhaps emission from ionized gas or an unexpected variation of the stellar initial mass function is required? Or perhaps the discrepancy reflects a residual systematic error in the measurements? Further observations at a variety of wavelengths are needed to solve this mystery.

To search for intracluster light, we selected a sample of 683 galaxy clusters between $z = 0.2$ and 0.3, including a broad range in mass and richness. Using appropriate masks to include or exclude cluster galaxies, we were able to study the three main stellar components of the clusters: the brightest central galaxy (BCG), the other galaxies, and the diffuse intracluster light (ICL). After removing the noncentral galaxies the mean cluster light profile contains contributions from the BCG's and the ICL. As Figure 2.15 shows, the intracluster light is apparent as a brightness excess above an extrapolation of decline of the BCG light. (This is the straight line fit to the inner regions of the plot, corresponding to surface brightness declining with radius as $R^{1/4}$). The ICL is clearly detected out to 600-700 kpc from the centre where it reaches a level ~32 mag arcsec^{-2}.

On average, the intracluster light clearly declines much faster than the light in galaxies as a function of radius. This strengthens the idea that the ICL is not simply made up of undetected galaxies and the outer parts of detected galaxies. The process responsible for creating and accumulating intergalactic stars must be associated with the cluster as a whole and must be more efficient in its central regions. With our stacking technique it is possible to study the colour of the intracluster light and the variation of the ICL with properties like the mass, richness and shape of the parent cluster. Putting together the many pieces of this puzzle, a picture emerges in which the intracluster stars are primarily stripped by gravitational tides from the outer parts of galaxies that plunge through the cluster along almost radial orbits, in some cases being completely disrupted in the process.

Although the present work is only a first step towards understanding the cumulative effects of tidal damage in galaxy clusters, the improvement provided by stacking is impressive. For example, while previous studies of individual clusters estimated the ICL to be anywhere between 0 and 50% of the total light in the cluster, we now know that *on average* this fraction is 11% within 500 kpc, with an uncertainty of 5% . This "large" error bar is due mainly to our uncertainty about how much of our measured diffuse component could be due to faint galaxies below the detection limit of SDSS. Understanding our ICL measurements in conjunction, for example, with gravitational lensing studies of cluster galaxies will tell us a great deal about how the visible component relates to the unseen dark matter halo during the formation of cluster galaxies. (Stefano Zibetti & Simon White).

2.5 Accretion onto Black Holes in the Local Universe as Mapped by SDSS

Over the past few years there have been remarkable developments in our understanding of active galactic nuclei (AGN) and their role in galaxy formation and evolution. There is now compelling evidence for the existence of the supermassive black holes that were long hypothesized to be the powersource for the AGN. It has been shown that the total amount of mass in these black holes would yield enough enough radiative energy to have powered the known AGN population over the whole history of the Universe. Finally, the discovery of a very tight relation between the mass of the black hole and the velocity dispersion and mass of the galactic bulge within which it resides provides evidence for a strong connection between the formation of the black hole and its host galaxy.

Up to now, studies of AGN host galaxies have been limited by small sample size. In order to carry out detailed statistical analyses of host galaxy properties, one requires complete magnitude-limited samples of galaxies with spectra of high enough quality to identify AGN based on the characteristics of their emission lines.

The Sloan Digital Sky Survey is currently using a dedicated 2.5-meter wide-field telescope at the Apache Point Observatory to conduct an imaging and spectroscopic survey of about a quarter of the extragalactic sky. The imaging is conducted in the u, g, r, i, and z bands and spectra are obtained with a pair of multi-fiber spectrographs. When the current survey is complete, spectra will have been obtained for nearly 600,000 galaxies. MPA researchers, in collaboration with colleagues at Johns Hopkins University in baltimore, have developed algorithms for automatically measuring emission line luminosities and absorption line equivalent widths in the spectra and have used this information to construct a sample of around 33,000 AGN, which is a factor of 100 larger than the samples that were studied in the past.

One of the great advantages of a large sample is that one can compare the results for AGN hosts with those derived for "normal" galaxies in a very precise way. The MPA researchers found that AGN occupy host galaxies with structural properties similar to ordinary early-type galaxies, but with stellar populations that were considerably younger. They also found signatures in the spectra of the presence of a significant population of A-F type stars, which indicates that many of the host galaxies had experienced and enhanced episode or burst of star formation in the past 1-2 Gigayear. Finally, by studying how the stellar populations of similar AGN hosts differed as a function of distance from the observer, it was demonstrated that the young stars were spread over a radius comparable to the size of the galaxy bulge and not concentrated in the inner nucleus.

In order to put these results on more quantitative footing, transformations were made from the observed quantities to a set of *physical quantities*. The luminosity of the [OIII]λ5007 emission line was used to estimate the AGN luminosity and hence the mass accretion rate onto the black hole (for an assumed radiative efficiency of 10%). The stellar velocity dispersion measured within the central region of the galaxy was used to estimate the black hole mass. Finally, a combination of stellar absorption and emission line indicators were used to derive star formation rates for the galaxies and AGN in the sample.

It was then possible to demonstrate that the volume averaged ratio of star formation to black hole accretion in bulge-dominated galaxies in the local Universe is $\sim$ 1000. This is remarkable similar to the observed ratio of stellar mass to black hole mass in nearby bulges and elliptical galaxies that are not accreting at the present day. The analysis also demonstrated that most of the present-day black hole growth is occurring in black holes with masses less than $3 \times 10^7 M_\odot$. The estimated accretion rates implied that these low mass black holes are growing on a timescale that is comparable to the age of the Universe (see Fig. 2.16). The growth timescale increases by more than an order of magnitude for the most massive black holes in our sample. These systems were apparently formed much further in the past and are currently experiencing very little additional growth.

The results of the MPA/JHU team give further credence to the concept of ”cosmic downsizing”. Cosmic downsizing describes a scenario in which active star formation and black hole growth occurs shifts to lower and lower mass galaxies as the Universe evolves. This is seen as something of a paradox by theoreticians who try to understand how galaxies may have formed from the evolution of tiny density perturbations generated in the earliest moments of the Universe following the Big Bang. According to now-standard theory, the dominant matter component of the Universe is not in the form of the ordinary baryons that make up ordinary human beings and stars, but consists of unseen dark matter that interacts only via gravitation. Dark matter does not undergo cosmic downsizing. The collapse of dark matter starts on small scales and proceeds to ever more massive structures. Understanding exactly why the behaviour of galaxies and dark matter should be so different remains one of the major challenges for cosmologists today. (Guinevere Kauffmann)

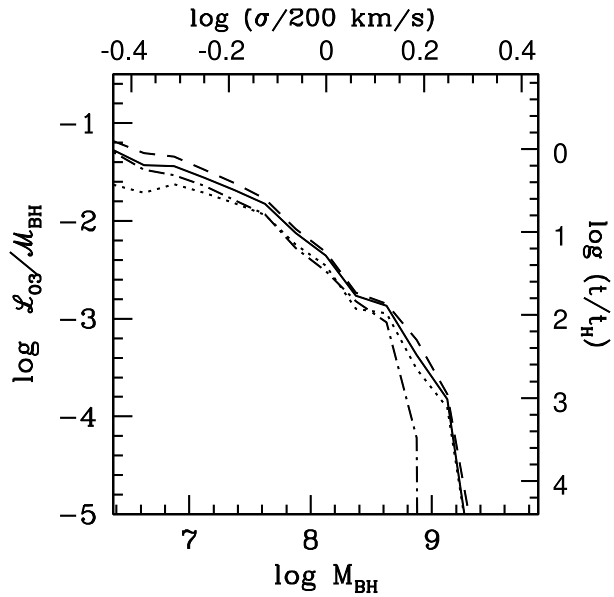

Figure 2.16: The logarithm of the ratio of the total volume-weighted [OIII] luminosity in Type 2 AGN to the total volume-weighted mass in black holes (both in solar units) is plotted as a function of velocity dispersion σ (upper axis) and $\log M_{BH}$ (lower axis). The right axis shows the corresponding growth time for the population of black holes in units of the Hubble time.

2.6 Following the formation of galaxies and the first quasars on a supercomputer

Recent progress in observational cosmology has established a standard model for the material content of the Universe, and its initial conditions for structure formation 380000 years after the Big Bang. Most of the mass in the Universe ($\sim 85\%$) consists of dark matter, an as of yet unidentified weakly interacting elementary particle. Initial fluctuations in this cold dark matter (CDM) mass component, seeded by an early inflationary epoch, are amplified by gravity as the universe expands, and eventually collapse to form the galaxies we see today. To model this highly non-linear and intrinsically three-dimensional process, the matter fluid can be represented by a collisionless N-body system that evolves under self-gravity. However, this representation of the Universe as a N-body system is only a coarse approximation whose fidelity improves when the particle number is increased. It is therefore crucial to make the number of particles used in the simulation as large as possible while remaining computationally tractable.

Scientists at the Max-Planck-Institute for Astrophysics (MPA), together with collaborators in the international Virgo consortium, were able to carry out a new simulation of this kind using an unprecedentedly large particle number of $2160^3 \simeq 1.0078\times10^{10}$, more than 10 billion. This is an order of magnitude larger than the largest computations carried out in the field thus far and significantly exceeds the long-term growth rate of cosmological simulations, a fact that inspired the name "Millennium Simulation" for the project. This progress has been made possible by important algorithmic improvements in the employed simulation code, and the high degree of parallelisation reached with it, allowing the computation to be done efficiently on a 512 processor partition of the IBM p690 supercomputer at the Computing Center of the Max-Planck Society (RZG). Still, the computational challenge of the project proved to be formidable. Nearly all of the aggregated physical memory of 1 TB available on the massively parallel computer had to be used, and the analysis of the more than 20 TB of data produced by the simulation required innovative processing methods as well.

The simulation volume is a periodic box of $500\,h^{-1}$Mpc on a side, giving the particles a mass of $8.6\times10^8\,h^{-1}\mathrm{M}_\odot$, enough to represent dwarf galaxies by about a hundred particles, galaxies like the Milky Way by about a thousand, and the richest clusters of galaxies with several million. The different panels of Figure 2.17 give a visual impression of the dark matter structure as seen on different scales at the present time. The Millennium Simulation shows a rich population of halos of all sizes, which are linked with each other by dark matter filaments, forming a structure which has become known as *Cosmic Web*. The spatial resolution of the simulation is $5\,h^{-1}$kpc, available everywhere in the simulated volume. The resulting large dynamic range of 10^5 per dimension in 3D allows extremely accurate statistical characterisations of the dark matter structure of the universe, including the detection of dark matter substructures within individual halos. In Figure 2.18, we show the non-linear halo mass function of the simulation at different times, serving as an example for the exquisite accuracy with which key cosmological quantities can be measured from the simulation.

An important feature of the new simulation is that is has a good enough mass resolution to give a complete inventory of all luminous galaxies above about $0.1\,L_\star$, despite covering a volume comparable to the large observational redshift surveys that have become available recently. This is crucial for studying rare objects of low space density, such as rich clusters of galaxies, or the first luminous quasars at high redshift.

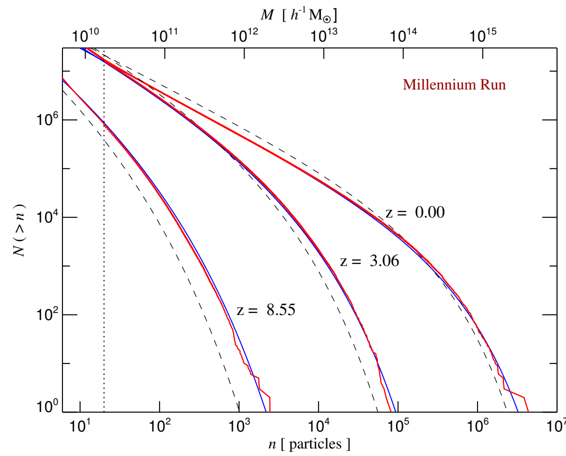

Figure 2.18: The number of dark matter halos above a given mass threshold, shown at three different times. The blue line is an analytic fitting function by Sheth & Tormen which describes the simulation results accurately, much better than the older Press & Schechter theory (dashed). The vertical dotted line marks the halo resolution limit of the simulation.

We have developed new semi-analytic modelling techniques for following the physical processes of galaxy formation along dark matter merger history trees measured from the Millennium Simulation. This provides a powerful framework for the quantitative physical interpretation of galaxy and gravitational lensing surveys. Our semi-analytic model integrates a number of differential equations for the time evolution of the galaxies that populate each hierarchical merging tree. In brief, these equations describe radiative cooling of gas, star formation, growth of supermassive black holes, feedback processes by supernovae and AGN, and effects due to a reionising UV background. In addition, morphological transformation of galaxies and processes of metal enrichment are modelled as well. For given assumptions about the processes controlling galaxy formation, a few CPU hours on a workstation then suffice to calculate the positions, velocities and intrinsic properties of all galaxies brighter than the Small Magellanic Cloud throughout a volume comparable to those of most current and planned surveys. A prime goal made possible by our methodology is to evaluate different assumptions about the galaxy formation physics against each other and against the observational data in order to understand which processes determine the various observational properties of the real galaxy population.

The power of this approach is demonstrated by some of the first results we obtained for a galaxy

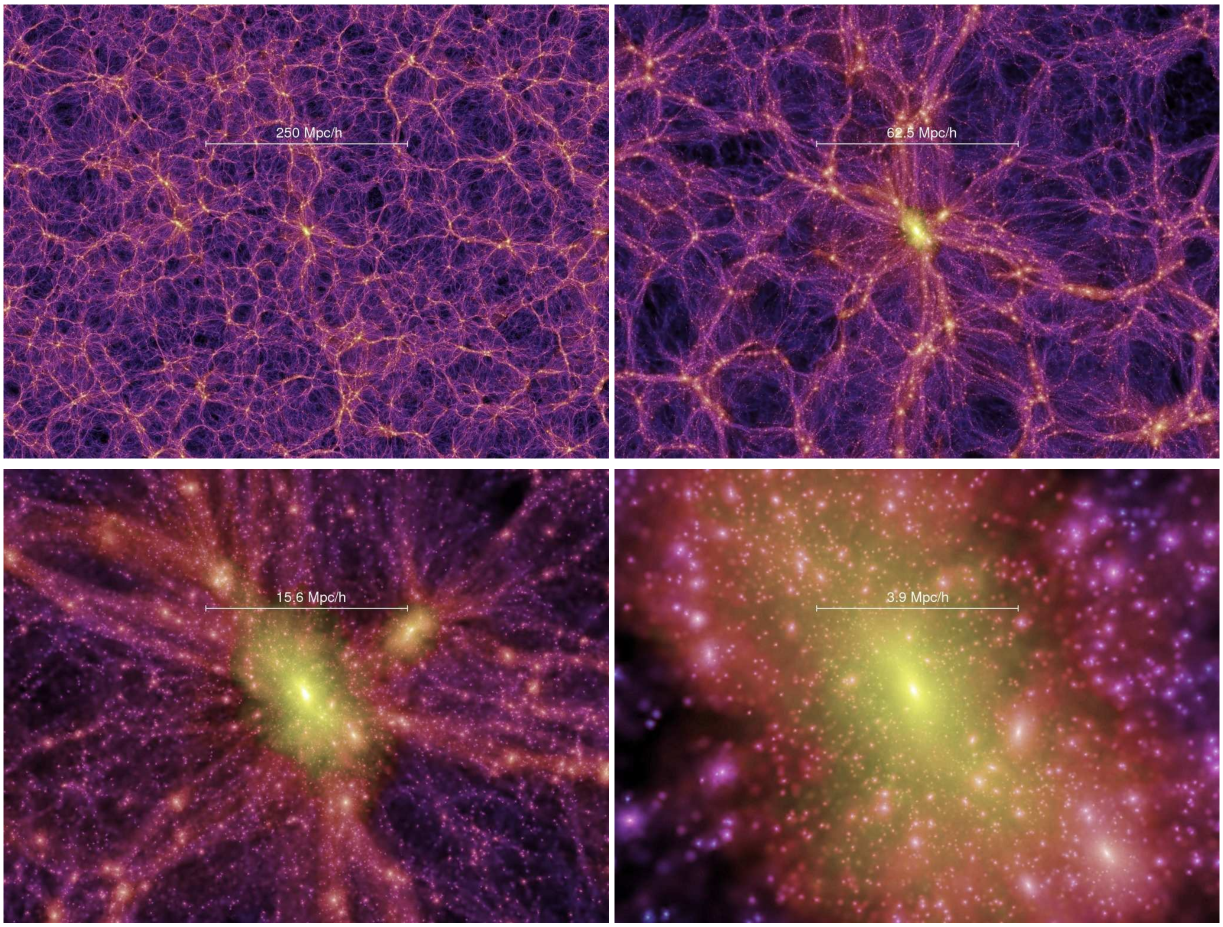

Figure 2.17: Large-scale structure in the dark matter on different scales, as seen in slices through a small part of the simulated universe. Clearly visible in the different panels is the 'Cosmic Web' which connects individual galaxies, groups and clusters by filaments of dark matter, and surrounds large underdense voids. The bottom right panel has zoomed in onto a rich cluster of galaxies.

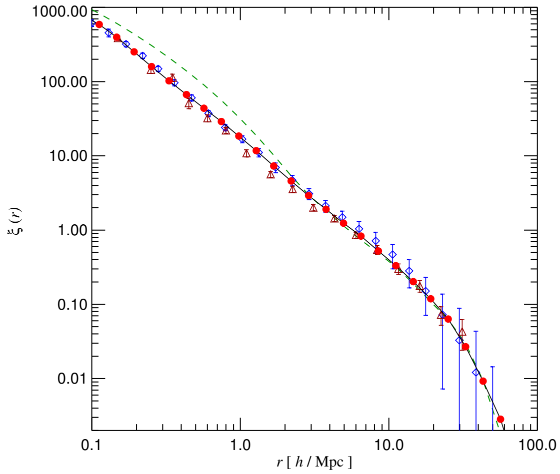

Figure 2.19: The 2-point correlation function of galaxies in the Millennium Simulation (red dots and black solid line), compared with observational data. Diamond symbols give results based on the APM galaxy survey, while triangles are for the spectroscopic 2dF Galaxy Redshift Survey. Our model prediction has negligible statistical error bars and is very close to a power-law, despite the strongly non-power law behaviour of the dark matter (dashed line).

formation model tuned to fit the observed luminous properties of the low redshift galaxy population. In Figure 2.19 we show the 2-point correlation function of model galaxies and compare it to results from the 2dFGRS and APM galaxy surveys. We find a nearly perfect power-law for our model predictions which is in very good quantitative agreement with observations. At the same time, we are able to reproduce the observed dependence of clustering on luminosity and colour. This is a remarkable success for the theory of hierarchical galaxy formation based on the ΛCDM cosmology.

