Max-Planck-Institut

für

Astrophysik

Annual Report 2002

Contents

1 General Information **3**
1.1 A brief overview of the MPA . . . 3
1.2 Current MPA facilities . . . 4
1.3 2002 at the MPA . . . 5

2 Scientific Highlights **7**
2.1 The Physics of Type Ia Supernova Explosions: A European Research Training Network 7
2.2 Type Ib supernovae and the explosion mechanism of massive stars . . . 9
2.3 The Growth and Structure of Dark Matter Halos . . . 12
2.4 The Galaxy-Dark Matter Connection . . . 14
2.5 Lessons about Galaxy Formation from 100,000 SDSS Spectra . . . 17
2.6 The history of cosmic star formation . . . 18
2.7 Cosmic Rays from Microquasars . . . 22
2.8 Magnetically powered Gamma-ray Bursts . . . 24

3 Research Activities **27**
3.1 Stellar Physics . . . 27
3.2 Nuclear and Neutrino Astrophysics . . . 29
3.3 Numerical Hydrodynamics . . . 31
3.4 High Energy Astrophysics . . . 33
3.5 Accretion . . . 37
3.6 Interaction of radiation with matter . . . 40
3.7 Galaxy evolution and the Intergalactic Medium . . . 41
3.8 Cosmic structure from z=0 to the Big Bang . . . 45
3.9 Gravitational Lensing . . . 46
3.10 Cosmic Microwave Background Studies . . . 48
3.11 Quantum mechanics of atoms and molecules, astrochemistry . . . 49

4 Publications and Invited Talks **51**
4.1 Publications in Journals . . . 51
4.1.1 Publications that appeared in 2002 . . . 51
4.1.2 Publications accepted in 2002 . . . 60
4.2 Publications in proceedings and monographs . . . 62
4.2.1 Publications in proceedings that appeared in 2002 . . . 62
4.2.2 Publications available as electronic file only . . . 67
4.3 Popular articles and books . . . 68
4.4 Invited talks . . . 68

5 Personnel **71**
5.1 Scientific staff members . . . 71
5.1.1 Staff news . . . 72
5.1.2 Ph.D. theses 2002 . . . 72
5.2 Visiting scientists . . . 73

1 General Information

1.1 A brief overview of the MPA

The Max-Planck-Institut für Astrophysik, usually called the MPA for short, is one of the 80 autonomous research institutes within the Max-Planck-Gesellschaft (MPG). These institutes are primarily devoted to fundamental research. Most of them carry out work in several distinct areas, each led by a senior scientist who is a “Scientific Member” of the MPG. The MPA was founded in 1958 under the direction of Ludwig Biermann. It was an offshoot of the MPI für Physik which at that time had just moved from Göttingen to Munich. In 1979 the decision was made to transfer the headquarters of the European Southern Observatory (ESO) from Geneva to Munich. As part of the resulting reorganization the MPA (then under its second director, Rudolf Kippenhahn) moved to a new site in Garching, just north of the Munich city limits. The new building lies in a research park barely 50 metres from ESO headquarters and is physically connected to the buildings which house the MPI für Extraterrestrische Physik (the “MPE”). This park also contains two other large research institutes, the MPI für Plasmaphysik and the MPI für Quantenoptik, as well as many of the scientific and engineering departments of the Technische Universität München (the “TUM”). In 1996 the institute’s management structure was altered to replace the third director, Simon White, by a board of directors, currently Wolfgang Hillebrandt, Rashid Sunyaev and Simon White, the Managing Directorship rotating every three years. Since 2000 Wolfgang Hillebrandt has acted as Managing Director, and Rashid Sunyaev will take over in 2003.

The MPA was founded specifically as an institute for theoretical astrophysics, intended to foster the development of basic theoretical concepts and effective numerical methods to master the challenges of stellar constitution and evolution, the interstellar medium, its hydrodynamics and magnetic fields, hot plasmas, energetic particles, and the calculation of transition probabilities and cross-sections important for astrophysics. In later years these efforts also complemented the observational and instrumental activities carried out in other Max-Planck institutes.

Very soon this specialization grew to include strengths in numerical astrophysics which are unparalleled elsewhere in the world in institutions of similar size. These traditions have been strongly promoted in recent years while diversifying to include a wide range of data analysis activities. Resources are specifically channeled into areas where new instrumental or computational capabilities are expected to lead to rapid developments. Current concentrations of interest 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 of the earlier concentrations of interest, for example, solar and solar system physics, the quantum chemistry of astrophysical molecules, and General Relativity have been very substantially reduced over the last decade.

Although MPA scientists are mainly working on problems in theoretical astrophysics, they also participate in a number of observational projects. The European microwave satellite Planck, scheduled for launch in early 2007, is being planned and will be operated by a consortium of groups and institutions across Europe. The MPA represents Germany in this consortium. Specifically, part of the software system required for Planck data processing and information exchange within the consortium will be developed at MPA, the development and use of a data simulation pipeline for Planck is coordinated by MPA, and MPA will be the place where the final data products of the Planck mission will be prepared for release, documented, and finally released to the astronomical community. MPA is also involved in the overall management and coordination of the data-reduction software required for the mission, and in several of its scientific aspects.

In 2000, MPA became a partner of the “Sloan Digital Sky Survey” (SDSS) project. This survey will map one-quarter of the entire sky, determining the positions, brightnesses and colours of more than 100 million celestial objects. It will also obtain spectra and so measure distances to more than a million galaxies and quasars. After more than a decade of planning, building, and testing, the Sloan Digital Sky Survey was officially dedicated in 2000; by the end of 2002 about 40% of the survey had been completed.

Finally, on October 17, 2002, the European gamma-ray mission *Integral* was successfully launched on a Russian Proton rocket, addressing, among others, questions related to compact objects, stellar nucleosynthesis, the Galactic center and structure, and extragalactic astronomy. These scientific goals are attained by fine spectroscopy with imaging and accurate positioning of celestial sources of gamma-ray emission. The MPA is involved in this mission through Rashid Sunyaev and his affiliation with IKI in Moscow, and will have access to a significant fraction of the data.