Our framework for studying galaxy formation also allows us to establish evolutionary links between objects observed at different epochs. For example, we have demonstrated that systems with the abundance, total mass, stellar content and black hole mass inferred for luminous redshift $z \sim 6$ quasars are indeed present at $z \sim 6$, their progenitors were already massive by $z \sim 16$, and their $z = 0$ descendents are cD galaxies at the centres of rich galaxy clusters; no previous simulation has been able to trace the origin and fate of such rare objects. Figure 2.20 shows an example of such a quasar candidate $z \sim 6.2$, which is hosted by the galaxy with the largest stellar mass in the entire simulation volume at this epoch. The galaxy is forming stars vigorously at a rate of

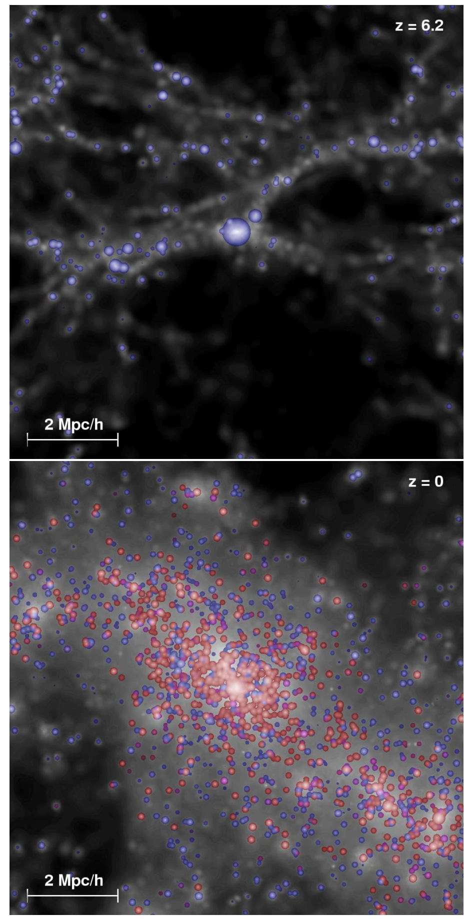

Figure 2.20: Environment of a first quasar candidate at high and low redshift. The two panels show the galaxies of the semi-analytic model overlayed on a gray-scale image of the projected dark matter distribution in a cube of comoving sidelength $10\,h^{-1}$Mpc. The volume of the sphere representing each galaxy is proportional to its stellar mass, and the chosen colours encode the restframe stellar $B - V$ colour index. While at $z = 6.2$ (top) all galaxies appear very blue due to ongoing star formation, many of the galaxies that have fallen into the rich cluster at $z = 0$ (bottom) have turned red.

$235\,M_\odot yr^{-1}$ and its descendant at the present time is found at the centre of a rich cluster with mass $1.46 \times 10^{15} h^{-1} M_\odot$.

In conclusion, N-body simulations of CDM universes are now of such size and quality that realistic modelling of galaxy formation in volumes matched to modern surveys has become possible. Further studies of galaxy and AGN evolution exploiting the unique dataset of the Millennium Simulation will enable stringent new tests of the theory of hierarchical galaxy formation. Extrapolating the remarkable progress since the 1970s for another three decades, we may expect cosmological simulations with $\sim 10^{20}$ particles some time around 2035. This would be sufficient to represent all stars in a region as large as the Millennium volume with individual particles. (Volker Springel)

2.7 Clumping of dust in protoplanetary disks

According to conventional wisdom planets are formed in the dark dusty molecular circumstellar disks left over from the star formation phase. Such 'protoplanetary disks', like those surrounding T Tauri and Herbig Ae/Be stars, are cool environments in which the gas is in molecular form and in which some molecules such as H_2O and CO may freeze out onto the surfaces of the abundantly available dust grains. While these disks may seem rather tame in comparison to the accretion disks found in e.g. X-ray binaries, they are in fact fairly active in their own way. Turbulence continuously stirrs up the dust particles in the disks, and the charging of dust grains can lead to lightning discharges within the disk. In these unusual environments the dust grains, initially less than a micron in size, coagulate and grow to ever larger aggregates, eventually leading to the formation of bodies the size of a few kilometers. These planetary precursor bodies, often called 'planetesimals', are the building blocks with which the final assembly of planets then takes place through gravitational agglomeration.

The initial steps of this growth process are of particular interest. The growth of dust particles from sub-micron size to about 1 mm leaves directly observable signatures in the infrared spectra and sub-millimeter fluxes of such protoplanetary disks. The new Spitzer Space Telescope has produced high-quality infrared spectra of over 50 of such disks (with many more yet to come) and signatures of grain growth are indentifiable in most of these spectra. Additionally, the Very Large Telescope mid-infrared Interferometer (MIDI) has spatially resolved these disks down to about 1 AU radius (distance from the central star), i.e. well within the habitable zone around these stars, and found that grain growth appears to be a strong function of radius.

These exciting new data allow a new boost in the study of grain growth in protoplanetary disks. At the MPA, C.P. Dullemond, in collaboration with C. Dominik (University of Amsterdam), has developed a new code for modeling the process of dust coagulation in detail in an axisymmetric model of a protoplanetary disk. This model also produces synthesized infrared spectra that can be compared to the Spitzer and VLT data, and in this way a link is established between the detailed coagulation calculations and the observed infrared spectra.

The calculations show that the strongest mode of grain growth appears to be the growth caused by 'rain out'. Due to the force of gravity, dust particles tend to sediment to the mid-plane of the disk. Just like the formation and growth of rain drops in clouds in the Earth's atmosphere, the bigger dust grains sediment fast, and sweep up many slowly sedimenting small grains. These bigger grains therefore tend to grow in a run-away fashion until they reach the disk's midplane.

This 'rain out' growth process is shown in Fig. 2.21. Initially the growth of the grains is dominated by random encounters due to Brownian motion. After about 500 years, however, a new peak at 0.3 millimeter appears in the distribution of particle sizes, caused by the 'rain shower' reaching the midplane of the disk. This rain shower also washes out the pre-existing smaller grain population. On a longer time scale remnant small grains sediment to the midplane.

In principle the rain-out is over once most of the grains reach the midplane. But turbulence can stirr big grains up again so that they can sediment once more and collect even more small grains. This leads to an continued growth to sizes well beyond 1 mm. An analogy with the formation of giant hail stones in thunder clouds is possible here. Such large stones are produced by repetitive up- and down motions through a strong updraft in a cumulonimbus cloud.

The comparison of the spectra and images from these models to actual observations of protoplanetary disks has already yielded interesting new discoveries. They have shown that the invisibility of some disks in near-infrared imaging appears to be

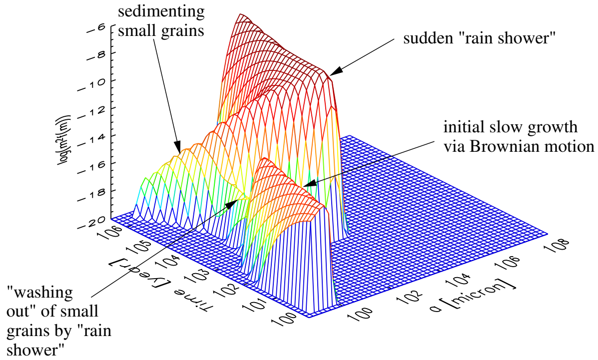

Figure 2.21: Diagram showing the time-evolution of the size-distribution of dust grains at the disk midplane at 1 AU distance from the central star. On the x-axis is the size of the dust aggregate in micron, on the y-axis is time in years and on the z-axis is the distribution function of the dust. The distribution function is written as $m^2 f(m)$ which is the equivalent of νF_ν for spectra in the sense that the surface under the curve means the total mass density of dust at that location in the disk.

a result of dust sedimentation. Since dust grains tend to sediment more effectively in the outer regions of the disk than in the inner regions, the inner regions cast a shadow over the outer regions, so that no stellar radiation reaches the disk surface in the outer regions, hence no scattered emission from the disk surface. A time sequence of this shadowing process is shown in Fig. 2.22.

Another result of the model-observation comparison was that the time scale for pure grain growth in the model is much smaller than the typical time that protoplanetary are observed to contain large amounts of small dust grains. Apparently the model predicts a *too efficient* grain growth. A solution could be that in addition to growth, the grains also now and then experience disruptive collisions. The fragmentation of grains replenishes the small grain population, which could then explain why even after 1 Myr the disks still have enough small dust grains to be optically thick.

The work shown here is the start of a project in which the new data on protoplanetary disks from the Spitzer Space Telescope and the VLT is being interpreted with a detailed model of dust coagulation, with the aim of improving the understanding of the initial phases of planetesimal formation through grain growth. (C. Dullemond)

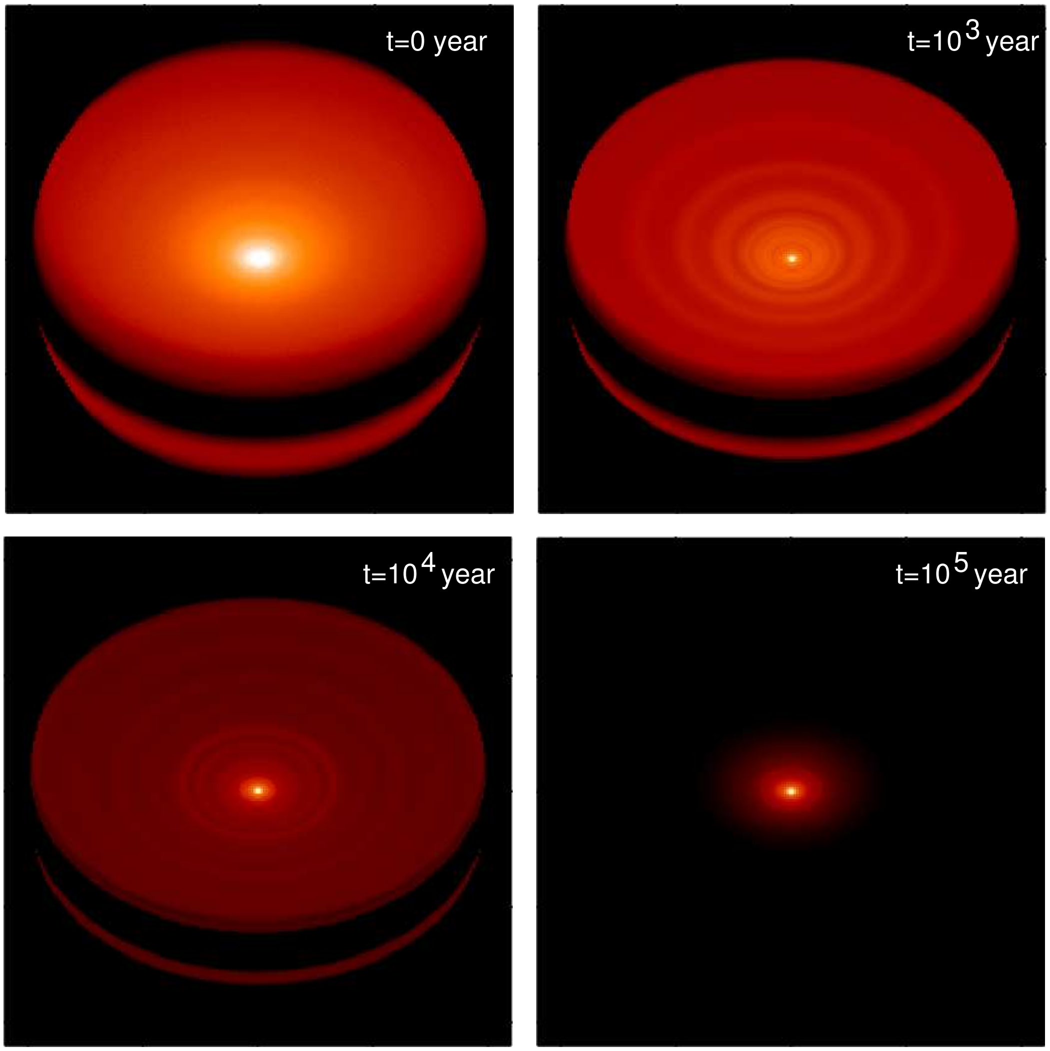

Figure 2.22: A time-sequence of images of a protoplanetary disk with sedimenting grains, as seen in scattered light at 0.55 micron. Because in the outer regions the refractory dust sediments deeper than in the inner regions, the outer regions become shadowed and therefore 'invisible'.

2.8 A faint population of gamma-ray bursts

Cosmic gamma-ray bursts (GRBs) are flashes of gamma rays that can last from less than a second to a few minutes and occur at random positions in the sky. A large fraction of them is thought to result when a black hole is created from a dying star in a distant galaxy. Astronomers believe that a hot disc surrounding the black hole, made of gas and matter falling onto it, somehow emits an energetic beam parallel to the axis of rotation. According to the simplest picture, all GRBs should emit similar amounts of gamma-ray energy. The fraction of it detected at Earth should then depend on the opening angle and orientation of the beam as well as on the distance. The energy received should be larger when the beam is narrow or points towards us and smaller when the beam is broad or points away from us. New data collected with ESA's high energy observatories, INTEGRAL and XMM-Newton, now show that this picture is not so clear-cut and that the amount of energy emitted by GRBs can vary significantly.

On 2003 December 3, IBIS, a hard X-ray coded aperture mask imager on the INTEGRAL satellite detected a gamma-ray burst, GRB 031203, of 40 s-duration. Within a record 18 seconds of the burst, the INTEGRAL Burst Alert System had pinpointed the approximate position of GRB 031203 in the sky and sent the information to a network of observatories around the world. A few hours later one of them, ESA's XMM-Newton, determined a much more precise position for GRB 031203 and detected a rapidly fading X-ray source, which was subsequently seen by radio and optical telescopes on the ground.

This wealth of information allowed astronomers to determine that GRB 031203 went off in a galaxy at a redshift of $z = 0.105$, making it the second closest GRB ever observed. With a duration of 40 s and rest-frame spectral peak energy of $>$ 200 keV (see Fig. 2.23) this event appears to be a typical long duration GRB, even though its isotropic gamma-ray energy, $\sim 10^{50}$ erg, is about three orders of magnitude smaller than typically found for cosmological (at redshifts $z \sim 1$) GRBs. This burst as well as the other nearby event GRB 980425, both associated with core-collapse supernovae, are clear outliers for the much discussed isotropic-energy peak-energy relation and luminosity spectral-lag relations. Futhemore, radio calorimetry shows that both these events are under-energetic explosions.

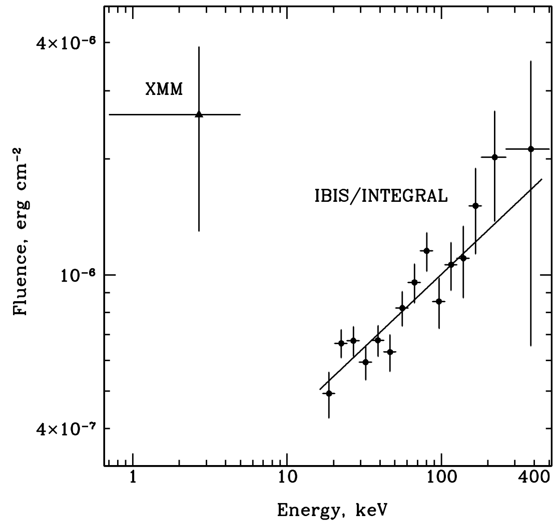

Figure 2.23: Spectral energy distribution of GRB 031203, shown in νF_ν units. The data points in the 17–500 keV range were obtained from the data of the IBIS/ISGRI detector for the first 20 s of the burst, when 80% of its total energy was emitted. The best fit power law model with $\Gamma = -1.63 \pm 0.06$ is shown by the line. The cross towards the top left corner of the figure is the soft X-ray (0.7–5 keV) fluence, F_X inferred from the dust scattered halo discovered in *XMM-Newton* observations.

This discovery suggests the existence of a new population of GRBs that are much less energetic than the majority of those known so far. Such under-luminous bursts may occur very frequently in the Universe, and the bulk of this population has probably escaped our attention simply owing to its intrinsic faintness. GRB 980425 and GRB 031203 can be just the tip of the iceberg and the recently launched NASA's SWIFT spacecraft should be able to extend the search to a much larger volume of the Universe and find many more sub-energetic GRBs (Sergey Sazonov, Alexander Lutovinov and Rashid Sunyaev).

2.9 Hard X-ray view of the past activity of Sgr A* in a natural Compton mirror

Our Galactic Center (GC) harbors a black hole (BH) with a mass of $3 \times 10^6 M_\odot$. It has remained puzzling why the source Sgr A* associated with the BH is faint despite the presence of significant amounts of ambient gas capable of fuelling it.

Among many complex structures near the GC, X-ray telescopes have detected 8–20 keV continuum and 6.4 keV line diffuse emission associated with giant molecular clouds, in particular Sgr B2 located at a projected distance of ∼100 pc from Sgr A*. That was suggested to be radiation emitted in the past by Sgr A*, Compton scattered and reprocessed by the cloud neutral gas and delayed by the light travel time.

The scattered emission is strongly photoabsorbed within the Sgr B2 cloud at energies below 5–10 keV. However, since the efficiency of photoabsorption rapidly declines with energy, one could expect Sgr B2 to be a strong X-ray source at energies above ∼15 keV, that was really observed by the INTEGRAL sattelite (see Fig. 2.25)

It was known before the INTEGRAL observations that the soft X-ray (2–10 keV) emission of the Sgr B2 cloud is dominated by diffuse emission in a fluorescent line at 6.4 keV superposed on strongly absorbed continuum emission. A number of smaller molecular clouds in the GC region also exhibit powerful 6.4 keV line emission, although with low absolute fluxes compared to Sgr B2. Common for all of these sources is the huge (1–2 keV) equivalent width of the 6.4 keV line. Such an equivalent width is consistent with a model in which the cloud reflects (partially scatters and partially reprocesses into fluorescent emission) X-rays from a hidden illuminating source that is located either inside or outside the cloud. In the latter case, different reflecting clouds may be exposed to the same source. Whether located internally or externally relative to the clouds, the illuminating source(s) should be quiet now, otherwise it (they) would be readily detectable by X-ray telescopes.

One could hope to discriminate between the internal and external primary source scenarios by studying the variability of X-ray flux from molecular clouds. The 6.4 keV line flux was measured with defferent X-ray telescopes from 1994 till 2001 and no significant variability is evident during this period. INTEGRAL observations similarly indicate that the continuum flux in the 17–60 keV band was constant within 25% during 2003–2004.

The observed stability of X-ray flux from Sgr B2 in combination with the finite size (∼ 10 pc) of the latter rule out that the observed diffuse X-ray emission resulted from illumination of the molecular gas by a source inside the cloud. Such a scenario predicts a clear decline of the reprocessed X-ray flux on a time scale of years after the source switches off. On the other hand, the constancy of the 6.4 keV-line flux from Sgr B2 over a decade is consistent with the idea that there was a powerful outburst of the suppermassive BH in the GC (the Sgr A* source) some 300 years ago that lasted at least 10 years and illuminated the Sgr B2 cloud.

Unless the spectral energy distribution of Sgr A* during the outburst fell off abruptly above ∼ 10 keV, it is natural to expect reflected hard X-ray emission above 10 keV from Sgr B2 in addition to the observed contninuum and line emission below 10 keV. Indeed, molecular gas is a perfect reflector of hard X-rays since the photoabsorption cross section strongly decreases with photon energy while the cross section for Compton scattering declines slowly with energy. It is therefore extremely intriguing that INTEGRAL does see a hard X-ray source associated with Sgr B2. Figure 2.24 shows a hard X-ray spectrum of Sgr B2 covering a broad range from 2 keV to 200 keV. This spectrum is well fit by a model in which X-rays from Sgr A* are scattered and reprocessed in a homogeneous spherical cloud of cold gas. Scattering of the hard X-rays occurs on the neutral molecular hydrogen and helium while the abundance of iron determines the intensity of the fluorescent K_α line.