While most MPA research addresses theoretical issues, the neighboring institutes provide complementary expertise and there are many collaborative projects with them. Major research programmes at MPE are concerned with instrumental and observational aspects of infrared, X-ray and gamma-ray astronomy, together with supporting theoretical work, while ESO carries out a broad range of instrumental and observational projects in the optical and infra-red making use, among other telescopes, of the VLT, the largest optical telescope in the world.

At any given time the MPA has about 40 scientists working on long-term positions at post-doctoral level and above, up to 15 foreign visitors brought in for periods of varying length under a vigorous visitor programme, and more than 30 graduate students. The students are mostly enrolled for degrees in one of the two large universities in Munich, the TUM and the Ludwig-Maximilian-Universität (LMU). A number of the senior staff at MPA have teaching affiliations with one or other of these universities. Ties with the the universities are also established via joint research projects, such as the special research program ("Sonderforschungsbereich") on particle astrophysics, which also includes the MPI für Physik.

As a major initiative designed to further enhance the visibility of astronomy in Garching/Munich and to increase collaboration between the different institutions an *International Max-Planck Research School on Astrophysics* was founded in 2000 on an initiative of the Max-Planck Society. It is open for students from all countries world wide. The school intends to attract highly-qualified and motivated young scientists who aim for a graduate degree in physics and astronomy. The first group of students arrived in October 2001, followed by a second group in fall of 2002. They will obtain their degrees either from the LMU or from the TU.

Since 1996 the MPA is part of EARA, a European Association for Research in Astronomy which links it to the Institut d'Astrophysique de Paris, the Leiden Observatory, the Institute of Astronomy, Cambridge, and the Instituto Astrofisico de Canarias in a programme dedicated to fostering inter-European research collaborations. Such collaborations are also supported by membership in a number of EC-funded networks, some of which are coordinated by the MPA, dealing with the physics of the intergalactic medium, the cosmic microwave background, gravitational lensing, and accretion onto black holes, compact stars and protostars, type Ia supernova explosions, and gamma-ray bursts.

Finally, in 1999, a proposal to establish a Max-Planck Cosmology Group at the the Shanghai observatory was realized. The group has approximately 8 to 10 researchers, mainly young postdocs and graduate students, and a very active exchange between that group and the MPA has continued in the following years.

1.2 Current MPA facilities

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

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 and microfilm reader/printer, 2 X-terminals, 4 PCs, 2 laser printers and a fax machine.

An urgent need for more shelf space was alleviated in 2002. After the completion of the new MPE building in 2000, the library acquired a large archive room in the basement of the new MPE building and also obtained additional space in the new MPA basement. This room currently provides about 400 meters of shelf space and holds the MPA/MPE preprint and reprint archives, the observatory publications and the preprints. The available space in the basement will allow additional shelf space of up to 400 meters to be installed if necessary. Because the preprint and reprint archives and the observatory publications have moved, new space has become available in the main library room. This section has been redecorated and is used as office space for the librarians. A user help desk has also been installed.

The MPA has always placed considerable emphasis on computational astrophysics and has therefore ensured access to forefront computing facilities. The MPA-computer centre consists of about 10 powerful workstations (IBM, SGI and SUN, 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. All users have free access to all resources. User access is mainly through desktop PCs (with Linux as the operating system), which are also administered by the system managers, and, to a smaller extent, through X-window terminals. 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. Special requirements (GB-sized memory; very large disk space; specialized hardware for N-body simulations – currently a set of five GRAPE 3A +boards and front-end workstation) are met as well. The MPA also supports a fully equipped and modern video-conferenceing facility.

MPA scientists also have access to the RZG, the main computer centre of the MPG, and they are among the top users of the facilities there. The most important resources provided by the RZG are parallel and vector supercomputers, TByte mass storage facilities, and the gateway to GWIN/Internet. The exchange of expert knowledge with RZG staff is also very valuable. Fast network connection to the RZG is required and the connection to RZG has recently be upgraded to Gigabit-Ethernet. An AFS file system ensures that the transfer of data among the MPA machines and from MPA to the RZG is now almost transparent to the user. Recently, a LINUX-PC-cluster was bought jointly with the RZG and other MPIs to satisfy increasing needs for cheap, but effective CPU-resources.

Further computing power is available at a second Max-Planck Society computer centre which is operated jointly with the University of Göttingen, and provides additional access to large parallel machines. Finally, MPA scientists can apply (and have applied successfully) for time on the tera-flop tera-byte supercomputer Hitachi SR8000 of the Leibnitz-Rechenzentrum in Munich.

1.3 2002 at the MPA

Everyone at MPA was very happy when the news broke that the Nobel Prize in Physics for 2002 had been awarded in part to Riccardo Giacconi for his ground-breaking efforts in establishing X-ray astronomy. Riccardo was the Director General of ESO (and so our direct neighbour) for most of the 1990's. In 1999 he was appointed an External Scientific Member of MPA so that he can return to his Garching scientific collaborations without treading on the toes of his ESO successor.

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 2002 by Ramesh Narayan from the Harvard-Smithsonian Center for Astrophysics. The subject of his lectures was "Accretion Flows", and this series of superb talks consistently filled the

MPA lecture theatre to its limits.

Another major event in 2002 was the visit of the MPA Fachbeirat (the institute's Visiting Committee) from June 17 through 19. All committee members (Catherine Cesarsky (Chair), Claes Fransson, Ramesh Narayan, Ken'ichi Nomoto, Bohdan Paczynski, and Dieter Reimers) were able to attend the meeting, together with MPG Vice-President Kurt Mehlhorn; they were apparently very pleased by what they saw and heard.

Immediately after the Fachbeirat, the MPA's Board of Trustees also visited the institute. This external committee, which is joint with the MPE, is concerned with interactions between the two institutes and other sectors of society, principally universities, industry and government.

In the first meeting of its type, members of the four Max-Planck-Institutes on the Garching Campus (including the MPI's for Plasma Physics and Quantum Optics) met the Mayor and the City Council of Garching in an informal manner to discuss problems of joint interest, in particular, the housing of young researchers and students who come to the institutes as short or long term visitors. Such accommodation has become increasingly difficult to locate in recent years.

As in every year several local workshops and conferences were organized by MPA scientists in 2002. These including a MPA/ESO/MPE Conference on "From Twilight to Highlight: The Physics of Supernovae", which took place in Garching from July 29 through 31, workshops on "Nuclear Astrophysics" and "(Alternative) Dark Matter, Cosmic Structure, and the Early Universe" at the Ringberg Castle in February and April, respectively, and the CMBNet Ringberg Meeting and Mid Term Review "CMB & Cosmology: Where Are We?" also at Ringberg in December.

MPA's national and international cooperations and collaborations continued to flourish in 2002. A European COST project "Knowledge Exploration in Science and Technology" chaired by Geerd H. F. Diercksen took shape in 2002, a new RTN on "The Physics of Type Ia Supernova Explosions", coordinated by Wolfgang Hillebrandt, began its work in July, just prior to the supernova conference, and the MPA high-energy astrophysics group, led by Rashid Sunyaev, is participating in a new RTN on "Gamma-ray Bursts". A large international consortium involving several MPA scientists and with Simon White as PI has been carrying out an ESO Large Programme "The ESO Distant Cluster Survey". The consortium obtained substantial time on the VLT and NTT telescopes in 2002 and its observational programme is now 60% complete.

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 2002. As in previous years, a serious problem has been the quest for housing for such guests, as well as for new postdocs, and graduate students. The plans of the MPG to build a guest-house with 80 apartments on campus, mentioned already in the last report, still did not materialize because strong objections raised by the City of Garching could not be overcome. However, we will not give up: the joint discussions with the town council still give room for hope!

In 2002 the partner group at Shanghai observatory was evaluated after two years of operation by a visiting committe consisting of J.Silk(Oxford), K.Sato(Tokyo), Chen Jiansheng(Beijing), S.White (MPA), and Zhao Junliang(Shanghai). The president of the MPG H. Markl was also present. The report was very positive, and fully in support of continuing for the next 3 years.

Several visitors from Shanghai to the MPA, a number of joint publications, and a conference on cosmology in Beijing in September 2002 organised in part by the group demonstrated that it has become an active research center in China.

Finally in 2002, construction work for the subway connecting the City of Munich to Garching finally reached the institutes on campus. The present plans are to finish construction work by 2006/7. Until then everyone commuting between Munich and Garching will have to live with many inconveniences.

2 Scientific Highlights

2.1 The Physics of Type Ia Supernova Explosions: A European Research Training Network

Some stars end their lives with a powerful explosion which can destroy them completely. Usually, these explosions are accompanied by a dramatic increase of the light output from what was the star. If one such event occurs in our Milky Way Galaxy, it can be observed even with the naked eye during day time. Only a few such events were ever so bright, and they were called 'novae' ('new' stars) by ancient astronomers.

We now differentiate between mild (in relative terms!) surface explosions (Novae) and the very bright explosions that mark the sudden end of a star's life, and call the latter, rather un-inventively perhaps, 'Supernovae'. This is however a well-deserved name. For a few weeks, a single supernova (SN) can emit almost as much light as a whole galaxy, even though a galaxy contains about a billion stars (Fig. 2.1).

When looked at closely, SNe are not all the same. We now know that their properties depend on the properties of the star that exploded. The one common feature is that their light output depends on the synthesis of ^{56}Ni in the nuclear reactions that accompany or lead to the explosion. ^{56}Ni is an unstable nucleus, and it decays into ^{56}Co, which then decays into stable ^{56}Fe. These decays are accompanied by the emission of gamma-rays, which eventually become the supernova light.

The spectra of the brightest of them, commonly called Type Ia SNe, show strong lines of Fe (Fig. 2.2), confirming that they produce much ^{56}Ni. Lines of intermediate-mass elements such as Si and Ca are also present, while the lighter elements, H and He, which are the basic constituents of stars, are completely absent from the spectra. Actually, this is the defining property of SNe Ia. This is commonly taken to suggest that SNe Ia are the results of the explosion of very old stars, which have lost their outer, H-rich envelopes, and have evolved to the state of White Dwarfs. These are essentially

Figure 2.1: Supernova SN 2002bo in NGC 3190.This supernova was discovered on March 9, 2002, and is visible as bright spot on top of the equatorial dust band of its host galaxy. This galaxy is a normal spiral galaxy, seen nearly edge-on, at a distance of about 20 million light years. This supernova was detected very early, about 16 days before maximum, and then monitored on an almost daily basis. The picture was taken with the Asiago-telescope in VRI-bands on March 12.

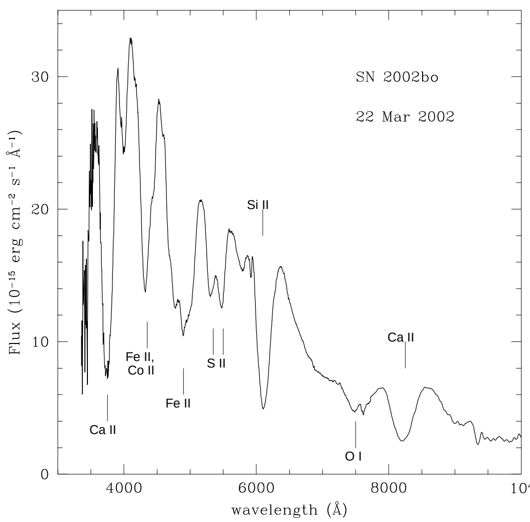

Figure 2.2: Spectrum of SN 2002bo in optical wave bands, taken with the Asiago telescope on March 22. Several lines are labeled with the atom that causes the absorption. The most prominent lines are those of singly ionized silicon (Si II), iron (Fe II), calcium (Ca II), and sulfur (S II). From their position and shape one can infer the velocity and abundance of these chemical elements in the supernova ejecta.

the inner cores of relatively low-mass stars, which are left behind to cool after the star has exhausted its energy source.

It is fortunate that the brightest among all SNe also appear to be the most homogeneous group: their light curves are all very similar, and so are their spectra at all phases. So, in principle, they could be very powerful tools to measure cosmic distances and they have in fact been used for this purpose.

Clearly, if the luminosity of SNe Ia is roughly constant, we should easily be able to determine their distances comparing the observed flux with the flux at the source. Because they are so bright, SNe Ia can be used to probe very large distances, so that not only can we determine the size of the local universe, but also question the shape and nature of the universe as a whole, which is known as Cosmology.