Alternative explainations of the X-ray emission of Sgr B2 meet serious difficulties. Superposition of a large number of weak undetected point sources is very unlikely. The cumulative emission of X-ray sources in nearby molecular clouds such as Orion or ρ Ophiucci is substantially softer than that of Sgr B2 and does not exhibit a strong 6.4 keV emission line. One may argue that a strong fluorescent line can be imposed by the reprocessing of the point sources' contninuum emission by the molecular gas within their host cloud, but then it is impossible to explain the remarkable independence of the line equivalent width on the photoabsorption column of the multiple clouds in the GC region.

The bombardment by the low energy cosmic ray electrons was suggested as an alternative explanation of the 6.4 keV emission. The electrons produce inner-shell ionizations of iron atoms leading to 6.4 keV line emission and simultaneously generate bremsstrahlung radiation. Lack of the strong cutoff below 200 keV in the INTEGRAL data implies that electrons with energies higher than at least few hundred keV are present, while the slope of the observed spectrum (photon index ∼ 2) constrains the distribution of electrons over energy. Given these observational constraints and using thick target approximation one can estimate that only $1-3\times10^{-5}$ fraction of cosmic ray electrons power goes into radiation around 50 keV. Thus to produced observed luminosity at 50 keV of $\sim 3 \times 10^{35}$ erg/s at least $10^{40} - 3 \times 10^{40}$ erg/s of energy in cosmic ray electrons has to be dumped in to the cloud, which is comparable or more than total emissivity of Sgr B2. This estimate shows that there is no large room for additional energy in the nonthermal cosmic ray protons. An equivalent width of the 6.4 keV line (with respect to the bremsstrahlung continuum) is estimated to be of order of 250-350 eV for solar abundance of iron. Therefore observed ~2 keV equivalent width translates into factor of $5-6$ overabundance of iron. To conclude, the cosmic rays model cannot be completely ruled out, but it encounters very serious problems.

In the framework of the reflection nebula model we can draw very important conlusions. The Sgr A* was luminous some 300 years ago and since than its flux has descreased to the present value. The broad band luminosity of Sgr A* can be estimated to be $\sim 5 \times 10^{39}$ erg/s. The observed broad-band spectrum of Sgr B2 allows us to reconstruct the illuminating spectrum of Sgr A* and therefore we can for the first time measure the spectrum of low luminosity active galactic nuleus (LLAGN). The obtained spectrum is similar to that of usual Seyfert 1 galaxies.

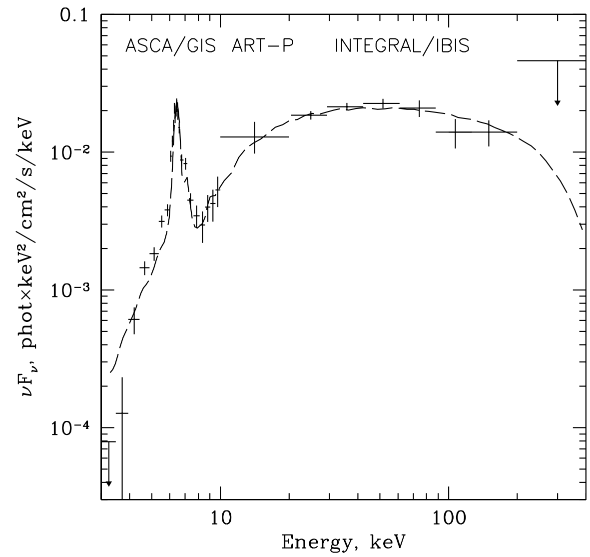

Figure 2.24: Broad band X-ray spectrum of the source IGR J17475-2822 associated with the Sgr B2 cloud. Data of ASCA/GIS (3–10 keV), GRANAT/ART-P (10–20 keV) and INTEGRAL/IBIS (20–400 keV) are presented. 1σ error bars and 2σ upper limits are shown. The dashed line is the best-fit model (see main text) convolved with the resolution of ASCA/GIS ($\sigma \approx 230$ eV).

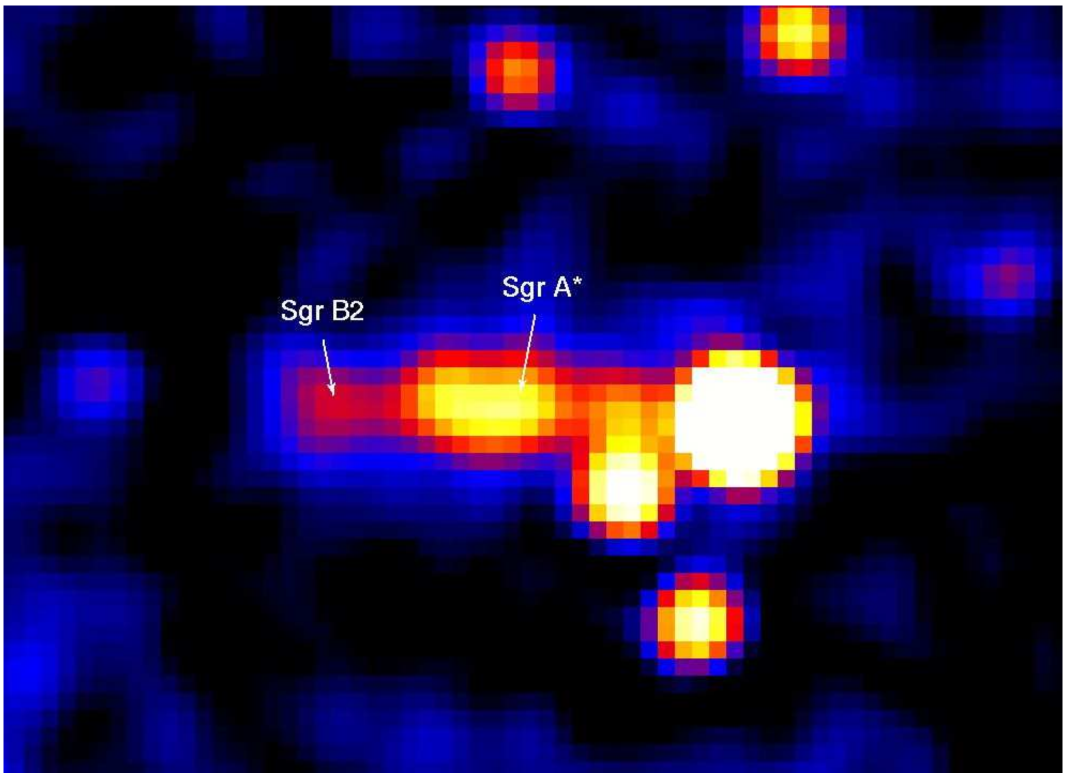

Figure 2.25: $3.5^\circ \times 2.5^\circ$ hard X-ray (18–60 keV) image of the GC region obtained with INTEGRAL/IBIS. Contours denote levels of the signal to noise ratio, which start from S/N=5.0 and increase with a multiplicative factor of 1.4. Detected known X-ray sources are indicated

3 Research Activities

3.1 Stellar Physics

A sophisticated theoretical prediction for the Planetary Nebulae Luminosity Function based on synthetic populations of AGB- and post-AGB stars was developed by A. Weiss in collaboration with colleagues from Padua (M. Marigo, C. Chiosi), Trieste (L. Girardi) and Leuven (M. Groenewegen). While for galaxies with on-going or recent star formation the observations could be reproduced well and therefore understood, the model so far fails for elliptical galaxies, probably because of the lack of models for old, but metal-rich AGB-stars. This will be added in a thesis by A. Kitsikis. — Previous investigations in cooperation with M. Salaris (Liverpool) into the ages of galactic stellar components were continued with age determiations of mostly old open clusters (S. Percival, Liverpool), and halo field stars (with D. Rohr, Mannheim). For the latter project stellar data from the Sloan Digital Sky Survey are being used. – Further activities in this group were concerned with models for carbon enriched extremely metal-poor stars (with H. Schlattl, MPA, S. Cassisi, Teramo, and M. Salaris, Liverpool), the use of solar models and helioseismology for the determination of basic physical quantities, in particular for the determination of Newton's constant of gravity (with H. Schlattl, MPA, J. Christensen-Dalsgaard, Arhus, and M.P. Di Mauro, Catania), and with methods for construction Horizontal Branch models (with A. Serenelli, Princeton).

One of the most baffling problems in solar MHD is posed by the structure of the penumbra of sunspots, now seen in spectacular detail (0.12") with the new Swedish solar telescope at La Palma. In collaboration with G. Scharmer (Stockholm), H. Spruit developed a model for the filamentary structure of the penumbra, based on the theoretical idea that just below the observed surface a sunspot consists of a bundle of magnetic flux strands separated by field free convecting fluid.

The nature of the magnetic fields observed in Ap-stars is one of the oldest problems in astrophysical magnetohydrodynamics, with competing explanations proposing a 'fossil' origin (remnant of star formation) or a dynamo in the convective core. J. Braithwaite has solved this problem in his PhD thesis (superviser H. Spruit). With numerical 3-D MHD simulations he showed how an arbitary initial field configuration decays to a stable equilibrium. This configuration consists of a poloidal field appearing as an approximate dipole at the star's surface, stabilized by a torus of linked poloidal-toroidal field inside the star. These results imply that the magnetic fields seen in Ap stars, as well as those of magnetic white dwarfs and magnetars are probably long-lived stable fields rather than dynamo-generated.

A. Heger (Los Alamos), in collaboration with S. Woosley (Santa Cruz) and H. Spruit computed the evolution of massive stars using Spruit's (2001) theory for magnetic torques in differentially rotating stars. The results predict a value of about 10ms as initial spin period of newly born pulsars, within a factor of 2 of the initial spin periods inferred for many pulsars.

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.

In this context H. Ritter, in collaboration with N. Sakhibullin, V. Shimansky, I. Bikmaev, V. Suleimanov (Kazan State University, Kazan), N. Borisov (Special Astrophysical Observatory, Nizhnij Arkhyz), and A. Galeev (Kazan State University and Kazan State Pedagogical University, Kazan) has investigated the new precataclysmic binary PG 2200+085. Whereas the available observations are constistent with an orbital period of either 0.31858 days or twice that value, a theoretical interpretation of the observed light curve and a comparison of this system with other precataclysmic binaries indicates that the observed light variations are due to a reflection effect and that, therefore, the shorter of the two possible orbital periods is the correct one.

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 now available only on-line. In collaboration with U. Kolb (Open University, Milton Keynes), three releases (the latest as of 1 July 2004) of this catalogue have so far been issued (with the next release due 1 January 2005).

Also in the contex 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 of the Catalog and Atlas of Cataclysmic Variables which is provided in collaboration with R. Downes (Space Telescope Science Intitute, Baltimore), R. Webbink (Univeristy of Illinois, Urbana), M. Shara (American Museum of Natural History, New York), and H. Duerbeck (Free University Brussels, Brussels).

A. Pastorello coordinated the observations and analyzed the data of the Type Ia SN 2004eo, one of the targets selected for the European Supernova Collaboration, led by W. Hillebrandt. This work, together that of other members of the network, should contribute to provide new impulse in understanding the physical mechanisms regulating Type Ia SN explosions.

Other Type Ia supernovae recently monitored by the RTN include SN 2003hv, SN 2003kf, SN 2004aw, SN 2004dt, and SN 2005W. SN 2004dt received special attention because it was also the first target of a large international collaboration aiming at early UV spectroscopy for very nearby Type Ia supernovae.

In collaboration with L. Zampieri and other members of the Padua's Observatory, observational properties of a sample of hydrogen rich core-collapse SN have been studied by A. Pastorello, including low-luminosity, ^{56}Ni-poor SN IIP and SN produced by the explosion of blue supergiants. Despite the observed differences, a number of correlations exists among physical parameters of SN IIP, suggesting their use as distance indicators. Finally he also studied supernovae (labeled IIn) showing evidence of interaction ejecta-circumstellar material. For SN 1995N, in particular, has been provided the largest available data set for a Type IIn SN, extended from the X-ray to the infrared wavelengths.

In the course of his Diploma work, supervised by W. Hillebrandt, Stefan Taubenberger coordinated the observations and reduced and analysed the data of the nearby supernova 2004aw. This SN had initially been classified as type Ia, but turned out to be a type Ic event instead during the campaign, maybe a mild hypernova. This initial misclassification +brought up the question of a possible contamination of the cosmological type Ia sample with SNe of type Ic.

M. Stritzinger working under the tutelage of W. Hillebrandt and B. Leibundgut has been using detailed observations of type Ia supernovae to place constraints on the progenitor system(s) and explosion(s) mechanisms of these cosmic explosions. In addition through coupling models of type Ia supernova with observations he has been able to place lower limits on the Hubble constant, independently of any external calibrators.

P. Ruiz–Lapuente and colleagues from an international team completed the survey of the central part of the remnant of SN 1572, in search for the binary companion star of this supernova, that is the mass donor to the white dwarf which exploded. They have discovered a G0–G2 star, similar to our Sun in surface temperature and luminosity but with lower surface gravity (labelled *Tycho G*), close to the centroid of the X–ray remnant and at the right distance, moving at more than three times the average velocity of the stars in that region. This peculiar velocity most likely arises from the orbital velocity of the companion when the binary system was disrupted by the explosion. The star's metallicity excludes its belonging to the halo population as an alternative explanation of its motion. The discovery points to systems akin to the recurrent nova U Sco as SNeIa progenitors. In the survey, the 4.2m William Herchel Telescope and the 10m Keck Telescope have been used for spectroscopy of the stars in the field and the WFPC2 of the Hubble Space Telescope for proper motion measurements. The international team included F. Comeron (European Sothern Observatory), J. Mendez and R. Canal (University of Barcelona), S. J. Smartt (IoA Cambridge University), A. V. Filippenko, R. Chornock and R. J. Foley (University of California, Berkeley), R. L. Kurucz (Harvard–Smithsonian Center for Astrophysics), V. Stanishev (University of Stockholm) and R. Ibata (Observatoire de Strasbourg).

P. Ruiz–Lapuente reconstructed the light curve and color evolution of SN 1572 (Tycho Brahe's supernova) from historical records and measured accurately the interstellar extinction in the supernova field. She deduced that the event was a normal Type Ia supernova, with a *stretch factor* $s = 0.9 \pm 0.5$ and absolute visual magnitude $M_V = -19.24 - 5\ log(D/3.0\ kpc) \pm 0.42$ (D being the distance in kpc). It thus falls well in the middle of the SNeIa class and it is excluded to be a peculiar, subluminous event as it had been suggested. That also leads to a new estimate of its distance: $D = 2.8 \pm 0.4\ kpc$, for the distance scale $H_0 = 65\ km\ s^{-1}\ Mpc^{-1}$.

P.A. Mazzali modelled the spectra and light curves of nearby SNe Ia observed by the RTN on SNe Ia in order to determine their properties. PhD student M. Stehle worked on the analysis of spectra of type Ia supernovae in the early phase. Well observed nearby objects, observed by the RTN network, are suitable to apply a new method called "Abundance Tomography". Here the abundances of the SN envelope are derived by means of spectral synthesis calculations. Each spectrum in a time series defines a new abundance shell. The combination with late time spectra provides the complete abundance distribution of the SN ejecta. This method allows to constrain different explosion models and progenitor scenarios. SN 2002bo was analyzed in detail and the results are being published.

In collaboration with K.Nomoto (U. Tokyo) P.A. Mazzali modeled the spectra and light curves of the energetic Type Ic SNe ("hypernovae") observed in coincidence with long-duration GRBs, deriving the presence of a possible relation between the mass of the progenitor star and the strength of the explosion. These explosions probably occur only for very massive stars (>30 $M_\odot$) and under special conditions (possibly binarity). In collaboration with K. Nomoto (U. Tokyo), P. Podsiadlowski (Oxford), D. Lazzati (Cambridge) and E. Cappellaro (Neaples), he derived a rate for such "hypernovae", and showed that it is compatible with the rate of long-duration GRBs, which suggests that the two events are intimately related.

With a number of collaborators P.A. 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 has its greatest manifestation in the case of GRBs and hypernovae.

PhD student M. Stehle, supervised by P.A. Mazzali and W. Hillebrandt, worked on the analysis of spectra of type Ia supernovae in the early phase. Well observed nearby objects, observed by the RTN network, are suitable to apply a new method called "Abundance Tomography". Here the abundances of the SN envelope are derived by means of spectral synthesis calculations. Each spectrum in a time series defines a new abundance shell. The combination with late time spectra provides the complete abundance distribution of the SN ejecta. This method allows to constrain different explosion models and progenitor scenarios. SN 2002bo was analyzed in detail and the results are being published.

A. Geminale, an EARA Marie Curie fellowship, and P. Popowski have been working on using ultraviolet color excesses to find total to selective extinction ratio Rv and visual extinction Av values and their errors. They constructed a catalog of Rv and Av values for a sample of 782 lines of sight. They extended the analysis of Gnacinski & Sikorski (1999) by considering various sources of statistical and systematic errors and by introducing the weights associated with the errors in each UV band to their chi square minimization procedure (Geminale A. & Popowski P., 2004, Acta Astron., 54, 375). Since Rv value may characterize the entire extinction curve, extending their study into wavelength regions beyond ultraviolet will provide a check on the universality of CCM law in various parts of the spectrum.

F. Kupka investigated a new approach to describe statistical properties of convection dominated flows which had previously been studied for geophysical cases. Using numerical simulations of solar granulation (by F. Robinson, Yale Univ.) it was possible to show that an improvement of up to a factor of 3 to 10 in comparison with previous models is obtained for third and fourth order correlation functions which are required in non-local models of convection. The new approach model is expected to be used in calculations of stellar structure and evolution. A simplified version of the non-local convection model, previously used by F. Kupka to study envelopes of white dwarfs, was derived for application to stellar convective cores, in collaboration with I.W. Roxburgh (QMUL, London).

In collaboration between F. Kupka and C. Boisson, J. Frémaux, and M. Joly (Observatoire de Meudon) program suites for model atmosphere and spectrum synthesis calculation as well as collections of atomic and molecular data were compared to observational data to judge on their usefulness in creating a new generation library for stellar population synthesis. The goal of that library is to remove some of the ambiguities in current population synthesis approaches.

U. Anzer,in collaboration with P. Heinzel, Astron. Inst. Ondrejov, continued the work on solar filaments observed in EUV lines. They developped a new model combining the effects of absorption and blocking of coronal iron lines which were observed by SOHO/EIT and TRACE. They derived effective absorption cross sections for the lines in a cool gas consisting of hydrogen and helium.They also extended their magneto-hydrostatic model of filament extensions based upon twisted flux tubes. They now consider tubes which are embedded in a two-dimensional potential field arcade of finite width. They found that such models are capable of reproducing the observed structures.

R. Wegmann in collaboration with K. Dennerl (MPE) and C.M. Lisse (University of Maryland) studied by means of model calculations the morphology of cometary X-ray emission. He devised a statistical method to infer from observed X-ray photons the gas production of the comet and the solar wind heavy ion flux. R. Wegmann and K. Dennerl (MPE) extracted by a tomographic method from the X-ray data received from comet C/2000 WM1 (LINEAR) information about the position, the shape and the structure of the detached bow shock.