Unfortunately, things are not that easy, and all SNe Ia are not exactly equal. They can however be placed on a relative brightness scale based on some small variations of the shapes of their light curves. Using this method, astronomers have been able to measure distances for SNe Ia out to a redshift of about 1.

The surprising result was that the universe seems to be accelerating its expansion, which is the opposite of what the most favoured cosmological theories predicted. This result has important consequences for all of physics, because the acceleration would be caused by either a cosmological constant (a term in the cosmological equations initially introduced by Einstein to allow for a static Universe in his theory of gravitation) or by a yet unknown form of 'dark energy' with negative pressure.

Currently, our understanding of the supernova physics is the major systematic uncertainty of this result. The distant supernovae exploded at a time when our solar system was just forming. There is no guarantee that these distant explosions are the same as the nearby ones on which the empirical relations are based. Only once we understand the physics of the explosions will we be able to assess whether they can be used as distance indicators reliably, and whether we have to search for new physics beyond the standard models of particle physics and cosmology.

In order to improve our knowledge of these key objects through an advance in both observations and modelling, a group of European astronomers led by Wolfgang Hillebrandt at MPA has organized as a team and proposed for a Research Training Network (RTN), which has been funded by the EU and has recently started its work. The idea is that accurate observations and modelling of a sufficiently large sample of relatively nearby SNe is the only way that we can presently follow to understand their nature and the causes of their range of properties.

Participants to the Network include German, British, Italian, French, Spanish and Swedish institutes. Researchers involved have begun the programme by successfully applying for joint observing time on most major European telescopes, thus maximizing and optimizing the amount of telescope time allocated for SN studies.

In the short time since its beginning, the RTN, also named 'European Supernova Collaboration' (ESC) has already collected very accurate data on two nearby SNe Ia, SNe 2002bo and 2002er. Both of these SNe appear to be rather standard. A spectrum of SN 2002bo near maximum is shown in Fig.2.2. It is possible to identify many of the lines in the spectrum, which is dominated by elements such as Fe, Si, S, Ca. The photometry of SN 2002er (Fig.2.3) is perhaps the most accurate coverage of the evolution of a SN Ia available to date. It is through data such as these that we can hope to make significant progress in our understanding of Type Ia SNe. We expect that the elements visible in the spectrum change as the SN evolves. The

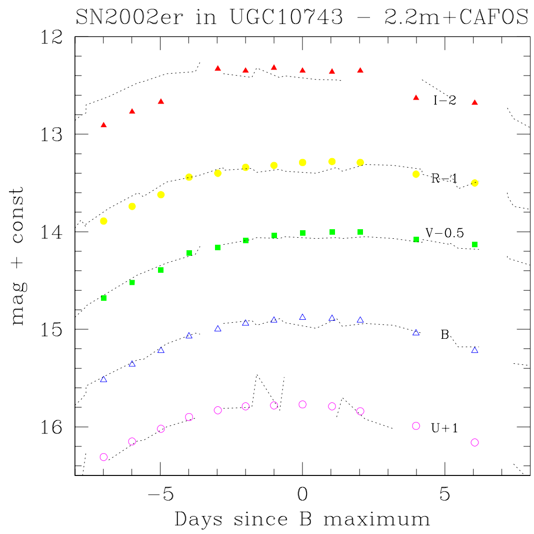

Figure 2.3: ightcurves of SN 2002er in different wave bands. Shown are the luminosity of this supernova in the U, B, V, R, and I bands (going from violet and blue to red colours) from its discovery until 6 days after maximum light. The dashed lines give, for comparison, the data of the few other well-monitored supernova (SN 1994D). The data were taken with the 2.2m telescope at Calar Alto in Spain.

material ejected with the SN thins out with time, as it expands, and deeper and deeper layers are therefore revealed. The structure of these layers can show how SNe Ia explode, something we only have indirect and vague knowledge on so far.

At the same time, advances in multi-dimensional modelling of thermonuclear explosions of White Dwarfs carried out at MPA will give accurate predictions, through the use of radiative transfer codes, of the observational consequences of these theoretical models. The RTN is in an ideal position to make a decisive step in our knowledge, and will be ready to treat observations of distant SNe Ia as soon as they will be of a quality comparable to that of nearby ones. (P. Mazzali, W. Hillebrandt)

2.2 Type Ib supernovae and the explosion mechanism of massive stars

Roughly every second, somewhere in the universe a supernova explosion terminates the life of an evolved star. The violence of the processes that are hereby involved is extraordinary, and hardly comprehensible in human terms. Within only a few seconds, a typical supernova releases about 10^{51} erg as kinetic and internal energy of expanding stellar debris. The same amount of energy would be set free if one could ignite 10^{27} of the frightening 20 Mt hydrogen bombs that are stored in terrestrial nuclear arsenals. Equivalently, to unleash this much energy, the earth would have to be struck by 2×10^{15} asteroids of the Pallas/Vesta class with a diameter of 500 km, every one of them much more destructive than the 10 km asteroid that led to the extinction of the dinosaurs.

The importance of supernovae reaches far beyond the different branches of astrophysics. It is under these extreme conditions that substantial amounts of heavy elements are produced and together with the products of the star's previous hydrostatic burning phases are expelled to interstellar space, thereby enriching the interstellar medium with elements heavier than helium, the prerequisites of life.

Observational astronomers divide supernovae into two main types. In Type I explosions, hydrogen, the most abundant element in the universe, is absent, while in the spectra of Type II supernovae it is clearly present. Depending on the strength of the lines of other elements, Type I supernovae are further subdivided into Types Ia, Ib, and Ic. Type Ib supernovae, for instance, show very strong absorption lines of neutral helium in addition to being poor in hydrogen. By its nature, this classification emphasizes only differences in the outermost layers (i.e. the atmospheres) of the supernovae. It does not necessarily imply differences in the mechanisms that are at work in the deep interior of the star and cause the explosion. Therefore, theoretical astrophysicists prefer to distinguish supernovae according to their energy source. It turns out that this depends on the mass and on the type of the star that explodes. The explosion of white dwarfs, i.e. the compact remnants of low-mass stars, gives rise to supernovae of Type Ia. These draw their energy from the fusion of the light nuclei carbon and oxygen to heavier elements like nickel and iron. Hence, they can be compared to giant thermonuclear bombs. The explosion of massive stars on the other hand produces supernovae of Types II, Ic, and Ib, to which we will focus in the following. In these cases, the explosion energy stems from gravitational collapse of the stellar core.

Despite decades of intense reasearch, the complex mechanisms that lead to the explosion of massive stars are still only poorly understood. There is general agreement between astrophysicists, that about 100 times as much energy as is observed in the ejecta, is released when the inner stellar iron core collapses to a neutron star. However, most of this energy is carried away by neutrinos. Hence, it is not directly available to transform the infall of the layers surrounding the collapsed core to an explosion of the mantle and envelope of the star. The simple hydrodynamic mechanism in which a shock wave forms after core collapse and propagates outward, reversing the infall and accelerating the matter outwards, has been shown to fail. The shock looses too much energy in breaking up iron nuclei into neutrons, protons, and alpha particles while propagating through the outer iron core. Within only a few milliseconds it stalls. If this state persists, the entire mantle and envelope of the star would collapse onto the neutron star and the result would be a black hole. Heating by the abundantly available neutrinos has been suggested and studied extensively as a means to revive the shock. However, since the neutrinos interact only weakly with the matter behind the shock, the efficiency of the heating is also weak.

The hopes of supernova theorists currently rest on mixing processes that develop in the neutrino-heated region between the neutron star and the shock. Comparable to the situation in a pot of boiling water heated on a kitchen stove, bubbles of low-density material form in the heating region and rise toward the shock. Between them, colder material falls inwards toward the heating region and after absorbing energy from the neutrinos rises itself toward the shock. This mechanism greatly enhances the efficiency of neutrino heating. Since the heated matter has a higher pressure it pushes the shock outwards. Eventually the shock regains its strength and leaves the iron core, accelerating the outer stellar layers and giving rise to the supernova.

So far we have described a scenario that rests almost exclusively on sophisticated hydrodynamic simulations that follow the events within the first second after core collapse. However, there exists also significant observational evidence that such mixing does indeed occur during the explosion. Especially interesting in this respect are the strong helium lines of Type Ib supernovae. This supernova type is thought to originate from originally massive stars, that have lost their entire hydrogen-rich envelopes due to stellar winds or due to interaction with a nearby companion star. The layers below the (lost) hydrogen envelope consist predominantly of helium. Hence, the appearance of helium in the atmospheres of Type Ib supernovae was actually expected. What was not expected, however, when the first Type Ib supernova spectra were taken in the 1980's, was the strength of the helium lines. The atomic levels from which these lines originate lie more than 20 eV above the ground state. Even in the atmospheres of supernovae, however, thermal energies are hardly larger than a few eV. To excite as much neutral helium as was required to reproduce the strength of the lines in model atmospheres, one had to postulate an additional, non-thermal energy source.

There is only one such energy source conceivable, namely radioactive decay of unstable nuclei like ^{56}Ni, that are synthesized due to the high temperatures close to the collapsed core during the early phases of the explosion. To affect the spectra, however, the nickel needs to be transported all the way from the innermost zones of the ejecta close to the atmosphere. In spectral modeling studies of Type Ib supernovae it was therefore *assumed* that strong mixing would occur during the explosion. Models computed with this assumption indeed showed very good agreement to observed spectra. For the first time, calculations of the supernova group at MPA have recently succeeded in demonstrating that the amount of mixing deduced from observations can actually be obtained as a natural consequence of the hydrodynamic processes that occur during and after the shock revival phase. This result is important because it does not only help to explain the observations. It is the most direct existing hint that significant mixing accompanies the revival of the shock wave during the explosion of massive stars. It thus suggests that our basic understanding of the explosion mechanism is correct.

Actually there are several mixing episodes occuring during and after shock-revival. The calculations show that first the shock wave is accelerated outward as a result of neutrino-heating, assisted by the mixing of hot and cold material. The bubbles forming due to neutrino heating follow the shock wave in its motion out of the iron core until the shock has also overrun the layers in which the chemical composition changes from silicon to oxygen nuclei. In these layers, an unstable configuration develops that resembles the following kitchen experiment. Trying to pour some water into a cup of oil one quickly finds that the denser water will always fall to the bottom while the lighter oil will stay on top. If one is very careful with pouring in the water, it is possible to obtain a layer of water on top of the oil. However, a small perturbation of this layer will immediately cause strong mixing and an overturn of the two fluids. The water will sink to the bottom and the oil will rise to the top. The water-oil layer is unstable in a