3.2 Nuclear and Neutrino Astrophysics

L. Scheck in his PhD Thesis, supervised by E. Müller and H.-Thomas Janka, in collaboration with K. Kifonidis and T. Plewa (Univ. of Chicago), continued his two- and three-dimensional (2D and 3D) simulations for studying the convectively supported neutrino-heating mechanism of supernova explosions of massive stars. These simulations revealed the generic occurrence of low-mode ($l = 1, 2$) fluid flow in the convective accretion layer around the nascent neutron star. A large number of 2D simulations demonstrated the potential to explain pulsar kicks in excess of 1000 km/s, and indicated the possibility of a bimodal distribution of kick velocities. Due to the lack of computer time, unfortunately only two 3D simulations could so far be finished.

Finishing his PhD Thesis, R. Buras, supervised by H.-Th. Janka, has continued evaluating 1D and 2D simulations with a new Boltzmann scheme for solving the neutrino transport in supernovae. A weak explosion was obtained in a 180-degrees simulation (full pole-to-pole 2D grid, assuming azimuthal symmetry) of an 11.2 solar mass progenitor from Woosley and Heger, indicating the importance of the $l = 1, 2$ low-mode convection also seen in the simulations with simplified neutrino transport. A model of a successful supernova, obtained in a 2D simulation with the Boltzmann neutrino transport by regression from the most accurate transport treatment by omitting the velocity-dependent terms in the neutrino-momentum equation, was used by J. Pruet, R.D. Hoffman (both Lawrence Livermore Nat. Lab.) and S.E. Woosley (UCSC, Santa Cruz) for nucleosynthesis calculations of the proton-rich, neutrino-heated ejecta and early neutrino-driven wind. The resulting abundance pattern is rich of interesting rare isotopes like ^{45}Sc, ^{49}Ti, and ^{64}Zn with yields approximately sufficient to account for the solar abundances. The overproduction problem of $N = 50$ (closed neutron shell) nuclei of previous explosion models does not occur. The 2D simulations with an accurate treatment of the neutrino transport were also severely hampered this year by the lack of computer time on shared-memory machines.

A. Arcones and A. Marek both advanced from Diploma students to PhD students (supervised by H.-Th. Janka) and wrote papers of their Diploma results on "Studies of Neutrino-Heating and Shock Revival in a Supernova Core by Using an Analytic Toy Model" and "The Effects of the Nuclear Equation of State on Stellar Core Collapse and Supernova Evolution", respectively. A. Arcones has started to perform nucleosynthesis relevant calculations of supernova explosions, and A. Marek has continued to investigate nuclear physics effects (ion-ion correlations in neutrino-nuclei interactions, electron captures on heavy nuclei, high-density equation of state) in collapsing stellar cores using Boltzmann neutrino transport. F.S. Kitaura Joyanes. K. Kifonidis, R. Buras, and H.-Th. Janka have improved the treatment of the equation of state and microphysics (nuclear burning, nuclear statistical equilibrium) at sub-nuclear densities, mainly to be able to treat accurately the collapse of very degenerate O-Ne-Mg cores of supernova progenitors in the 8–10 solar mass range. A preliminary computation, performed by F.S. Kitaura Joyanes in his Diploma work (supervised by H.-Th. Janka), showed that prompt explosions also fail in these stars, but mass ejection is driven later after bounce by the onset of a neutrino-driven wind. Improved simulations, which were performed by F.S. Kitaura Joyanes after his Diploma Thesis, confirmed the thesis results for two different nuclear equations of state.

1D and 2D explosion models, computed by L. Scheck in his PhD Thesis work, supervised by H.-T. Janka, K. Kifonidis and E. Müller, were used to study time-dependent signatures of neutrino flavor oscillations by the propagation of the forward and reverse shocks in the first tens of seconds of a supernova explosion (together with R. Tomàs, M. Kachelrieß, G. Raffelt (all MPI for Physics, Munich), and A. Dighe (Tata Institute of Fundamental Research, Mumbai, India)). The prompt electron neutrino burst as obtained in one-dimensional core collapse simulations for a variety of different progenitor stars and with varied input physics, was evaluated in a collaborative project of R. Buras, H.-T. Janka, and A. Marek with R. Tomàs, M. Kachelrieß (MPI for Physics, Munich) for information about neutrino flavor oscillations and distance determination to a supernova. The near-standard candle properties of the burst will allow to measure the distance to a future galactic supernova with an accuracy of about 5%, using a megaton water Cherenkov detector.

In his PhD work, supervised by W. Hillebrandt and J.C. Niemeyer (University of Würzburg), L. Iapichino has performed multi-dimensional simulations to study the ignition of Type Ia supernovae. The physical processes leading to flame ignition in Chandrasekhar-mass SNe Ia are considered to be a key ingredient for the understanding of the explosion mechanism. A parameter study of buoyant, reactive bubbles, generated during the convective phase in the progenitor, is used as a tool in order to probe their properties at ignition (i.e., diameters, temperatures and evolutionary time scales) and to infer some clues about the SN Ia explosion.

Details of the Type Ia supernova (SN Ia) explosion mechanism have been unveiled in several studies based on three-dimensional numerical models. These models follow the propagation of a thermonuclear flame which – according to the standard astrophysical scenario – disrupts the progenitor white dwarf (WD) star in a violent explosion. Although SNe Ia form a class of events that is strikingly uniform in the main properties, one of the main challenges in SN Ia theory is to explain the still remaining diversity. Only the empirical correction of this diversity according to correlations in the observables facilitated high-precision distance measurements that revolutionized the cosmological standard picture. A promising approach is to vary the initial parameters of explosion models and to investigate the resulting changes in the explosion characteristics. Naturally, this approach requires the explosion model to be free of tunable parameters, a constraint that is met with three-dimensional simulations. F. Röpke and W. Hillebrandt have carried out the first systematic survey of initial parameters of such models by varying the carbon-to-oxygen ratio of the progenitor WD, its central density and its metallicity in a grid of simulations. In agreement with theoretical expectations we found the luminosity of SNe Ia to depend on the WD's central density and its metallicity. Surprisingly, the carbon-to-oxygen ratio proved to have little impact on it – an effect that can only be understood in the context of three-dimensional modeling. They found that the initial parameters under consideration can partially account for the observed SN Ia diversity.

A second investigation by F. Röpke and W. Hillebrandt addressed the asymmetries that develop in three-dimensional SN Ia explosion models. This study is motivated by recent observations showing spectra of (at least some) SNe Ia to be significantly polarized. To this end, we performed the first simulations in a full star in contrast to previous simulations that comprised only one single octant and imposed an artificial mirror symmetry on the setup. Such full-star simulations provide a path towards a more realistic modeling of the event. The results of the study show that starting with an asymmetric ignition of the flame (which is motivated by the pre-ignition evolution) the explosion proceeds in an asymmetric way which may well contribute to the observed polarization of the spectra. It did, however, not reveal unexpected new features in the flame evolution and thus confirmed the standard picture of SNe Ia explosions.

In order to facilitate a comparison of numerical SN Ia models with observations via synthetic light curves and spectra, it is necessary to evolve the simulations to the stage of homologous expansion. This requires to follow the models for about 10 s – a time interval in which the explosion expands the material for almost two orders of magnitude. With previous simulations on a static Cartesian computational grid, it is impossible to follow this expansion and F. Röpke therefore implemented a new moving grid that co-expands with the WD. This method is particularly favorable since it only marginally increases the computational expenses of the simulations. With this technique it was possible to show that our models indeed reach homologous expansion to a sufficient accuracy after 10 s. Changes in the distribution of the explosion ejecta between $\sim$2 s (where all previous multi-dimensional models terminated) and 10 s were observed. Simulations carried out in this way by F. Röpke provide the input for the first synthetic spectra obtained from three-dimensional SN Ia models done in a collaboration between the group at Stockholm Observatory (C. Kozma, C. Fransson and J. Sollerman) and MPA (W. Hillebrandt, M. Reinecke, F. Röpke, and C. Travaglio).

The 3D models also have been the input for detailed predictions of the nucleosynthesis yields ejected by Type Ia supernovae. C. Travaglio, W. Hillebrandt, M. Reinecke, F. Röpke, and Dipl.-student M. Gieseler, in collaboration with F.-K. Thielemann (U. Basel) 'post-processed' performed a parameter study in which the ingnition conditions and the chemical composition of the white dwarf were varied and the explosion models were 'post-processed'by means of a marker-particle method with a full nucleosynthesis network. The outcome was within the expectations based on 1D models, tuned to fit typical observed spectra. The only shortcoming of the deflagration models seems to be that they leave too much unprocessed material at low velocities.

The influence of presupernova structure and mixing of ^{56}Ni on the bolometric light curve of SN 1987A was investigated by V. Utrobin (also ITEP Moscow) and N. Chugai (Sternberg Institute, Moscow) in the frame of the one-energy group radiation hydrodynamics taking non-LTE effects, nonthermal ionization, and a contribution of lines to opacity into account. It was shown that the medium mixing of ^{56}Ni, in the velocity range $\leq$ 2500 $\mathrm{km\,s^{-1}}$, is enough to reproduce the observed light curve if the outer layers of presupernova have a higher density by 2–5 times than that of the evolutionary model of non-rotating single stars. Calculating the equation of state, the average opacities, and the thermal emissivity under non-LTE and with nonthermal ionization results in a significant departure of the gas temperature from that of radiation in the optically thin layers of supernova envelope. Radiative transfer plays a key role in reproducing the observed dome of the light curve. Neglecting the expansion opacity of lines leads to an error of $\sim$ 20% in the explosion energy and a larger one in the mass of ejecta. Resonance scattering of radiation in numerous lines accelerates the outermost layers of envelope up to velocity of $\approx$ 36000 $\mathrm{km\,s^{-1}}$ and this additional acceleration involves the outer layers of mass of $\approx 10^{-6} M_{\odot}$. A correct calculation of the supernova luminosity should include not only the retardation effects but the limb darkening.

3.3 Numerical Hydrodynamics

H. Dimmelmeier continued his research on astrophysical phenomena leading to the formation of compact objects like core collapse supernovae, neutron stars, and black holes using relativistic hydrodynamic simulations. In his collaboration with J. Novak (Meudon Observatory, Paris, France), J.A. Font (University of Valencia, Spain) and E. Müller he made important progress towards stable and efficient 3-dimensional simulations of compact objects. For the first time a successful combination of both state-of-the-art spectral methods and modern finite difference methods were accomplished in a hydrodynamic code with an approximation of general relativistic gravity. The next step in this collaborative project will be the extension of the up to now approximative approach to a non-approximate formulation of the full general relativistic field equations.

Together with N. Stergioulas (University Thessaloniki, Greece) and J.A. Font, H. Dimmelmeier nearly completed a project on simulations of rotating neutron stars in axisymmetry. In this parameter study, neutron star models are perturbed and evolved with a numerical code in order to extract the characteristic oscillation frequencies of the neutron stars and to investigate their dependence on the star's rotation rate and profile. An interesting outcome of this work is the observation that some linear perturbations can interact with each other in a nonlinear way and exchange properties of their oscillation pattern in case the respective oscillation frequencies come close. The confirmation of this theoretically known feature in a numerical simulation opens a path for new discoveries in the field of asteroseismology, where observers plan to gain more insight into the structure of neutron stars using information from gravitational wave astronomy.

H. Dimmelmeier was also involved in a collaboration with P. Cerdá, J.A. Font (both University of Valencia), G. Faye (Universität Jena) and E. Müller to apply a flexible and stable approximation of Einstein's general relativistic field equations called CFC+ in simulations of supernova core collapse. It is planned to test the quality of this approximation against simulations with the full set of equations using the community code Cactus. To this end H. Dimmelmeier and B. Zink, together with I. Hawke and C. Ott (both AEI, Golm) have begun with test calculations using both approaches.

R. Oechslin has investigated the sensitivity of binary neutron star merger simulations with respect to numerical uncertainties by varying resolution, artificial viscosity, the implementation of the hydrodynamics equations and the initial orbital parameters. The physics (equation of state, initial stellar masses and spins) is kept fixed. He also developed a scheme to produce equilibrium initial data by relaxing a fluid configuration to a chosen spin and orbital distance. With this scheme, binary neutron star initial data with arbitrary orbital separations and spin states can be obtained. A Smooth Particle Hydrodynamics prototype module to be used with the Cactus toolkit (Albert Einstein-Institut, Golm) has been developed. It generalizes the treatment of general relativity in the existing code from a conformal flat approximation to full GR. In a collaboration with C. Koellein (Universität Tübingen, SFB/TR7 Teilprojekt B6) and Sven Ganzenmueller (WSI Universitaet Tuebingen) a parallelized version is underway.

Burkhard Zink has studied the process of black hole formation through fragmentation of toroidal polytropes. This PhD project supervised by E. Müller showed that differentially rotating toroids are unstable to non-axisymmetric 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.

In a collaboration with N. Stergioulas (Univ. Thessaloniki), I. Hawke (Univ. Southampton), C. Ott and E. Schnetter (Albert Einstein Institute), and under the supervision of his PhD adviser E. Müller, B. Zink implemented an adaptive mesh refinement method in the general relativistic toolkit *Cactus/Whisky* developed by the European Network on Sources of Gravitational Waves, and applied it to the fragmentation and off-center black hole formation of self-gravitating toroidal polytropes.

R. Buras, H. Dimmelmeier, A. Marek, B. Müller, H.-Th. Janka, and E. Müller started a project to investigate the effects of using modified gravitational potentials in a Newtonian hydrodynamic code for simulations of astrophysical 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, which allows for simpler, faster, and more stable numerical simulations of astrophysical phenomena with strong gravitational fields.

M.A. Aloy and S. Heinz begun a study of the interaction of micro-quasar 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 slow down process of a relativistic outflow. With the results obtained from numerical simulations it is possible to check whether the relative duration (i.e., time measured in natural units GM/c^3, where M is the mass of the central engine) of the relativistic propagation of the jet-environment interface is much longer in microquasars than in AGN jets.

Martin Obergaulinger, in a Diploma thesis advised jointly by M.A. Aloy and E. Müller, adopted a multi-dimensional Newtonian MHD-code based on the relaxing-TVD method and the constraint-transport method for studies of magneto-rotational core collapse. He performed a comprehensive set of two-dimensional simulations of collapsing polytropes varying the amount and distribution of the initial angular momentum and magnetic field. The initially purely toroidal field is amplified during collapse by differential rotation resulting in a strong poloidal component with energies of the order of the rotational energy of the cores, i.e. several percent of the gravitational binding energy. For relatively weak initial magnetic fields the dynamics and the gravitational wave signals are similar to those of the corresponding non-magnetized cores. Strong initial fields cause significant angular momentum transport leading to a slow down of the core's rotation rate, and in some cases even to a loss of its centrifugal support which is reflected by a qualitatively different gravitational wave signal.

Within his PhD project jointly advised by M.A. Aloy, E. Müller and W. Brinkmann (MPE) P. Mimica has performed one- and two-dimensional relativistic hydrodynamic simulations of collisions of density inhomogeneities (shells) within a blazar jet, in order to study the influence of the shell and jet properties (mass, temperature, size, velocity) on the characteristics of X-ray blazar flares. He finds that the jet medium external to the shells has a significant dynamic influence on the shells *prior* to their interaction. The total radiated energy in the observer frame depends on the total initial rest mass of the shells and the relative velocity, but is independent on the mass distribution inside the shells. One-dimensional simulations of collisions of a large number (> 500) of shells indicate that, in order to reproduce global characteristics of observed X-ray blazar light curves, the central engine must work *intermittently*, ejecting discrete shells instead of a continuous fluid.

K. Kifonidis has started to work on a multidimensional hydrodynamics code that is based on the method of lines and makes use of a second order accurate shock capturing scheme. Several approximate Riemann solvers, reconstruction algorithms, and slope limiters were evaluated for this purpose. The code allows for implicit time stepping and will be eventually applied to core collapse supernovae in order to study the long-time hydrodynamic evolution of the layers near the neutron star.

The numerical methods to model thermonuclear combustion in Type Ia supernovae were improved further. W. Schmidt, in a PhD thesis supervised by W. Hillebrandt in collaboration with J.C. Niemeyer (U. Würzburg), has investigated different sub-grid scale models for turbulence and their impact on the propagation of turbulent thermonuclear flames in degenerate mixtures of carbon and oxygen. As always in the MPA-approach, the flame was represented by a level-set method. The computational domain for the numerical simulations was cubic with periodic boundary conditions and the aim was to develop a suitable flame-speed model for the small-scale dynamics of turbulent deflagrations. Because the burning process in a supernova explosion proceeds in a transient and spatially inhomogeneous manner, the localized determination of sub-grid scale closure parameters turned out to be essential. From the simulations an analytic asymptotic flame-speed relation was derived.

The same group (W. Schmidt, W. Hillebrandt, and J.C. Niemeyer) also computed energy spectrum functions from data of various three-dimensional simulations of forced isotropic turbulence. The piece-wise parabolic method (PPM) was used to treat flows with Mach number of the order unity. Therefore the dissipation was of purely numerical origin. For the dimensionless mean rate of dissipation, they found values in agreement with results from other, mostly incompressible turbulence simulations. The so-called bottleneck phenomenon was identified in the turbulence energy spectra. Although the bottleneck reduced the range of nearly inertial scales considerably, they were able to estimate the value of the Kolmogorov constant. In the statistically stationary regime, $C \approx 1.7$ for strictly subsonic turbulence, but also in the presence of shocklets in moderately transonic flows. As compressive components become more significant, however, the value of C appears to decrease.

Another improvements of the physical modeling of SNe Ia was proposed in a first attempt to include a description of burning in late phases of the explosion process in global SN Ia simulations by F. Röpke and W. Hillebrandt. Here the regime of turbulent flame propagation flame propagation changes from the so-called *flamelet regime*, where the flame is affected by turbulent motions on larger scales only, to the regime of *distributed burning*, where turbulence penetrates the internal structure of the flame. A change in the burning law is required to model this effect. First results show that the trends of including the distributed burning may help to cure problems of current SN Ia models, such as unburnt material in the inner parts of the ejecta and low explosion energies, by extending the burning to longer times.

F. Kupka collaborated with H. Muthsam (Univ. of Vienna) on the implementation of realistic microphysics for numerical simulations of stellar convection in his Antares code. This code is also going to be used for numerical simulations of semiconvection in collaboration with H.C. Spruit.

3.4 High Energy Astrophysics

E. Churazov in collaboration with N.Inogamov (Landau ITP, Moscow) studied the devlopment of the Kelvin-Helmholtz instability for curved flows near stagnation points. This problem is related to the question of formation and stability of "cold fronts" observed by Chandra and XMM-Newton observatories in many clusters of galaxies. It is shown that due to acceleration of the flow along the interface even a small intrinsic width of the order of a few per cent of the curvature radius strongly limits the growth of perturbations. The main conclusion is that for the best studied case of a cold front in the Cluster Abell 3667 all current observational data on the width and extent of the front can be explained even in the absence of dynamically important magnetic fields.

P. Rebusco, E. Churazov, H. Boehringer (MPE) and W. Forman (CfA) evaluated the impact of stochastic gas motions on the metal distribution in the galaxy cluster cores. Peaked abundance profiles are a characteristic feature of clusters with cool cores and abundance peaks are likely associated with the brightest cluster galaxies (BCGs) which dwell in cluster cores. The width of the abundance peaks is however significantly broader than the BCG light distribution, suggesting that some gas motions are transporting metals originating from within the BCG. Assuming that this process can be treated as diffusive and using the brightest X-ray cluster A426 (Perseus) as an example, we estimate that a diffusion coefficient of the order of $2 \cdot 10^{29} \mathrm{cm}^2 \mathrm{s}^{-1}$ is needed to explain the width of the observed abundance profiles. Much lower (higher) diffusion coefficients would result in too peaked (too shallow) profiles. Such diffusion could be produced by stochastic gas motions and our analysis provides constraints on the product of their characteristic velocity and their spatial coherence scale. We speculate that the activity of the supermassive black hole of the BCG is driving the stochastic gas motions in cluster cores. When combined with the assumption that the dissipation of the same motions is a key gas heating mechanism, one can estimate both the velocity and the spatial scale of such a diffusive processes.

E. Churazov, R. Sunyaev, S. Sazonov, M. Revnivtsev and D. Varshalovich (Ioffe Institute, St. Petersburg, Russia) studied the electron-positron annihilation spectrum deep Galactic Center region exposure SPI/INTEGRAL. The line energy (510.954 ± 0.075 keV) is consistent with the unshifted annihilation line. The width of the annihilation line is 2.37 ± 0.25 keV (FWHM), while the strength of the ortho-positronium continuum suggests that the dominant fraction of positrons (94 ± 6%) form positronium before annihilation. Compared to the previous missions these deep INTEGRAL observations provide the most stringent constraints on the line energy and width. Under the assumption of an annihilation in a single-phase medium these spectral parameters can be explained by a warm $T_e \sim 7000 - 4\,10^4$ K gas with the degree of ionization larger than a few 10^{-2}. One of the wide-spread ISM phases - warm ($T_e \sim 8000$ K) and weakly ionized (degree of ionization ~ 0.1) medium satisfies these criteria. Other single-phase solutions are also formally allowed by the data (e.g. cold, but substantially ionized ISM), but such solutions are believed to be astrophysically unimportant. The observed spectrum can also be explained by the annihilation in a multi-phase ISM. The fraction of positrons annihilating in a very hot ($T_e \geq 10^6$ K) phase is constrained to be less than $\sim$8%. Neither a moderately hot ($T_e \geq 10^5$ K) ionized medium nor a very cold ($T_e \leq 10^3$ K) neutral medium can make a dominant contribution to the observed annihilation spectrum. However, a combination of cold/neutral, warm/neutral and warm/ionized phases in comparable proportions could also be consistent with the data.

S. Nayakshin has shown that close star passages of young stars observed near the super-massive black hole in our Galactic Center can be used to constrain the properties of the accretion flow near the black hole event horizon. Specifically, these stars are quite bright in the optical-UV band, in which the GC black hole is actually very dim. When they are passing near the pericenter of their orbits, their photons are up-scattered into the X-ray and γ-ray band. The effects in the former wavelength can be observed by Chandra, for example, and then constrain the density of hot gas near the super-massive black hole.

P. Shtykovskii (Space Research Institute, Moscow) and M. Gilfanov studied X-ray luminosity function of HMXBs in Large Magellanic Cloud, based on the data of a large number of XMM-Newton observations. The bright end of the luminosity distribution is consistent with extrapolation of the universal HMXB XLF, derived by Grimm, Gilfanov & Sunyaev (2003). However, there seems to be fewer low luminosity sources, $\log(L_X) \lesssim 35.5$, than predicted. They considered the impact of the "propeller effect" on the HMXB luminosity distribution and showed that it can qualitatively explain the observed deficit of low luminosity sources. There are significant field-to-field variations in the number of HMXBs across the LMC, uncorrelated with the star formation rates inferred by the FIR and H_α emission. These variations are caused by the dependence of the HMXB number on the age of the underlying stellar population. Using the existence of large coeval stellar aggregates in the LMC, they constrained the number of HMXBs as a function of time τ elapsed since the star formation event in the range of τ from $\sim 1-2$ Myr to $\sim 10-12$ Myr.

J. Chluba in collaboration with S.Y. Sazonov and R.A. Sunyaev studied the details of double Compton scattering in a thermal plasma for arbitray energies of the interacting photons and electron numerically. Also analytic approximations were derived in the soft photon limit. These may find applications for the discription of the thermalization of spectral distortions of the cosmic microwave background in the early universe.

S. Sazonov and M. Revnivtsev analyzed a sample of approximately 100 AGN detected in the RXTE all-sky hard X-ray (3–20 keV) survey to study the statistical properties of the local ($z < 0.1$) population of AGN. It was found that the proportion of unobscured (with intrinsic absorption column density $N_{\rm H} < 10^{22}$ cm^{-2}) and obscured (10^{22} cm$^{-2} < N_{\rm H} < 10^{24}$ cm^{-2}) AGN strongly depends on luminosity. While obscured objects amount to two thirds of low luminosity ($L_{\rm X-ray} < 10^{43.5}$ erg s^{-1}) AGN, the corresponding fraction drops to below 15% for more luminous AGN. It was also found that AGN with luminosities ranging between 10^{41}–$10^{43.5}$ erg s^{-1} provide similar contributions to the total energy release by accretion onto local supermassive black holes. Continuing their study of the high-energy emission of AGN, S. Sazonov,

M. Revnivtsev and R. Sunyaev together with A. Lutovinov and S. Grebenev (Space Research Institute, Moscow), measured for the first time the hard X-ray (20-200 keV) spectrum of the luminous Seyfert 1 galaxy GRS 1734-292 located behind our Galactic Center. The broadband X-ray spectrum, obtained with the INTEGRAL, GRANAT and ASCA observatories, has a power law shape without cutoff up to at least 100 keV. Spectra of similar quality have previously been measured only for a few bright AGN.

R. Voss studied the X-ray point source population in the elliptical galaxy Centaurus A. This was done using 4 CHANDRA X-RAY OBSERVATORY observations. The statistical properties of the sample were investigated and used to divide the population into its main components: HMXBs, LMXBs and cosmic background X-ray sources. Especially weighted was the investigation of the luminosity function of LMXBs which was analysed to a limiting luminosity of a few times 10^36 erg/s.

A. Merloni has studied different phenomenological and theoretical aspects of the physical connection between accretion and jets acceleration. First, in a work done in collaboration with J. Malzac and A. C. Fabian (both from the IoA, Cambridge, UK) a model has been put forward to interpret the rapid correlated UV/Optical/X-ray variability of the black hole binary XTE J1118+480 as a signature of coupling between the X-ray emitting corona and a jet emitting synchrotron radiation in the optical band. By comparing the model predictions with the observed spectral and variability properties of the source, strong constraints can be derived, among others, on the radiative efficiency of the jet and the accretion flow. In collaboration with S. Heinz (MIT, USA), A. Merloni has also investigated the statistical properties of relativistic Doppler boosting relevant for studies of relativistic jets from compact objects. Applying Doppler beaming statistics to a large sample of X-ray Binaries (XRB) and Active Galactic Nuclei (AGN), they concluded that: 1) if the X-ray emission from these sources is unbeamed, the width of the distribution of Lorentz factors should be about one order of magnitude, or less; 2) if the scatter about the observed radio-X-rays-mass correlation for the same sources is dominated by relativistic beaming, a lower limit on the mean Lorentz factor ($\beta\Gamma > 5$) can be derived. This has important consequences for our understanding of relativistic jet acceleration on accreting black holes.

D. Giannios in collaboration with H.C. Spruit have explored the spectra that result from strongly-magnetized GRB outflows. The very high magnetic field strengths (super-equipartition) in such a flow lead to very efficient synchrotron emission. In contrast with internal shocks, dissipation of magnetic energy by reconnection is gradual and does not produce the spectrum of cooling electrons associated with shock acceleration. It is shown that 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.

S. Sazonov, A. Lutovinov (Space Research Institute, Moscow) and R. Sunyaev studied the gamma-ray burst detected by INTEGRAL on 3 December 2003, the second nearest GRB to date ($z = 0.106$). This burst had a duration of 40 s and peak energy of more than 200 keV, and therefore appears to be a typical long-duration GRB. Its isotropic gamma-ray energy of $< 10^{50}$ erg, however, is about three orders of magnitude smaller than that of typical distant ($z \sim 1$) GRBs. Moreover, this event – as well as the other nearby but somewhat controversial GRB 980425 – is a clear outlier from the isotropic-energy/peak-energy relation and luminosity/spectral-lag relations that describe the majority of well-studied GRBs. Radio calorimetry shows that both of these events are under-energetic explosions. The discovery of GRBs 980425 and 031203 thus strongly suggests that there exists a large population of sub-energetic GRBs.

Rapid, hyper-Eddington accretion is likely to power the central engines of gamma-ray bursts (GRBs). In the extreme conditions of densities and temperatures the accreting torus is cooled by neutrino emission rather than by radiation. T. Di Matteo with A. Janiuk, R. Perna and B. Czerny have computed the time evolution of a neutrino-dominated disc that proceeds during the burst both in the case of a collapsar model and the binary merger scenario relevant for long and short bursts respectively. Within the context of the collapsar model, we have also studied the evolution of the photon luminosity of the remnant disc up to times of the order of 1 day. This calculation has important implications for the production of emission lines in GRB spectra.

For coded mask imaging in high energy astrophysics, B. M. Schäfer found a new mask pattern generation scheme based on Gaussian random fields. While this new pattern was found to be inferior to traditional masks with respect to sensitivity in the observation of point sources, it extensive numerical simulations revealed that it shows a better performance in the observation of extended sources.

3.5 Accretion

Sgr A* is currently being fed by winds from a cluster of gravitationally bound young mass-loosing stars. Using observational constraints on orbits of these stars, mass loss rates and wind velocities, J. Cuadra, S. Nayakshin, V. Springel and T. Di Matteo numerically modelled the distribution of gas in the 0.1 – 10" region around Sgr A*. They found that radiative cooling of recently discovered slow winds leads to formation of many cool filaments and blobs, and a thin and rather short-lived light accretion disk of about an arcsecond scale. As a result, the accretion rate onto Sgr A* is highly variable.

F. Meyer and E. Meyer-Hofmeister together with B.F. Liu raised the question whether in the past a disk could have existed in our Galactic Center which has disappeared now. Using a model for the interaction of a cool disk and a hot corona above they came to the conclusion that such a putative accretion disk left over after a last star forming event would have evaporated by coronal action by now.

S. Nayakshin has considered effects that presence of stars embedded into an accretion disk could have onto the evolution of such a disk in the low luminosity Active Galactic Nuclei. Potential implications of these effects are large. For example the stars could modulate the accretion rate onto the SMBH by slowing down the accretion of gas onto the black hole. They can also lead to a large scale time-variability of AGN luminosity. However it appears that the main interesting feature of Low Luminosity AGN – their surprisingly small luminosity – is best accounted for by accretion disk physics, not by the possible presence of the embedded stars.

In addition, in collaboration with J. Cuadra, S. Nayakshin studied the constraints onto the properties of the accretion disk in the Galactic Center few million years ago. Such constraints can be derived from the properties and spatial distribution of tens of young massive stars observed to exist surprisingly close to the SMBH. As a result, the mass of the accretion disk was constrained to be in the range of 10^4 - 10^5 Solar masses. It was also concluded that our Galaxy hosted a moderately bright AGN at that time.

S. Nayakshin has also considered the accretion disk warping in the Galactic Center and AGN in general. It seems highly likely that accretion disks are formed at random inclinations to the galactic plane in AGN. The disks are also known to be gravitationally unstable and form stars at distances of order a fraction of parsec. S. Nayakshin thus noted that a newly created accretion disk will find itself in a combined gravitational field of the central black hole and a stellar disk (similar to those observed in our Galactic Center). Keplerian orbits precess in such an axi-symmetric potential, warping an initially flat disk in few hundred to few thousand orbital times. Such warped accretion disks may be highly relevant to the obscuration and Unification schemes of AGN.

T. Di Matteo with G. Dewangan, R. Griffiths and N. Schurch (Carnegie Mellon University) have investigated the accretion flow geometry of low luminosity active galactic nuclei using the iron K-α emission line profile as probed by XMM-Newton observations.

A. Merloni has presented a new method to unveil the history of cosmic accretion and the build-up of supermassive black holes in the nuclei of galaxies, based on observations of the evolving radio and (hard) X-ray luminosity functions of AGN. The redshift evolution of the black hole mass function and the black hole accretion rate function are calculated self-consistently, and show that half ($\sim 85\%$) of the local black hole mass density was accumulated at redshift $z < 1$ ($z < 3$), mostly in radiatively efficient episodes of accretion. The evolution of the black hole mass function between $z = 0$ and $z \sim 3$ shows clear signs of an *anti-hierarchical* behaviour: while the majority of the most massive objects ($M > 10^9 M_\odot$) were already in place at $z \sim 3$, lower mass ones mainly grew at progressively lower redshift, so that the average black hole mass increases with increasing redshift. Also, the average accretion rate decreases towards lower redshift.

M. Revnivtsev, E. Churazov, M. Gilfanov and R. Sunyaev have used advantages of the recently launched INTEGRAL observatory to perform a set of studies. First of all there was constructed the ultra deep survey of the Galactic Center region which revealed the presence of 63 point-like sources in the field in the hard X-ray energy band (20-60 keV). A similar deep survey was performed for the Saggitarius spiral arm region in collaboration with S. Molkov the subsequent study of one of discovered sources (namely - IGR J17475-2822) – showed the association of this source with the large molecular cloud Sgr B2. An analysis of all available data supports the hypothesis that the emission of Sgr B2 cloud is a result of reprocessing the past emission of a supermassive black hole in the center of our Galaxy Sgr A* 300 years ago. M.Revnivtsev and S. Sazonov for the first time presented the detailed broad band spectrum of the bright active galactic nucleus GRS 1734-292 in the Galactic Center region using the data of INTEGRAl, ASCA and GRANAT satellites. Such a spectrum could not be obtained with other instruments because of a number of technical problems to observe the Galactic Center region. It was shown that GRS 1734-292 demonstrates the energy spectrum typical for AGN – power law continuum with a tentative cutoff at energies ∼100-150 keV.

Using INTEGRAL observations A. Lutovinov and M. Revnivtsev have performed a detailed study of a number of sources in the Galactic center region (XTE J1550-564, IGR J17091-3624, IGR/XTE J17391-3021, IGR J17464-3213 = XTE J17464-3213 = H 1743-322, IGR J17597-2201, SAX/IGR J18027-2017). In addition to that, an increased sensitivity in the Galactic plane allowed them to enlarge the sample of high mass X-ray binaries and to construct the most sensitive distribution of Galactic HMXBs up to date. It was shown that the HMXBs are mostly concentrated towards the Galactic spiral arms tangents. However there was detected a significant offset of peaks of the HMXBs distribution with respect to the current position of the Galactic spiral arms. It was proposed that such a displacement can be caused by the a time delay in the formation of HMXBs with respect to initial star formation epoch, which is traced by spiral arms. The time delay needed to explain the observed displacement of the HMXBs density is approximately 10-20 Myrs, which is compatible with theoretical estimates of HMXB evolution time.

M. Revnivtsev in collaboration with the Space Research Institute, Moscow, Russia, SAO, Russia, Sternberg Astronomical Institute, Russia, Kazan State University, Russia and TUBITAK National observatory, Turkey, for the first time studied the short term variability of Galactic microquasar SS433 simultaneously in optical and X-ray energy bands. It was shown that the X-ray variability from the source (that is supposed to originate as a result of hot outflowing plasma emission in the jet) is delayed with respect to the optical variability. The proposed model allows to measure the length of the optically thick cocoon around the central region of the accretion flow in SS433.

M. Revnivtsev in collaboration with the Space Research Institute, Moscow, Russia and TUBITAK National observatory, Turkey, studied the time evolution of the optical and X-ray flux of thermonuclear bursts from the neutron star binary system GS1826-264 with the RXTE observatory and the RTT-150 optical telescope. Detailed analysis of the energy budget and time profiles allowed to put constraints on the size of the accretion disk in the binary system and consequently on the binary parameters.

S. Molkov, M. Revnivtsev, A. Lutovinov and R. Sunyaev have studied a very peculiar powerful X-ray burst detected from the neutron star binary system SLX 1735-269. This is the first such burst known from this system and only few more are known from any Galactic system up to date. Detailed analysis of this burst combined with available theoretical models of regimes of thermonuclear burning on the neutron star surface allowed to propose the hypothesis that a such long and powerful burst is a result of unstable burning of a large pile of hydrogen and helium accelerated by electron capture processes.

M. Revnivtsev, M. Gilfanov and R. Sunyaev have studied the archival data of HEAO1 observatory in order to recalculate the normalization flux of the cosmic X-ray background (CXB) for detailed comparison with that previously done by the same authors using the RXTE observatory data. The clue in this study is an accurate crosscalibration of two used instruments. In this work it was shown that the measurements of HEAO1/A2 and the RXTE/PCA is perfectly compatible with each other and also with the most accurate measurements of the ASCA observatory.

P. Rebusco studied the possibility of non-linear parametric resonance in nearly circular, nearly Keplerian, nearly equatorial plane motion of test particles around compact objects. A perturbative method was used to find an analytic solution which is interesting in the context of kHz Quasi Periodic Oscillations. This investigation is done in collaboration with M.Abramowicz and W. Kluzniak, who have first noticed that the QPO variability frequencies in the X-ray flux of 4 microquasars are in the 3:2 ratio, and that rational ratios are a typical property of QPOs. This work is continuing by considering a fluid model of the phenomenon:the perturbation of a slender torus in a strong field.

D. Giannios in collaboration with H.C. Spruit has studied the possible mechanisms of excitation of quasiperiodic oscillations in the accretion flow of black hole accreters in their hard spectral states, in the context of the 'truncated disk' model. Quasi-spherical oscillations of the inner ion-supported accretion flow (ISAF) can be excited by the interaction of this hot flow with the cool disk extending outward from it. The fundamental mode of (p-mode) oscillation is most easily excited, and has a frequency near the Kepler frequency at the inner edge of the cool disk. The strongest excitation mechanism is a feedback loop involving cooling of the ISAF by soft photons from the cool disk and heating of the cool disk by the ISAF, while synchrotron emission can be a relatively strong damping effect.

M.A. Aloy in collaboration with H.-Th. Janka and E. Müller performed relativistic simulations of jet formation due to the release of thermal energy in the vicinity of black hole-torus systems. The jets were found to become highly relativistic with interesting implications for short cosmic gamma-ray bursts to be explored by the upcoming Swift satellite mission. The modeling of the thermal energy release near the black hole in these simulations was guided by recent three-dimensional simulations of non-stationary hyperaccretion of stellar-mass black holes by S. Setiawan, M. Ruffert (both University of Edinburgh) and H.-Th. Janka.

The puzzling phenomenology of X-ray binaries in their so-called hard states, in particular the presence of relativistic jets, would be easier to understand if the accretion disks in these systems contain strong, organized magnetic fields formed by the capture of magnetic flux from the environment of the disks. The problem with this idea has been that such capture is difficult to achieve with a turbulent disk. H. Spruit and D. Uzdensky (Princeton) have now shown that such capture is nevertheless possible if the captured flux gets organized into small patches of strong field.

The black hole candidate GX 339-4 was in one of its rare optically luminous hard X-ray states from February till August of this year. H. Spruit obtained simultaneous X-ray (RXTE) and optical (VLT) observations at high time resolution during this period. The data show violent optical variability (factors 2-3) and time scales as short as 0.05s. There is a strong correlation with the X-rays, but with properties different from those seen previously in the otherwise similar system XTE J1118+480.