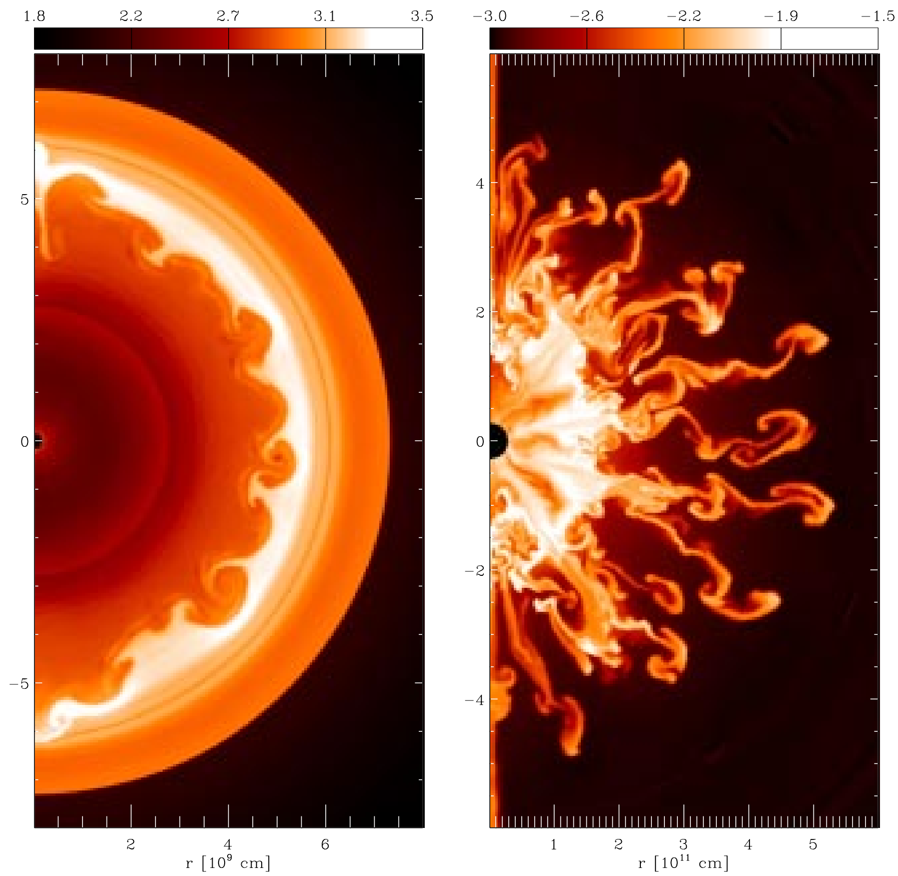

Figure 2.4: Density structures of a Type Ib supernova model 4 s (left) and 1500 s (right) after the collapse of the iron core. The shock wave is visible as the outermost orange discontinuity in the left plot. Note the bubbles of low-density material that was heated by neutrinos. Just outside the bubbles (beyond the outer edge of the dense, white-coloured material) lie the unstable layers where the composition changes from silicon to oxygen. The result of the interaction between the bubbles and the unstable layers is the formation of fingers which mix material from the inner ejecta outwards (right panel).

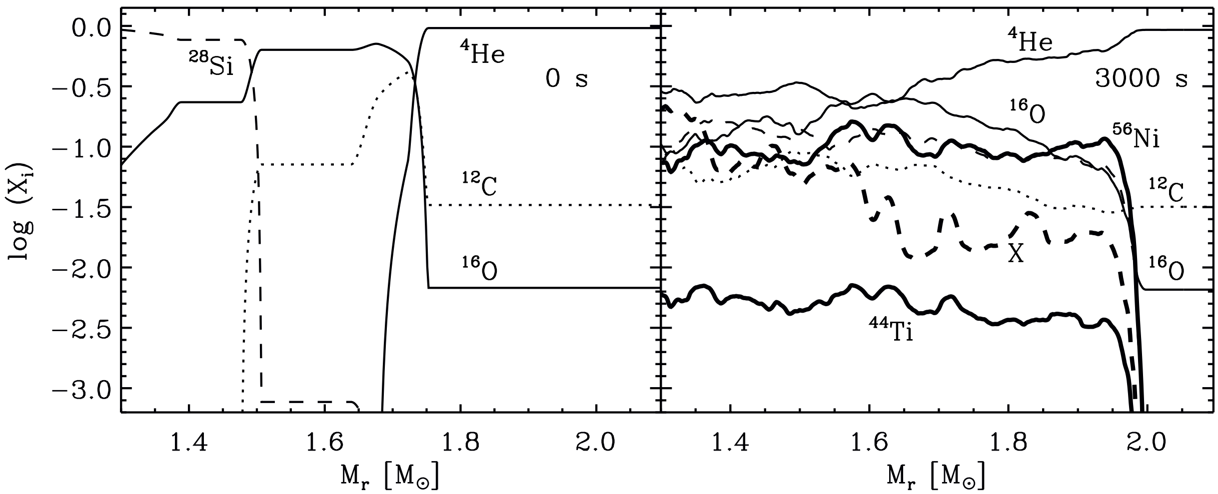

Figure 2.5: Left: Composition in a star exterior to the iron core prior to its explosion as a Type Ib supernova. The composition is given as a function of the enclosed mass. Right: Composition 3000 s after core collapse. Note that ^{56}Ni is mixed throughout the inner $2\,M_\odot$ of the ejecta. Without the mixing it would be confined to the mass range between $1.27\,M_\odot$ and $1.37\,M_\odot$. Observations, however, indicate that, for the stellar model considered here, ^{56}Ni needs to be mixed at least as far out as $2\,M_\odot$.

gravitational field. Similarly, the layers of varying composition in the ejecta of a supernova are unstable (although gravity is not the relevant factor in this case); they also develop strong mixing if perturbed appreciably. But where do the perturbations in a supernova come from? This question remained unanswered since researchers started to compute multi-dimensional hydrodynamic models of supernovae more than a decade ago. The calculations performed at MPA show that it is the bubbles of neutrino-heated gas, which perturb the unstable layers (Fig. 2.4). Moreover, the strength of the perturbation is apparently of the right magnitude to induce the amount of mixing of radioactive nuclei that is required to explain the helium line observations (Fig. 2.5). We are thus confident that supernova models based on neutrino heating are on the right track, although not all problems have been resolved yet in these calculations. (K. Kifonidis, T. Plewa, H.-Th. Janka and E. Müller)

2.3 The Growth and Structure of Dark Matter Halos

One of the great aims of modern cosmologists is to understand the formation of structure in the universe as the work of gravity on initially small inhomogeneities in an otherwise smooth matter distribution. The galaxies, clusters of galaxies, and even larger structures should all be seen as the end products of an evolutionary process, where in the course of time regions with a density slightly higher than the background density lag more and more behind the general expansion, until their density contrast has grown so much that they completely separate and collapse. This general picture is supported by various astronomical observations– the CMB anisotropies for example measure the small initial fluctuations. It seems, however, to work only for a cosmic medium which consists mainly (up to or even higher than 90%) of dark matter, particles interacting mainly by gravity and very weakly otherwise. The collapsed clumps of dark matter, the "dark matter halos", provide the places, where the normal, baryonic matter condenses, cools, and transforms into galaxies and clusters. Obviously then, the spatial distribution and the shape of the dark matter halos is an important ingredient in models of galaxy formation.