In an attempt to detect similar optical/X-ray correlations in the steady and nearby black hole candidate Cyg X-1, H. Spruit (in collaboration with G. Kanbach, MPE) completed a series of simultaneous observations with RXTE and Mt. Skinakas observatory (Crete). The data put an upper limit $\nu L_\nu < 3\,10^{34}$ erg/s on any optical emission that is correlated with X-rays. This is a factor of > 10 lower than the X-ray-correlated optical emission observed in XTE J1118 and GX 339, adding enigma to the mystery of the optical emission from black hole binaries.

Hard X-ray emission from X-ray binaries is often accompanied by soft flux indicating the presence of a cool disk. The transition of the accretion flow from this cool disk to a hot (2-temperature) flow has been a puzzle since the early days of X-ray astronomy. Extending previous work (by B. Deufel at MPA) C. Dullemond and H. Spruit have now developed detailed steady and time-dependent models for this transition, enabled by 'ion-illumination' of the cool disk by the hot phase.

F. Meyer, E. Meyer-Hofmeister and B. F. Liu worked on spectral transitions of low-mass X-ray binaries, explained as the result of the evaporation of matter from the cool disk forming the hot coronal flow/ADAF. The observed spectral transitions between hard and soft state show a surprising feature, the luminosity at which the hard-soft and the soft-hard transition occur is different. Based on the analysis of the interaction of corona and disk it can be shown that this hysteresis in the light curve is caused by the different amount of Compton cooling or heating acting on the accretion disk corona at the time of the transition, in one case from an inner disk, in the other case from a hot coronal flow at the center.

E. Meyer-Hofmeister studied the evolution of accretion disks in low-mass X-ray binaries and showed under which conditions X-ray transients can remain in the hard state during outburst as observed for some systems.

F. Meyer worked out a suggestion that super-Eddington luminosities of ultra-luminous X-ray sources can be understood as arising from a fragmented accretion disk in strong magnetic fields around black holes of standard stellar mass. An important ingredient of this process is the disk corona in which most of the energy is released and deposited into the fragmented disk by accelerated particles.

M. Gilfanov and V. Arefiev (Space Research Institute, Moscow) studied X-ray variability of persistent LMXBs in the $\sim 10^{-8} - 10^{-1}$ Hz frequency range, aiming to detect breaks in their power density spectra (PDS) associated with the viscous time scale of the accretion disk $t_{\rm visc}$. They found that the break frequency correlates very well with the binary orbital frequency in a broad range of binary periods $P_{\rm orb} \sim 12$ min $- 33.5$ days, in accord with theoretical expectations for the viscous time scale of the disk. However, the value of $f_{\rm break}/f_{\rm orb}$ is at least by an order of magnitude larger than predicted by the standard disk theory. This suggests that a significant fraction of the accretion $\dot{M}$ occurs through the optically thin and hot coronal flow with the aspect ratio of $H/R \gtrsim 0.1$. A clear dichotomy has been found in the value of $t_{\rm visc}/P_{\rm orb}$ between wide and compact systems, the compact systems having $\sim$ 10 times shorter viscous time. The boundary lies at the mass ration $q \approx 0.3$, suggesting that this dichotomy is caused by the excitation of the 3:1 inner Lindblad resonance in low-q LMXBs.

U. Anzer, G. Börner, I. Kryukov (Moscow) and N. Pogorelov (Moscow) continued the numerical investigation of wind accretion. They calculated a series of models with different values for the heating and cooling parameters and for different efficiencies of the energy conversion. They found that the calculated accretion rates can be lower than the theoretical rates estimated for the Bondi-Hoyle-Lyttleton model by factors between 0.1 and 0.6. All their models converged to steady state solutions.

M. Revnivtsev, V. Suleimanov and H. Ritter have performed an extensive study of magnetic white dwarf binary systems - intermediate polars – with the help of INTEGRAL and RXTE observatories. It was shown that the broad band spectral analysis (1-100 keV) significantly improves the reliability of white dwarf mass measurements with respect to that previously available from standard X-ray spectra (1-10 keV). The developed physical model of post-shock region on the surface of the white dwarf allows to predict the spectra of intermediate polars and provides WD mass estimates that agree with available estimates from optical observations.

F. Meyer together with Yoji Osaki (Univ. Tokyo) showed that, contrary to claims in the literature, enhanced mass transfer during dwarf nova outbursts due to irradiation of the secondary star is ruled out. They showed that the Coriolis force on the rotating secondary effectively prevents the heated material to reach the cool low pressure region around the mass transfer point that lies in the shadow of the accretion disk.

Recent advances in infrared telescope facilities and instruments have now opened up an observational window on the structure and appearance of protoplanetary disks around low- and intermediate-mass pre-main-sequence stars. In collaboration with C. Dominik (University of Amsterdam) C.P. Dullemond developed multi-dimensional models of protoplanetary disks including detailed computation of the sedimentation and coagulation in these disks. It was found that coagulation can be very fast, removing nearly all of the small grains in these disks in a matter of a few thousand years at 1 AU from the star. Since small dust grains are observed to be present in T Tauri disks with an age of about 1 Myr, there must be a process to replenish these grains. The models of Dullemond & Dominik show that grain-aggregate fragmentation due to collisions could be this missing piece of physics.

Together with K. Pontoppidan (Leiden Observatory), C.P. Dullemond has applied 2-D disk models to fit in detail the spectra *and* images of a number of nearly edge-on disks around T Tauri stars. These allowed them to draw conclusions about the nature of the icy dust particles in these disks, about the geometry and optical depth of the disks. A particularly interesting result is that the huge dark bands around some T Tauri stars which were often interpreted as large disks can in fact be explained by large shadows cast by small disks around these stars.

S. Walch and C.P. Dullemond have worked on modeling of the viscous evolution of protoplanetary disks, starting from the collapse of a protostellar core, and ending with a passive irradiated T Tauri star disk. The work of Walch & Dullemond (diploma thesis of S. Walch) therefore represents a step forward, and allows the interpretation of infrared spectra of disks in terms of non-stationary evolving protoplanetary disks.

Work by I. Kamp (Space Telescope Science Institute) and C.P. Dullemond has shed light on the chemical and thermal structure of the upper layers of protoplanetary disks, observed with infrared telescopes.

C.P. Dullemond has collaborated with people from the "Cores to Disks" Spitzer Legacy Team of N. Evans (Univ. of Texas) to model the first Spitzer spectra of T Tauri stars and pre-stellar cores. This has led to the insight that some starless cores are not so starless after all since a very dim object was observed at the center of one of these suposedly starless cores. This could be the very first object formed before the main collapse phase.

3.6 Interaction of radiation with matter

S. Sazonov, J. Ostriker (Institute of Astronomy, Cambridge, UK) and R. Sunyaev computed the characteristic emission spectrum of the average quasar in the Universe. Using information on the cumulative AGN light, composite quasar spectra and the estimated local mass density of supermassive black holes (SMBHs), the equilibrium Compton temperature was constrained to a narrow range around 2×10^7 K. Since this exceeds the virial temperatures of giant elliptical galaxies, radiation from a central quasar in an early-type galaxy can in principle heat and expel its interstellar gas. These authors together with L. Ciotti (University of Bologna, Italy) then discussed 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 shown 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.

C. Cramphorn, S. Sazonov and R. Sunyaev explored the possibility of obtaining information on the physical parameters of relativistic jets of radio loud AGN through the radiation of the jets scattered by the thermal plasma generally surrounding AGN. Sensible constraints can be placed on the inclination angle and bulk Lorentz factor of the jet. The method was applied to the jet of M 87 and the surrounding intracluster gas; the current observational limits of the surface brightness measured in the region of the putative counterjet provide fairly tight constraints on the jet parameters consistent with constraints derived by other methods.

3.7 Galaxy evolution and the Intergalactic Medium

Stellar Populations. S. Charlot, in collaboration with A. Gallazzi (MPA), G. Kauffmann (MPA), H. Mathis (Oxford) and S. White (MPA), exploited his recent, high-spectral resolution population synthesis code to constrain the stellar metallicities and star formation histories of over 10^5 SDSS galaxies. The high-resolution model also allows precise measurements of emission-line fluxes through the accurate subtraction of the stellar continuum in galaxies containing significant nebular emission. In collaboration with J. Brinchmann (Porto), G. Kauffmann (MPA), S. White (MPA), T. Heckman (JHU) and C.Tremonti (Steward Observatory), the spectra of over 10^5 SDSS galaxies were analyzed in this way to study in detail the physical properties of star-forming galaxies in the low-redshift universe. X. Kong (Tokyo), S. Charlot, J. Brinchmann (Porto) and M. Fall (STScI) also combined the new spectral evolution model above with a simple but physically motivated model for the transfer of starlight through the interstellar medium in galaxies. This new spectral-analysis tool was applied in collaboration with S. Salim (UCLA), G. Kauffmann (MPA), T. Heckman (JHU) and C. Martin (Caltech) to interpret the ultraviolet and optical emission from over 6000 nearby galaxies for which both GALEX and SDSS photometry was available.

G. Kauffmann studied the demographics of optical AGN in the Sloan Digital Sky Survey. in collaboration with T. Heckman (JHU), S. White, S. Charlot, J. Brinchmann and C. Tremonti. By using the central stellar velocity dispersion of a galaxy as a measure of its black hole mass and its [OIII] line strength as a measure of the mass accretion rate onto the black hole, it was shown that low mass black holes are still growing on a timescale comparable to the Hubble time, but that high mass black holes have apparently terminated their growth. The integrated star formation rate in bulge-dominated galaxies was compared with the integrated accretion rate onto black holes in these systems. It was found that the star formation rate was around 1000 times larger than the accretion rate. This ratio is remarkably similar to the ratio between bulge mass and black hole mass observed in nearby elliptical galaxies, demonstrating that bulge formation and black hole growth are closely linked even at the present day.

G. Kauffmann also studied the demographics of radio-loud AGN in the Sloan Digital Sky Survey in collaboration with Philip Best (Edinburgh) and Tim Heckman (JHU). A new algorithm was developed for matching SDSS galaxies to radio sources in the FIRST and NVSS surveys. Diagnostic features in the galaxy spectra were used to separate radio-loud AGN from galaxies where the radio emission is produced by star formation. It was then shown that radio-loud AGN are a completely independent AGN population. The probability that a galaxy is a radio loud AGN does not depend on whether it is an optical AGN. Radio loud AGN occur predominantly in the most massive galaxies and in the densest environments. Although the probability that a galaxy is a radio-loud AGN is a strongly increasing function of black hole mass, the distribution of radio luminosites does not depend on this quantity.

In collaboration with R. Chang (Shanghai Observatory), A. Gallazzi and S. Charlot, G. Kauffmann investigated the colours of elliptical galaxies using a combination of data from the SDSS and 2MASS surveys. It has long been known that the colours of ellipticals are correlated with their luminosities and velocity dispersions. The results of the new study showed that different colours can exhibit very different dependences on parameters such as velocity dispersion or mass. Optical or infrared colours correlate most strongly with velocity dispersion, but the optical-to-infared colours of ellipticals are only weakly correlated with velocity dispersion, but strongly correlated with stellar surface mass density. It is suggested that optical-to-infrared colours may be sensitive to the degree of enhancement of alpha-elements and the strong correlation with surface density may occur because denser galaxies formed their stars over shorter timescales.

B. Panter incorporated the higher resolution stellar spectral models of S. Charlot (MPA) into his implementation of the MOPED algorithm, allowing further information to be extracted from the SDSS galaxy survey. He has also worked with Alan Heavens (Institute for Astronomy, Edinburgh University) and Vivienne Wild (Institute of Astronomy, Cambridge) to compare the data compression of the MOPED algorithm with that of Principal Component Analysis (PCA). Investigations in the cosmic star formation rate continue with Alan Heavens and Raul Jimenez (University of Pennsylvania).

A. Gallazzi, in collaboration with S. Charlot, S. White and J. Brinchmann (Porto), used the high-resolution Bruzual-Charlot population synthesis code to constrain stellar metallicities, ages and stellar masses for a large sample of SDSS galaxies, including both quiescent early-types and star-forming galaxies. They explored the dependence of age and stellar metallicity on stellar mass for different classes of galaxies and investigated 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.

P. Coelho previously computed a large set of synthetic stellar spectra with variable alpha-elements over iron ratios. This grid is being connected with the new Bruzual-Charlot stellar population synthesis code in collaboration with G. Kauffmann (MPA), S. Charlot (MPA), G. Bruzual (CIDA) and B. Barbuy (IAG). This work will allow the group to address the impact of the alpha-enhancement on the colours and indices of galaxies. This is especially important for the analysis of elliptical galaxies, which are known to have non-solar alpha over iron ratios.

A. Moretti developed a minimization code based on the Bayesian statistics to derive informations such ages and metallicities for samples of globular clusters belonging to M104 and M33. Lick line indices measurements were compared to their theoretical counterpart derived from the SSP high resolution models by Bruzual G. & Charlot S., 2003. The gc population of M104 is found to be rich in intermediate age objects, while in M33 oldest clusters have an age much younger than the mean age of old stellar systems of the Local Group.

M. G. Kitzbichler compared pure luminosity evolution (PLE) models, which assume that massive galaxies were assembled and formed most of their stars at high redshift ($z > 3$) and have evolved without merging or substantial dust obscuration since then, with recent data at low and high redshift. The models are required to reproduce the abundance of galaxies by colour and luminosity in the Sloan Digital Sky Survey and it was investigated whether they can simultaneously fit (i) the observed galaxy counts as a function of redshift in magnitude limited surveys with $K < 20$, and (ii) the colour and M/L ratio evolution of red sequence galaxies in clusters. All models that are consistent with (ii) predict galaxy counts at $1.5 < z < 3$ which lie above the observations leading to the conclusion that the majority of massive galaxies were either assembled relatively late in this redshift interval or were substantially obscured by dust at these redshifts.

Galaxy Clusters S. White continued as Principal Investigator of the ESO Distant Cluster Survey (EDisCS), an ESO Large Programme carrying out a photometric and spectroscopic survey of 20 distant galaxy clusters which completed its observations in 2004. The EDisCS science team involves about 30 scientists from 7 countries and met in Ringberg in summer 2004 to review the observations and reductions and to plan their science exploitation. A first paper led by S. White, presents the sample as a whole and the optical photometry obtained for it using FORS on the VLT. The sample contains objects from redshift 0.4 to 0.8 with a wide range of richness, morphology and galaxy content. Another paper, led by D. Clowe (U. Arizona), has carries out a weak lensing analysis of the mass distribution of the clusters showing them to again span a very wide range, including two which show strong lensing signatures of giant arcs. C. Halliday, working within the spectroscopy subgroup of the collaboration, led a paper presenting first results of the survey's spectroscopic phase. This reviews the VLT FORS2 spectroscopic observations, including target selection strategy, mask design and data reduction methods, Catalogues were presented for positions, magnitudes and spectroscopic redshifts of galaxies in the fields of 5 of the EDisCS clusters. Velocity dispersions range between 400 $\mathrm{km\,s^{-1}}$ and 1100 $\mathrm{km\,s^{-1}}$. Significant cluster substructuring was detected in 2 clusters: both clusters have velocity dispersions exceeding 1000 $\mathrm{km\,s^{-1}}$ and are unlikely to be virialised.

G. De Lucia in collaboration with B. M. Poggianti (INAF - Osservatorio Astronomico di Padova) and other members of the EDisCS consortium, studied the colour-magnitude relation for a subsample of the EDisCS clusters at redshift $0.7 - -0.8$. The work demonstrated that EDisCS clusters exhibit a deficiency, with respect to low redshift clusters, of passive red galaxies at luminosities more than two magnitudes fainter than the brightest cluster galaxies. These results invalidate a synchronous formation scenario for red–sequence galaxies and suggest that a large fraction of faint passive galaxies in clusters today moved on to the red sequence relatively recently, possibly as a consequence of the the halting of the star formation due to the hostile cluster environment.

Under the supervision of V. Springel and S. White, D. Sijacki studied the effects of central AGN heating on the formation of galaxy clusters by means of hydrodynamical simulations. She implemented, in the parallel TREESPH-code GADGET, a periodic feedback mechanism in the form of hot buoyant bubbles in the ICM, produced during the active phases of accreting central AGN. She considered isolated cluster haloes of different mass for a detailed analyses of the bubble dynamics, and also applied the model to follow the full cosmological evolution of galaxy clusters, thereby obtaining the first self-consistent simulations of cluster formation with AGN heating. Sijacki found that AGN heating can substantially affect the properties of the central ICM, reducing, in particular, the mass deposition rate on the central object, and potentially solving the cooling flow problem.

M. Jubelgas has performed cosmological simulations of structure formation that included thermal conduction, using the formalism he had developed in the previous year in collaboration with V. Springel and K. Dolag. He analysed the formation of groups and clusters in a large volume, with the goal to determine the statistical impact of plasma thermal conduction on the cluster scaling relations. Because the thermal conductivity is strongly temperature dependent, one expects hotter, more massive clusters to be influenced in a more significant way. This can lead to a tilt of the cluster scaling relations, and changes in their normalisation. Indeed, M. Jubelgas has found a flattening of the luminosity-temperature relationship.

K. Dolag, together with S. Borgani (Dip. Astro. Trieste), G. Murante (INAF, Pino Torinese) and V. Springel worked on convergence of cooling and star formation in high resolution simulations of galaxy clusters. They were able to demonstrate that their numerical models of galaxy clusters had converged in their star formation rates and their final star fraction; within the chosen numerical scheme, they only depend on the choice of physical parameters like the background cosmology, the fraction of SN energy going into galactic winds and the treatment of additional physical processes within the intracluster medium, anf they are independent of resolution, of the choice of specific numerical parameters and of the details of the initial conditions for the simulations.

C. Vogt and T. Enßlin worked on methods for a statistical analysis of Faraday rotation maps, which cover most of the aspects required for an end-to-end understanding of the measurement of the power-spectra of intracluster magnetic fields from radio astronomical observations. This includes an optimal Faraday map making algorithm, (PACERMAN - Polarisation Angle CorrEcting Rotation Measure ANalysis) which was developed in collaboration with K. Dolag (then University of Padua, now MPA), artifact-detecting methods and the modelling of the structure of galaxy clusters in order to describe the 'experimental set up'. Further steps were the adaption and implementation of statistical methods for power-spectrum estimates such as the maximum likelihood method also used in CMB science. The results from this exercise are scientifically extremely interesting, since for the first time a Kolmogoroff-type spectrum could be clearly measured for this tracer of cluster turbulence. These results will be very important for an understanding of magnetic dynamo processes operating in galaxy clusters.

C. Pfrommer and T. Enßlin investigated thermal and non-thermal processes in galaxy clusters in order to study the cosmological implications of relativistic particle populations and magnetic fields. In the course of this work, they estimated magnetic field strengths of radio emitting galaxy clusters by minimizing the non-thermal energy density contained in cosmic ray electrons, protons, and magnetic fields. They developed a minimum energy criterion together with theoretically expected tolerance regions for observed synchrotron emission which is generated by a cosmic ray electron population originating from hadronic interactions of cosmic ray protons. Application to the radio halo of the Coma cluster and the radio mini-halo of the Perseus cluster yields equipartition between cosmic rays and magnetic fields within the expected tolerance regions.