It has been found from numerical simulations that the structure of dark matter halos can be described by a simple formula for the density profile. For any given halo an acceptable fit is obtained, if two parameters are adjusted appropriately: A characteristic radius r_s and the density ρ_s at that radius are sufficient. This is quite remarkable in view of the large range of halo masses and widely different cosmic times when halos are considered in simulations. How can physical processes give rise

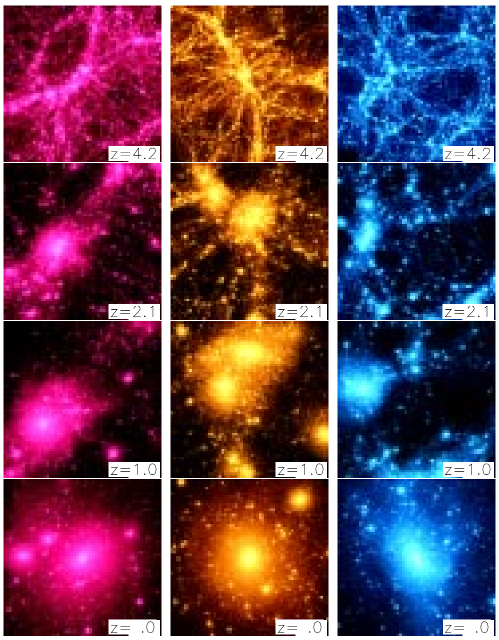

Figure 2.6: The images of dark matter halos as they evolve with cosmic time. The time sequences from top to bottom are labelled by the redshift z which measures the relative change in size of the universe. $z = 0$ corresponds to the present time, and $z = 4.2$ to an early time, when the universe was just one fifth its present size. In all panels the density of the dark matter particles is shown, and brighter colours correspond to higher density. From left to right the halo mass is that of a galaxy, a group of galaxies, and a cluster,respectively. The early distribution evolves gradually into a final relaxed configuration. These high resolution simulations were computed by Yipeng Jing of the MPA's partner group at Shanghai University making use of the supercomputer facilities at Tokyo University.

to such a structure? A step towards an answer has been made in an analysis carried out by scientists from the MPA and from the partner group of the MPA at Shanghai Observatory.

Within the context of a large set of cosmic N-body simulations the structure and evolution history of five selected halos was followed. The simulations have been carried out by Yipeng Jing from Shanghai observatory. In a first step the halos were selected from a cosmological simulation, and then resimulated with a much higher resolution in the dense halo regions. Thus masses larger than $2.5 \times 10^7 M_\odot$ can be resolved, and this allows to follow back in time the merging and accretion that finally give rise to the halos with mass $\simeq 10^{13} M_\odot$. Each final halo contains about 400 000 particles, and their merging is followed from an early time, when the cosmic redshift was 13.6 (i.e. the universe was about 15 times smaller than it is now.

The detailed analysis showed that these particles come together in two distinct stages. In a first phase of fast accretion the mass increases rapidly, clumps of dark matter particles merge more quickly than the previously assembled material can settle down. Then a transition to a second phase of slow accretion occurs, the accreted material can settle into an equilibrium configuration, but the total mass still increases substantially by a factor of 3 to 10. This transition is especially pronounced for the mass M_s within the inner radius r_s. In figure 2.7 the mass growth with cosmic time is shown, and clearly demonstrates this behaviour. The change from fast to slow accretion clearly marks a characteristic time in the evolution of a halo. The inner radius r_s also changes rapidly during the fast accretion phase, and only gradually afterwards. The circular velocities at the halo radius and at r_s are almost constant during the slow accretion phase, after they have increased very fast initially (see figure 2.8). This suggests that the gravitational potential well associated with a halo is built up mainly during the early phase of rapid growth.

The turn-over point is at a redshift of 2 for the five halos considered (i.e. the universe is 3 times smaller than at present).

This behaviour of the accreting dark matter particles is responsible for a tight dependence of the mass M_s on the inner radius r_s. The discovery of this relation is the main result of the work described here. A simple functional form ties these two quantities together, and describes how the structure of a halo can be determined from its mass. In fact, the time evolution of the structure of a halo can be predicted from the history of its mass

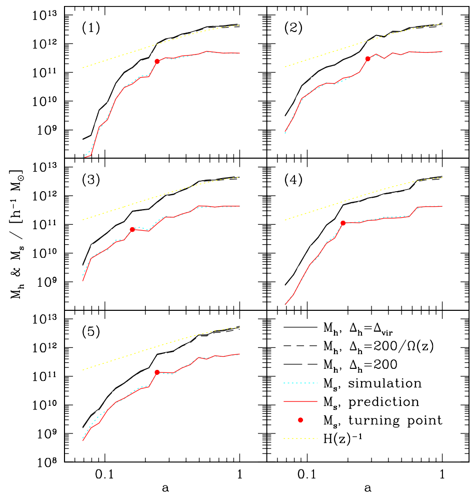

Figure 2.7: The mass of the main progenitor for each of the 5 high resolution halos as it changes withe cosmic time is shown (a is a scale factor, giving the size of the universe at an early time in units of its present time).The filled circle in each panel marks the transition between fast and slow accretion. The halo mass M_h can be defined in different ways which depend on the overdensity Δ_h chosen. Three different prescriptions are used here, but the difference among them is negligible. In each panel the evolution of the mass M_s within the characteristic radius r_s is shown. The dotted line is the direct determination from the simulation, the solid line shows the model prediction. Note how closely the model predictions follow the simulation results. The change in mass is markedly different between the fast and slow accretion phase. In the slow accretion phase M_h evolves on time scales given by the cosmic expansion rate H^{-1}.

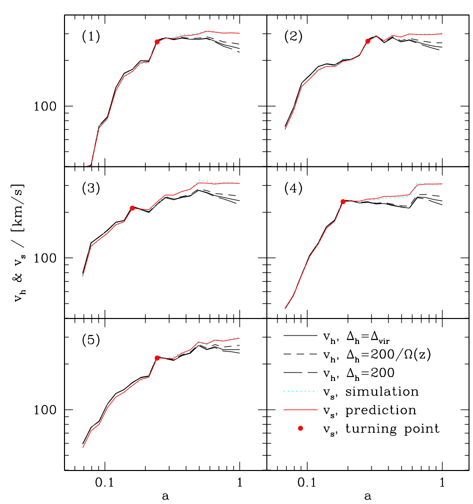

Figure 2.8: The evolution of the halo circular velocities at the outer radius of the halo v_h, and at the inner radius v_s is displayed. Note the pronounced difference between the fast and slow accretion phase.

accretion. Herein lies a big advantage, because the calculation of the mass evolution does not require as high resolution simulations as the computation of the structure. Even semi-analytic approaches have sufficient accuracy.