C. Pfrommer, T. Enßlin and Craig Sarazin propose a new method in order to elucidate the content of the radio plasma bubbles located at cool cores of galaxy cluster. Using the Sunyaev-Zel'dovich (SZ) effect, the *Atacama Large Millimeter Array* and the *Green Bank Telescope* one should be able to infer the dynamically dominating component of the plasma bubbles in suitable galaxy clusters within short observation times. Future high-sensitivity multi-frequency SZ observations will be able to infer the energy spectrum of the dynamically dominating electron population in order to measure its temperature or spectral characteristics. This knowledge can yield indirect indications for an underlying composition of relativistic outflows of radio galaxies because plasma bubbles represent the relic fluid of jets.

Co-evolution of galaxies and AGN V. Springel, together with T. Di Matteo and L. Hernquist (Harvard University, Cambridge), developed novel methods to follow the growth of supermassive black holes at the centers of galactic potential wells. Their simulations are able to follow radiative cooling of gas, star formation, and the gravitational dynamics of dark matter, stars and gas in galaxies at the same time. In simulations of colliding galaxies, they could hence study how tidally induced nuclear inflow of gas triggers starbursts and a rapid growth of the central black holes by gas accretion. The latter is accompanied by the release of intense radiation, letting the galaxy centers shine as bright quasars for a few tens of million years. Assuming that a small fraction of the energy released by the black holes couples thermally to the surrounding gas, it was found that the accretion is shut off eventually, when the black holes have grown enough to power strong outflows, which expel most of the remaining gas in the nuclei. The growth of black holes in galaxy interactions appears to be a self-regulated process. Interestingly, the final black hole masses and the velocity dispersion of their host stellar bulges are related in a way consistent with observations. The feedback energy of the black holes also affects the evolution of the host galaxies, because the black hole activity reduces the strength of starbursts, and the heating and expulsion of gas lowers the residual level of star formation in merger remnant galaxies. The latter therefore quickly develop red stellar colors, improving the match between major merger remnants and the properties of observed elliptical galaxies.

T. Di Matteo, in collaboration with R. Croft (Carnegie Mellon University), V. Springel and L. Hernquist (Harvard University) has coupled state-of-art cosmological simulations of galaxy formation in the Λ–Cold Dark Matter (CDM) model with a model for black hole growth and activity. Using their simulations and the quasar sample identified in it, they have estimated quasar metal abundances, showing that it is possible to construct self-consistent models for the locations where massive galaxies are being assembled while vigorously forming stars and building central black holes.

A. Merloni, G. Rudnick and T. Di Matteo have examined possible phenomenological constraints for the joint evolution of supermassive black holes (SMBH) and their host galaxies by comparing all the available observational data on the redshift evolution of the total stellar mass and star formation rate density in the Universe with the mass and accretion rate density evolution of supermassive black holes. They have found that, on average, black hole masses were higher at higher redshift for a given spheroid stellar mass. The data also suggest that the fraction of stellar mass in spheroids decreases with increasing redshift. This is consistent with recent determinations that show that the mass density at high redshift is dominated by galaxies with irregular morphology. Finally, the average radiative efficiency of black hole accretion was constrained to be between 0.04 and 0.11, depending on the exact value of the local SMBH mass density.

T. Di Matteo with D. Wake and C. Miller (both Carnegie Mellon University) studied the 2-point correlation function of the population of local active galactic nuclei within the SDSS sample and found that the clustering of local AGN is the same as that of normal galaxies, implying that AGN are a common phenomenon in all galaxies.

H. Arp has observed with the 10 meter Keck telescope Ultra Luminous X -ray sources near active galaxies. Spectra and direct images have resulted in a number of new high redshift quasars which are being prepared for publication. Currently a data mining analysis of the 2dF deep quasar survey is being carried out with collaborators. The associations of quasars with lower redshift galaxies in the field are being carried out on a large statistical scale with special attention to tests of quantization of the numerical values of redshift.

High-redshift IGM New observational probes of the reionization epoch have been actively searched for in the last few years. 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. On the other hand, the newly formed electrons during the reionization process induce secondary anisotropies in the CMB spectrum. Thus, the two signals are expected to be correlated. B. Ciardi, in collaboration with R. Salvaterra, A. Ferrara and C. Baccigalupi (SISSA, Trieste), has calculated the expected anti-correlation between the two signals, finding that it can be used to extract colors and indices of galaxies. This is special important for the analysis of information on the reionization history and the reionizing sources.

An exciting future probe of the epoch of reionization will be 21cm tomography of the neutral hydrogen in the IGM and in gravitationally collapsed systems. T. Di Matteo with B. Ciardi and F. Miniati (ETH, Zurich and MPA) has modelled the contaminating foregrounds to the primary 21 cm radiation due to extragalactic point source and extended sources. Point sources are the galaxies which produce radio emission and free-free emission. Extended sources include radio halos and relics and free-free amission from the IGM. They are using cosmological simulations and are producing simulated sky maps for the upcoming *Lofar* and *PAST* facilities.

Observations of QSOs and galaxies at $z > 6$ and more recently WMAP observations of CMB temperature and polarization anisotropies have rejuvenated the interest in the formation and the evolution of the first structures in the universe, and their effects on the IGM and the subsequent structure formation process. B. Ciardi, in collaboration with A. Ferrara (SISSA, Trieste), has collected the available studies into a Review paper on the subject.

3.8 Cosmic structure from z=0 to the Big Bang

V. Springel carried out the 'Millennium Simulation', a major project of the Virgo Consortium, which is an international collaboration of numerical cosmologists from the UK, Germany, Canada and the US, jointly led by Simon White and Carlos Frenk (University of Durham). This simulation utilized more than 10^{10} simulation particles, making it the largest N-body simulation of cosmological structure formation ever carried out. Thanks to its unprecedented dynamic range, the simulation allows the construction of theoretical models for galaxy formation in a volume as large as that probed by modern spectroscopic redshift surveys like SDSS or 2dGFRS, and containing all galaxies with luminosity above a tenth of $L_\star$. The accurate comparisons between theory and observation this allows are instrumental in gaining a better understanding of the importance of different physical processes in galaxy formation. Also, the statistics of dark matter clustering and its non-linear evolution can be measured with high accuracy and for a very large dynamic range using the Millennium Simulation. Analysis of the evolution of the power spectrum of density fluctuations on large-scales showed that the baryonic wiggles imprinted in the matter distribution at high redshift do partially survive until the present day, despite being affected by non-linear evolution. V. Springel and collaborators have also shown that these baryonic features can in principle be measured with the galaxy distribution alone, both at low and high redshift. The evolution of the corresponding length scale could be used as a powerful cosmological probe for the equation of state of dark energy.

G. Hütsi studied the clustering of the SZ-selected clusters on our past light-cone focussing on constraints on the dark energy properties one might hope to achieve with the future surveys. Special attention was paid to the question whether and under what circumstances it would be possible to see the traces of th acoustic oscillations in the cluster power spectrum.

G. Börner and Y.P. Jing studied the luminosity dependence of the pairwise peculiar velocity of galaxies in the 2dFGRS. This redshift catalogue is big enough to make such a study possible. The relative velocities of the faint galaxies at small separations (1 Mpc) are very high, about $700 kms^{-1}$, similar to the bright galaxies. At intermediate luminosities of $M_* - 1$ (M_* is the characteristic magnitude of the 2dF Schechter luminosity function) the relative velocities exhibit a well-defined deep minimum of $400 kms^{-1}$. The halo population model of galaxy formation cannot reproduce this result. Future work concerns tests of semianalytic models of galaxy formation.

Y.H. Hou together Y.P. Jing (Shanghai), D.H. Zhao (Shanghai), G. Börner have measured the bispectrum for four scale-free models of structure formation with spectral indices of $n = 1, 0, -1$, and-2. With these measured results, they found that the measured bispectrum depends on the shape and size of the k-triangle even in the strongly nonlinear regime. It increases with wavenumber and decreases with the spectral index. Based on the measurement, they developed a new fitting formula for the reduced bispectrum that is valid for $-2 \leq n \leq 0$ with a typical error of 10 percent only.

The interstellar medium (ISM) of galaxies and the intergalactic medium between galaxies are very complex: their energy budget includes non-thermal components such as magnetic fields and relativistic particles which are each known to contribute roughly as much energy and pressure each as the thermal gas, at least for the ISM in our own Galaxy. The collaboration of M. Jubelgas, Ch. Pfrommer, T. Enßlin, and V. Springel is currently working on the implementation of a description of relativistic protons into the cosmological TreeSPH-Code *GADGET*. This will not only allow to produce realistic emission signatures of galaxies and clusters of galaxies, but will also allow the in-vivo study of dynamical effects driven by relativistic particles and their impact on their structure and star formation history. Their formalism self-consistently traces relativistic protons originating from various kinds of sources, such as shocks occurring during structure formation and supernovae driven galactic winds, and also accounts for dissipative processes in the relativistic gas component.

Based on a first version of the cosmic ray (CR) model in GADGET, M. Jubelgas, under the supervision of V. Springel, has investigated the distribution of relativistic protons from different sources in structure formation on small and large scales. He has been studying the influence of the CR population on star formation in isolated galaxies and in clusters of galaxies, as well as on the shape and evolution of density and pressure profiles of these objects. Due to the different adiabatic index of the CR component compared with the thermal pressure of the gas, and due to its different cooling mechanism, non-relativistic protons may have a moderating influence on the strength of cooling flows in clusters of galaxies. Martin Jubelgas' preliminary results however suggest that these effects are probably too weak to explain the observational paucity of strong cooling flows in rich clusters.

3.9 Gravitational lensing

Together with M. Bartelmann, B. M. Schäfer evaluated the corrections to the weak lensing power spectrum due to gravitomagnetic potentials caused by mass currents in the large-scale structure. These post-Newtonian corrections were determined in perturbation theory. A close relation to the Rees-Sciama effect was found, which in turn measures the divergence of the gravitomagnetic potentials. This allows to treat the Rees-Sciama power spectrum within the framework derived for gravitomagnetic weak lensing and reduces the Rees-Sciama effect to a second-order gravitational lensing effect.

K. Dolag, together with M. Maturi (Dip. Astro. Padova), M. Meneghetti (ITA, Heidelberg), M. Bartelmann (ITA, Heidelberg) and L. Moscardini (Dip. Astro. Bologna) worked on constructing optimal filters for detection of galaxy clusters through weak lensing. These filters where tested using high resolution numerical simulations of galaxy clusters demonstrating that they heavily suppress spurious detection present in other filtering methods.

H. Sandvik developed together with J. Diego(MIT) and P. Protopapas(CfA) a non-parametric method for cluster lens mass reconstruction from strong gravitational lensing data. The method was used on the recently released image of the giant arc system A1689(Broadhurst et.al. 2004). A total mass of $0.25 \times 10^{15} h^{-1} M_\odot$ 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. The recovered mass profile is compatible with an NFW profile.

3.10 Cosmic Microwave Background Studies

A.J. Banday in collaboration with K.M. Gorski (JPL/CalTech, USA), H.K.E. Eriksen (Oslo, Norway), F. Hansen (Roma II, Italy), P. Lilje (Oslo, Norway), A. Balbi (Roma II, Italy) and P. Bielewicz (Warsaw University, Poland) has undertaken a comprehensive analysis of the statistical nature of the CMB anisotropy data collected by NASA's WMAP satellite. Evidence for non-Gaussian features has been found on a range of angular scales, together with an intriguing asymmetry in the distribution of temperature fluctuations between the northern and southern ecliptic hemispheres. Such a result, found in power spectrum measurements, n-point correlation functions and topological measures such as Minkowski functionals, poses an important question related to one of the fundamental assumptions of modern cosmology – that of cosmological isotropy.

It has also been determined that various statistically significant deviations in the angular power spectrum from predictions of the best-fit cosmological model (as derived by the *WMAP* team) also show unexpected associations with the coordinate frame which maximises the asymmetry. Specifically, the strong negative outlier at $\ell = 21$ and the strong positive outlier at $\ell = 39$ follow the general tendency of the multipoles $\ell = 5 - 40$ to be of systematically lower amplitude in the north and higher in the south.

A subsequent investigation into how the estimates of particular cosmological parameters vary when inferred from power spectra computed separately on the northern and southern hemispheres has tentatively implied that the estimated optical depth of τ=0.17 on the (nearly) full sky found by the *WMAP* collaboration and confirmed independently by us, could in large part originate in structure associated with the southern hemisphere. Indeed, when using a gaussian prior on the spectral index n centred at $n = 1$ with a flat prior on the optical depth τ, the preferred value in the north is $\tau = 0$, whereas in the south we find $\tau = 0.24$.

Recent analyses of the *WMAP* data have suggested that the low-order (large angular scale) multipoles of the CMB anisotropy distribution show cosmologically interesting and unexpected morphologies and amplitudes. Specifically, the quadrupole amplitude is unexpectedly low, and there is a plane of alignment between the quadrupole and octopole. A power equalization filter has been applied to the high-latitude *WMAP* data in order to reconstruct these low-l multipoles free from the largest Galactic foreground modelling uncertainties in the Galactic plane which plague other analyses. This study has confirmed the result from other groups that the octopole does indeed show structure in which its hot and cold spots are centred on a single plane in the sky, and that this is very stable with respect to the applied mask and foreground correction. The estimated quadrupole is much less stable showing non-negligible dependence on the Galactic foreground correction. Including these uncertainties is likely to weaken the statistical significance of the claimed alignment between the quadrupole and octopole.

Finally, although there is evidence that some methods of foreground cleaning of the *WMAP* data are not sufficient, the weak residual Galactic emission is unlikely to be the cause of the observed asymmetry over the range $\ell = 5 - 40$, or the non-Gaussian signals on scales of $\sim 10°$.

A. J. Banday in collaboration with K. M. Gorski (NASA-JPL, USA), E. Hivon (NASA-IPAC, USA), M. Bartelmann (Heidelberg) and M. Reinecke continue to maintain and develop the HEALPix software package for the simulation and analysis of CMB anisotropy maps. Version 1.22 was publicly released in early 2004. Work is currently focussed on diversifying the support for various programming environments. Toolkits in C++, Java and C# have been developed and will be realeased in 2005 as part of the Version 2.0 package. 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).

B. M. Schäfer, M. Bartelmann, C. Pfrommer and R. M. Hell set up extensive simulations for assessing the properties of the Sunyaev-Zel'dovich cluster sample the PLANCK satellite will be able to detect. They combined all-sky maps of the thermal and kinetic Sunyaev-Zel'dovich effects with maps of the fluctuating CMB, Galactic foregrounds (dust, synchrotron, free-free, rotational transitions of carbon monoxide molecules), sub-millimetric emission of planets and asteroids and instrumental noise. For amplifying and extracting the weak SZ-signal, they extended the theory of matched and scale-adaptive filtering to spherical coordinates, derived filter kernels and proved their functionality.

J. Chluba in collaboration with R.A. Sunyaev studied the spectral distortions of the Cosmic Microwave Background (CMB) introduced by the superposition of blackbody spectra. The possiblity of using these distortions for the calibration of CMB experiments was examined. Futhermore J. Chluba in collaboration with G. Hütsi and R.A. Sunyaev studied the changes of the SZ cluster brightness, flux and number counts induced by the motion of the Solar System with respect to the CMB rest frame. These corrections to the SZ cluster brightness and flux have similar spectral behavior and amplitude as the first order velocity correction to the thermal SZ and thus need to be taken into account for the precise modeling of the cluster signal.

K. Dolag, together with L. Moscardini (Dip. Astro., Bologna) and M. Roncarelli (Dip. Astro., Bologna) constructed full sky maps of the thermal and kinetic SZ effect using a hydrodynamical simulation of the local universe. This will be used to investigate the effect of the local supercluster structures on the lower multipoles within the SZ component of the CMB power spectrum. Also usage of these maps as template foregrounds for the Planck satellite simulation pipeline is foreseen.

C.Hernández-Monteagudo studied the presence of weak frequency dependent signals in current and future CMB data. On the theoretical side, and in collaboration with R. Sunyaev, he proposed a method to unveil weak signals by looking at their correlation with the dominant CMB component. On the observational side, an analysis was carried out aiming to detect the nature of sources of thermal Sunyaev-Zel'dovich induced signal in *WMAP* First Year data. In collaboration with R.Génova–Santos (IAC) and F.Atrio–Barandela (U.of Salamanca), he found a tSZ-induced decrement of $-35 \pm 7\mu$K in 26 sguare degrees, mostly due to ACO galaxy clusters generating a tSZ profile of 20-30 arcmin size. Further, a decrement of $-96\pm37\mu$K non associated to known ACO clusters is still found in 0.8 square degrees in the Zone of Avoidance (ZoA). In this case, most pixels coincide with cluster candidates in the ZoA. In a parallel project with the same collaborators, similar analyses were performed aiming to constrain the presence of ISW induced signal in WMAP's first year data by cross correlating the V *cleaned* band with templates built from 2MASS, SDSS and NVSS galaxy catalogs: no evidence of cross-correlation was found in any of the cases in angular scales above 1deg–4deg. This results in strong constraints on the contribution of those catalogs to *WMAP*'s V band (a few μK, 3–9 μK, at 99% confidence limit). Finally, in collaboration with J.Macias and M.Tristram (Laboratoire de Physique Subatomique et Cosmologie), further studies are being carried out trying to unveil the tSZ signal in ARCHEOPS' CMB maps at 143 GHz.

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) and configuration interaction (CI) methods. The spatial confinement is defined by an external one-particle potential introduced to the N-electron Hamiltonian. The low lying electronic spectra of 2- and 3 electron quantum dots, the helium atom and the lithum atom confined in an anisotropic harmonic oscillator potential have been studied for prolate and oblate potentials and different confinement strength. The dipole transition moments have been analyzed (G. H. F. Diercksen, S. Yamamoto and T. Sako). The electronic structure of the lithium molecule confined by an harmonic oscillator potential has been investigated for different confinement strength. Potential energy curves of the electronic ground state and of the three lowest excited singlet sigma states have been studied. Several avoided crossings have been observed as a result of the confinement (G. H. F. Diercksen, T. Sako and I. Černušák). The low-lying excited states of the hydrogen molecule confined in the 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). - The excited states of ethylene have been analyzed systematically and characterized according to the natural orbitals resulting from multireference configuration interaction single and double studies (G. H. F. Diercksen, S. Yamamoto and H. Tatewaki). A comparative density functional study of the torsional potential of 4-fluoro (trifluoromethoxy)benzene and related species has been performed. While two of the four investigated species exhibit a minimum at the perpendicular-planes [o]-form conformation the other two exhibit minima at the eclipsed [e]-form conformation (G. H. F. Diercksen, M. Kieninger and Oscar N. Ventura).

Continueing the ongoing work on basic exothermic binary reactions of potentially astrophysical relevance and extending in this context the recent innovative study of radiative association formation of the triatomic ground electronic state of the HeH_2^+ ion in a single-state process, the corresponding two-state process involving the lowest excited electronic state was investigated on the same rigorous quantummechanical state-to-state level of theory. Like in the formally related case of the simple diatomic HeH^+ ion the reaction rate constant of the two-state process is calculated to be several orders of magnitude larger compared to the reaction occurring entirely on the ground electronic state potential energy surface. Corresponding calculations for the LiH_2^+ molecular ion were started where the situation appears to be far more complex. (W.P. Kraemer together with F. Mrugala (Torun), and V. Špirko (Prague)). The influence of relativistic effects on macroscopic properties such as the radiative association rate constant in the formation of ionic species with heavy elements is investigated for different series of diatomics applying recently implemented coupled-cluster approaches (W.P. Kraemer together with M. Urban and V. Kelloe (Bratislava)).

Studies of the spectroscopy of interacting electronic states were extended investigating the characteristics of carbenes and their silicon containing analogues. Carbenes are known as highly reactive species and especially the halogen substituted compounds are expected to play an important role in atmospheric chemistry. The Renner-Teller effect on the transition spectra of the basic species CH_2 and SiH_2 and their halogenated derivatives HCX and CX_2 with X = F, Cl, Br ... are studied applying the conventional CASSCF/MR-CISD method for calculating the relevant parts of their potential energy surfaces (W.P. Kraemer together with P. Jensen (Wuppertal) and P.R. Bunker (Ottawa)). For the higher halogen compounds with their rapidly increasing number of electrons which need to be correlated in these calculations a new method on the coupled-cluster level has been developed and is now tested (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 2004

Abazajian, K., et al. (incl. S. White and S. Zibetti): The Second Data Release of the Sloan Digital Sky Survey Astron. J. **128**, 502–512 (2004).

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4.4 Popular articles and books

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4.5 Invited-, Colloquia- and Public talks

4.5.1 Invited and review talks

S. Charlot: International Workshop on "The Spectral Energy Distribution of Gas Rich Galaxies: Confronting Models with Data" (Heidelberg, 4.10–8.10.)

S. Charlot: 15th Annual October Astrophysics Conference in Maryland "New Windows on Star Formation in the Cosmos" (College Park, 11.10.–13.10.)

E. Churazov: X-Ray Polarimetry Workshop, Stanford, USA (9.02.-11.02)

B. Ciardi: "Galaxy-Intergalactic Medium Interactions" (Santa Barbara, 25.10.–29.10.)

B. Ciardi: "Frontiers in Computational Astrophysics" (Wengen, 26.9–30.9.)

B. Ciardi: " CMB and the First Objects at the End of the Dark Ages: Observational Consequences of Reionization" (Leiden, 26.4.–28.4.)

G. De Lucia: "The Role of Mergers and Feedback in Galaxy Formation", (Ringberg Castle, Oct. 31. Nov. 6.)

H. Dimmelmeier: Europäisches Graduiertenkolleg Basel - Tübingen, Graduiertentag in Basel zum Thema "Gravitational Waves" (Basel, Switzerland, 17.12.)

T.A. Enßlin: 3rd Korean Astrophysics Workshop on Cosmic Rays and Magnetic Fields in Large Scale Structure "Extragalactic Cosmic Rays and Magnetic Fields: Facts and Fiction" (Pusan, 16.8.-20.8, 2004)

T.A. Enßlin: International Conference on The Magnetized Plasma in Galaxy Evolution "Magnetic Fields in Clusters of Galaxies" (Krakow, 27.9.-1.10)

M. Gilfanov: NATO - Advanced Study Institute "The Electromagnetic Spectrum of Neutron Stars" Marmaris, Turkey (7.6–18.6)

M. Gilfanov: "Galaxies Viewed with Chandra" CfA, Cambridge, USA (07.07–09.07)

M. Gilfanov: "6-th CAS-MPG workshop on cosmology and galaxy formation" Tunxi, China (12.10–16.10)

M. Gilfanov: "Cosmology and High Energy Astrophysics (Zeldovich-90)" (Moscow, Russia, 20.12.–24.12.)

W. Hillebrandt: 5th INTEGRAL Workshop "The Integral Universe" (Munich, 16.2.–20.2.)

W. Hillebrandt: 10th International Conference on "Numerical Combustion" (Sedona, Arizona, 9.5.–12.5.)

W. Hillebrandt: International Conference on "Supernovae as Cosmological Lighthouses" (Padua, Italy, 16.6.–19.6.)

W. Hillebrandt: Workshop on “Supernova Theory and Nucleosynthesis” (Seattle, USA, 15.7.–17.7.)

W. Hillebrandt: Workshop on “Type Ia Supernovae and Cossmology” (Seattle, USA, 4.8.–7.8.)

H.-Th. Janka: “Nuclei in the Cosmos VIII” (Vancouver, 19.7.–23.7.)

G. Kauffmann: Royal Society Discussion Meeting “The Impact of Active Galaxies on th Universe at Large” (London, 16.2.–17.2.)

G. Kauffmann: IAU Symposium no. 222 “The Interplay among Black Holes, Stars and ISM in galactic Nuclei” (Gramado, 1.3.–5.3.)

F. Kupka: IAU Symposion 224 “The A-star puzzle”, Poprad, Slovakia (8.7.–13.7.)

F. Kupka: ASOS8 (International Colloquium on Atomic Spectra and Oscillator Strengths), Madison, Wisconsin, USA (8.8.–12.8.)

P. Mazzali: “Asphericity in Hypernovae: a link to GRBs” at the annual Meeting of the Italian Astron. Soc. (Milan, 20.4.-22.4.)

P. Mazzali: “Hypernovae/Supernovae in Gamma- Ray Bursts and X-Ray Flashes” at ”The Supernova - Gamma Ray Burst Connection” INT, (Seattle 15.7.-17.7.)

P. Mazzali: “Hypernovae and Gamma-Ray Bursts”, at ”Italian-Israeli Astrophysics Workshop” (Tel Aviv, 12.12.-13.12.)

A. Merloni: “From X-ray binaries to quasars: Black hole accretion on all mass scales” (Amsterdam, The Netherlands, 12.7–15.7)

A. Merloni: “The 2004 Ringberg Castle Workshop on AGN Physics” (Ringberg Castle, Germany, 22.11–25.11)

E. Müller: Meeting of the Physics Peer Review Committee of the AstroParticle Physics European Coordination (Orsay, 28.6.)

E. Müller: Conference on Computational Physics 2004 (Genua, 1.9.–4.9.)

E. Müller: CNRS summer school on ”Physique Stellaire: Dynamique des fluides stellaires et simulations numeriques associees (Aussois, 26.9 - 1.10.)

E. Müller: Isaac Newton Institute for Mathematical Sciences Workshop on ”Large-scale Computation in Astrophysics” (Cambridge, 11.10.–15.10.)

V. Springel: IAU Colloquium 195 “The Outskirts of Clusters of Galaxies” (Torino, 12.-16.3.)

V. Springel: MPA/MPE/ESO Conference “Growing Black Holes: Accretion in a Cosmological Context” (Garching, 21.-26.6.)

V. Springel: Aspen Summer Workshop “Star Formation in Galaxies” (Aspen, 6.-18.7.)

V. Springel: Workshop “Frontiers in Computational Astrophysics” (Wengen, 27.-29.09.)

V. Springel: KITP Conference “Galaxy-Intergalactic Medium Interactions” (Santa Barbara, 25.-29.10.)

S. Sazonov: “The Supernova-Gamma Ray Burst Connection” workshop at the Institute for Nuclear Theory (Seattle, 12.06).

R. Sunyaev: Special session of the Russian Academy of Sciences devoted to the 90th Birthday of Yakov Zeldovich, February 2004.

R. Sunyaev: Symposium “Exploring the Cosmic Frontier”, Berlin, May 2004

R. Sunyaev: Dark Universe Workshop at MPE, May 2004

R. Sunyaev: 31st EPS Conference on Plasma Physics, London, June 2004

A. Weiss: “Chemical Abundances and Mixing in Stars in the Milky Way and its Satellites”, (Castiglione della Pescaia, Italy, 13.9.–17.9.)

S.D.M. White: Planck Consortium Meeting, Paris 2004

S.D.M. White: Dark Matter Workshop, Garching 2004.

S.D.M. White: Ringberg Workshop on the Evolution of Galactic Disks.

S.D.M. White: IAU Symposium #225, Gravitational Lensing and Cosmology , Lausanne 2004

S.D.M. White: KITP conference on the Intergalactic Medium, Santa Barbara 2004.

S.D.M. White: Jerusalem Winter School on Galaxy Formation, Israel, 2004.

S.D.M. White: 1st Chinese Summer School on Extragalactic Astrophysics, Shanghai 2004.

S.D.M. White: Astroparticle Physics, Erlangen 2004.

S.D.M. White: German Astroparticle School, Obertrubach 2004.

4.5.2 Colloquia talks

B. Ciardi: UC Santa Cruz (Santa Cruz, 17.10.)

B. Ciardi: SISSA (Trieste, 7.3.)

A. Merloni: Seminaires d’Astrophysique de l’OMP (Toulouse, France, 6.12)

S. Yu. Sazonov: Weekly colloquium series at the Max-Planck-Institute for Radio Astronomy and the Astronomical Institutes of the University of Bonn (Bonn, 17.12.)

V. Springel: Physical Colloquium (Universität Heidelberg, 2.2.)

V. Springel: Astrophysical Colloquium (ETH Zuerich, 10.2.)

V. Springel: Astrophysical Colloquium (Saclay, 6.5.)

V. Springel: Astrophysical Colloquium (Berkeley, 27.10.)

V. Springel: Physical Colloquium (Universität Hannover, 23.11.)

R. Sunyaev: Caltech Physics Colloquium, January 2004

R. Sunyaev: Joint Astrophysical Seminar at ESO-Chile, April 2004

R. Sunyaev: Invited talk, colloquium, ESO-Chile, April, 2004

R. Sunyaev: Three Ooort Professorship colloquia, Leiden, April 2004

R. Sunyaev: Colloquium of Heidelberg Physicists, July 2004

R. Sunyaev: Oort Professor Colloquium, Groningen, September 2004

S.D.M. White: MPI for Solar System Research.

S.D.M. White: Astronomy Department, UC Berkeley.

S.D.M. White: Institute of Astronomy, Granada

S.D.M. White: Institute of Astronomy, Cambridge

4.5.3 Public talks

Börner, G.: – Katholische Akademie, München (27.1.)
– Universität Mainz–Studium Generale (13.6.)
– LMU, München (Reihe ”physik modern” 22.7.)
– Urania Graz (27.10.)

E. Müller: MPG-Hauptversammlung (Stuttgart, 23.6.)

Sunyaev, R.: Public Cosmology Lecture, Torino, March 2004.

5 Personnel

5.1 Scientific staff members

Directors

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

External Scientific Members

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

Staff

M.A. Aloy, A.J. Banday, G. Börner, S. Charlot, B. Ciardi, E. Churazov, L. Dessart, T. Di Matteo, H. Dimmelmeier, K. Dolag (since Oct. 1) K. Dullemond (till Sept. 30), T. Enßlin, M. Gilfanov, B. Groves (since Oct. 15), E. Hayashi (since Oct. 1), H.–T. Janka, G. Kauffmann, K. Kifonidis, C. Kobayashi, F. Kupka, T. Leismann (Febr 1 - April 30), L.X. Li (since Sept. 1), A. Merloni, O. Möller (since Sept. 1), E. Müller, S. Nayakshin, R. Oechslin, P. Popowski, M. Revnivtsev, H. Ritter, F. Röpke, G. Rudnick (till Sept. 30), H. Sandvik (since Oct. 1), S. Sazonov, J. Sheth, (Oct. 15 – Nov. 27)[1] V. Springel, H.C. Spruit, A. Weiss, S. Zaroubi (till Feb. 29).

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), G. De Lucia (since Aug. 1), C. Möller (till Sept. 30), B. Panter (since Oct. 1).

Alexander von Humboldt fellowships

Bifang Liu (till Aug. 30), J. Navarro (since Sept. 1),

EC–fellowships

A. Arbey (till 30.9.), S. Bertone (March 1 - Sept. 30), A. Ferguson, A. Geminale (since April 1), D. Giannios (since Sept. 15), C. Hernandez-Monteagudo, F. Miniati (till June 30), A. Moretti (since April 1), E. M. Rossi (since Oct. 1), A. Pastorello, (since Oct. 1), J.A. Rubiño-Martín (till March 31).

[1] Unfortunately Jatush Sheth was killed in an automobile accident on 27/11/2004 while on a weekend tourist visit to Rome. His loss was greatly mourned by his colleagues at the MPA.

Ph.D. Students

J. Braithwaite (till March 31), R. Buras, L. Gao, M. Gieseler (since June 1), L. Iapichino, M. Jubelgas, T. Leismann (till Jan. 31), M. Obergaulinger (since Sept. 1), C. Pfrommer, D. Sauer, B. M. Schäfer, L. Scheck, W. Schmidt (till March 31), M. Stehle, L. Wang (since Sept. 1.), B. Zink.

IMPRS Ph.D. Students

A. Arcones, K. Basu (till Nov. 30), J. Chluba, D. Croton, J. Cuadra, G. De Lucia (till Jul. 31), D. Docenko (since Sept. 1), A. Gallazzi, G. Hütsi, T. Jaffe, F. Kitaura, A. Kitsikis (since Sept. 1), M. Kitzbichler, A. Marek, P. Mimica, P. Rebusco, M. Righi (since Sept. 1), D. Sijacki, M. Stritzinger, L. Tasca, C. Vogt, A. von der Linden (since Sept. 1), R. Voss, J. Wang (since Sept. 1), F. Xiang (since Sept. 1), S. Zibetti (till Aug. 31).

Diploma students

M. Gieseler (till May 31), Ph. Löwenfeld (since Jan. 15.), F. Meissner (since June 1), B. Müller (since Nov. 1), M. Obergaulinger (till Aug. 30), S. Taubenberger, A. Waelkens (since Oct. 1).

Diploma theses 2004

M. Gieseler: “Nukleosynthese in Typ Ia Supernovae” Technische Universität München.

M. Obergaulinger: “Numerical Simulations of the Gravitational Collapse of Rotating Magnetised Stellar Cores” Technische Universität München.

St. Taubenberger: “ Lightcurves and Spectra of the Unusual Nearby Supernova 2 0 04aw” Technische Universität München.

Ph.D. theses 2004

K. M. Basu: “CMB Observations and the Metal Enrichment History of the Universe” Ludwig-Maximilians-Universität, München.

S. Bertone: “Chemical enrichment of the intergalactic medium by galactic winds, University Degli Studi di Torino, Italy.

J. Braithwaite: “Evolution of strong magnetic fields in stars”, University of Amsterdam.

C. Cramphorn: “Astrophysical Applications of Scattering in Interstellar and Intracluster Gases” Ludwig-Maximilians-Universität, München.

G. De Lucia: “Evolution of Galaxies in Clusters”, Ludwig-Maximilians-Universität, München.

L. Gao: “On the evolution of small scale cosmic structure” Ludwig-Maximilians-Universität, München.

T. Leismann: “Relativistic magnetohydrodynamics simulations of extragalactic jets. Technische Universität München.

P. Mimica: “Numerical Simulations of Blazar Jets and their Non-Thermal Radiation” Ludwig-Maximilians-Universität, München.

W. Schmidt: “Turbulent Thermonuclear Combustion in Degenerate Stars” Technische Universität München.

M. Stehle: “Abundance Tomography of Type Ia Supernovae”. Ludwig-Maximilians-Universität, München.

L. Tasca: “Bulge-to-disk decomposition of large galaxies in the Sloan Digital Sky Survey” Ludwig-Maximilians-Universität, München.

C. Vogt: “Investigations of Faraday Rotation Maps of Extended Radio Sources in order to determine Cluster Magnetic Field Properties” Ludwig-Maximilians-Universität, München.

S. Zibetti: “Diffuse stellar components in galaxies and galaxy clusters” Ludwig-Maximilians-Universität, München.

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
Mario Abadi	Victoria Univ. Canada	4.10. – 25.10.
Tom Abel	Univ. of California, USA	15.11. – 11.12.
Eric Armengaud	IAP Paris	1.5. – 31.5.
Joe Barranco	Univ. of California, USA	29.11. – 24.12.
Lars Bildsten	UC Santa Barbara, USA	5.7. – 30.7.
Sergey Blinnikov	ITEP Moscow, Russia	1.5. – 30.6.
Gustavo Bruzual	CIDA, Venezuela	1.7. – 30.9.
Ivan Černušák	Bratislava, Slovak Republic	28.07.–09.08.
Ruixiang Chang	Shanghai Obs. China	1.8. – 31.12.
Dongni Chen	Shanghai Obs. China	till 30.9.
Xuelei Chen	Shanghai Obs. China	21.1. – 20.2.
Paola Coelho	Univ. de Sao Paulo, Brasilia	since 27.9.
Rupert Croft	Carnegie Mellon Univ.	12.1. – 11.7.
Anna Geminale	INAF, Padova, Italy	1.4. – 30.11.
Violeta Gonzalez	Barcelona, Spain	27.9. – 27.11.
Claire Halliday	Oss. Astr. di Padova, Italy	1.3. – 31.3.
		20.9.–20.12.
Antonio Hernandez	Carracas, Venezuela	08.08.–06.09.
Yonghui Hou	Shanghai Obs. China	since 5.10.
Nail Inogamov	Landau Inst. Moscow, Russia	16.2. – 4.4.
Pascale Jablonka	Obs. de Paris, France	20.5. – 21.6.
Yipeng Jing	Shanghai Obs. China	15.2. –31.3.
Xi Kang	Shanghai Obs. China	till 4.4.
Vladimir Kell´o	Bratislava, Slovak Republic	21.07.–09.08.
Wang Lan	Shanghai Obs. China	4.9. – 30.11.
Guoliang Li	Shanghai Obs. China	till 30.9.
Weipeng Lin	Shanghai Obs. China	22.2 – 15.5.
Zhijian Luo	Shanghai Obs. China	1.9. – 31.12.
Alexander Lutovinov	Space Research Inst. Moscow	5.10 – 15.11.
Paolo Mazzali	Oss. Astr. de Trieste, Italy	10.5. – 18.6.
		12.9. – 30.9.
		since 1.10.
Sergei Molkov	Space Research Inst. Moscow	1.7. – 7.8.
		15.11. – 17.12.
Alessia Moretti	INAF Padova, Italy	since 1.4.
Madhusudhan Nikku	M.I.T., Cambridge, USA	29.7. – 3.9.
Dmitri Nadyozhin	ITEP Moscow, Russia	18.3. – 30.4.
Pierre Ocvirk	Obs. Astr. Strasbourg, France	till 30.9.
Igor Panov	ITEP, Moscow, Russia	1.10.–30.11.
Lorenzo Piovan	Padua, Italy	1.3. – 31.8.
Simone Recchi	Trieste Italy	till 30.6.
Tim Reichard	Baltimore, USA	31.5. – 18.6.
Alberto Rubino-Martin	Inst. de Astr. de Canarias, Spain	23.6. – 29.8.

Name	home institution	Duration of stay at MPA
Laura Sales	Obs. Astr. de Cordoba, Argentina	1.10. – 31.12.
Maurizio Salaris	Liverpool, U.K.	12.7. – 13.8.
Cecilia Scannapieco	Inst. de Astr. Buenos Aires, Argentina	14.2. – 2.3.
		24.8. – 24.11.
Susana Serna	Univ. of Valencia, Spain	12.1. – 12.2.
Nikolai Shakura	Sternberg Astr. Inst. Moscow	1.11. – 30.11.
Shen Shiyin	Shanghai Obs. China	till 31.8.
Pavel Shtykovskii	Space Research Inst. Moscow	20.9. – 10.12.
Miroslav Urban	Bratislava, Slovak Republic	21.06.–09.07.
Dmitri Uzdensky	Kavli Inst. UC Santa Barbara, USA	15.4. – 15.5.
Ronald F. Webbink	Univ. of Ilinois, USA	since 24.9.
Stanford Woosley	UC Santa Cruz, USA	21.3. – 30.4.
Donghai Zhao	Shanghai Obs. China	1.10. – 31.12.