In figures 2.7 and 2.8 mass and circular velocities obtained from the simulations are plotted together with the same quantities, as they are predicted from the calibrated relation between r_s and M_s. The model predictions agree perfectly well with the simulation results.

It must be checked, of course, whether this result holds for other halos besides the 5 thoroughly analyzed ones. Therefore many other simulations and a wide range of halo masses have been tested. The relation gives an excellent description of halo structure, and even the mean value and the dispersion of the structural quantities of halos of the same mass agree perfectly with the simulations.

It seems that this approach can eventually lead to an explanation of the halo structure. At least the original fitting formula finds a presentation in quantities which are very useful for a physical interpretation and for model building.

Many interesting consequences turn up. So, for example, the halo structure at high redshifts can be found just from the mass accretion histories without the need for high resolution simulations.

Definitely there are implications for the models of galaxy formation. In the standard picture galaxies form, when the gas contained in dark matter halos cools and condenses. In the fast accretion phase it is impossible to establish equilibrium in a mass clump, before it merges with another one. The gas in these clumps cannot settle into a thin disk, but is strongly disturbed, compressed, and heated by the mergers. Thus the fast accretion phase may correspond to a stage of active star formation in the history of a galaxy, and the formation of a galactic disk may occur later within the slow accretion phase. (G. Börner).

2.4 The Galaxy-Dark Matter Connection

Currently popular cosmologies consider a Universe that consists of baryonic matter, cold dark matter (CDM) and some form of vacuum energy or quintessence. In the standard paradigm, small fluctuations in the matter density, imprinted during an early epoch of inflation, are considered as the seeds for structure formation. Gravitational instability causes these density perturbations to grow until they collapse to form virialized dark matter halos. The baryonic gas associated with these perturbations gets shock heated to the virial temperature, cools, and accumulates at the halo center where star formation transforms the cold gas into a luminous galaxy. Galaxies and dark matter halos are therefore intimately linked together.

One of the ultimate challenges in astrophysics is to obtain a detailed understanding of how galaxies with different properties occupy halos of different masses. This "galaxy-dark matter connection" is an imprint of various complicated physical processes related to galaxy formation, such as gas cooling, star formation, merging, tidal stripping and heating, and a variety of feedback processes. Unfortunately, the majority of these physical processes is poorly understood, making it extremely difficult to address the galaxy-dark matter connection using ab initio models for galaxy formation.

A group of researchers at MPA, consisting of Frank van den Bosch, Houjun Mo, and Xiaohu Yang (visiting MPA from the Center for Astrophysics, Hefei, China), has introduced a new method to link galaxies to their dark matter halos which completely sidesteps the uncertainties related to how galaxies form. This technique assigns, in a statistical manner, galaxies of given luminosities to halos of given mass using only information regarding the observed clustering properties of galaxies. Since halos of different masses are clustered differently, there is only a limited amount of possibilities by which one can distribute galaxies over dark matter halos such that their clustering properties are consistent with observations. We have introduced what we call the Conditional Luminosity Function, which gives the average number of galaxies with luminosity L that reside in a halo of mass M. This function establishes a direct link between the halo mass function and the galaxy luminosity function, yields the average mass-to-light ratios as function of halo mass, and provides useful insights into the luminosity dependence of the so-called galaxy bias.

Using data from the 2-degree Field Galaxy Redshift Survey (2dFGRS) on the luminosity and type dependence of the clustering strength of galaxies, we were able to obtain conditional luminosity functions for both early- and late-type galaxies that are in perfect agreement with the data and well constrained. They indicate that the average halo mass-to-light ratio reaches a minimum of $\langle M/L_B \rangle \sim 100 h M_\odot/L_\odot$ for halos with $M \simeq 3 \times 10^{11} h^{-1} M_\odot$ (i.e., these halos are the most efficient in producing galaxy light). Towards lower masses $\langle M/L_B \rangle$ increases rapidly and matching the faint end slope of the galaxy luminosity function requires that halos with $M < 10^{10} h^{-1} M_\odot$ are virtually devoid of galaxies. The fact that early-type galaxies are more strongly clustered than late-type galaxies implies that the fraction of late-type galaxies is a strongly declining function of halo mass. A comparison of the halo occupation statistics thus derived with predictions from semi-analytical models for galaxy formation reveals excellent agreement as long as the models are tuned to reproduce the galaxy luminosity function. This indicates that our conditional luminosity function technique has recovered a statistical description of how galaxies populate dark matter halos which is not only in perfect agreement with the data, but which in addition fits nicely within the standard framework for galaxy formation.

Since the statistical properties of dark matter halos are cosmology dependent, this technique can also be used to constrain cosmological parameters. We have used the same 2dFGRS data to constrain the matter density Ω_m and the linear amplitude of mass fluctuations σ_8. Since the conditional luminosity function yields direct measures of the luminosity dependent galaxy bias, b, we can break the degeneracy between bias and σ_8 which has hampered previous attempts of using large scale structure data to determine σ_8. In addition, it allows the inclusion of constraints on the redshift space distortion parameter $\beta = \Omega_m^{0.6}/b$, and yields average mass-to-light ratios as function of halo mass. Using only the luminosity function and the correlation lengths as function of luminosity we obtain relatively poor constraints on Ω_m and σ_8. Only models with low Ω_m and high σ_8 as well as those with high Ω_m and low σ_8 are ruled out because they over (under) predict the amount of clustering, respectively.

Adding constraints from pre-WMAP CMB data plus additional constraints on the average mass-to-light ratio of clusters, $\langle M/L \rangle_{\rm cl} = (350 \pm 70) h M_\odot/L_\odot$, and on the redshift space distortion parameter $\beta = 0.49 \pm 0.09$, significantly tightens the constraints: $\Omega_m = 0.24^{+0.04}_{-0.03}$ and $\sigma_8 = 0.74^{+0.06}_{-0.05}$ (see Figure 2.9). Thus, we find evidence that both the matter density Ω_m and the mass variance σ_8 are slightly lower than their "standard" concordance values of 0.3 and 0.9, respectively. Remarkably, cosmologies with $\Omega_m \simeq 0.25$ and $\sigma_8 \simeq 0.8$ predict dark matter halos that are significantly less centrally concentrated than for the standard ΛCDM concordance cosmology (see Figure 2.9). This helps to alleviate both the problem with the rotation curves of dwarf and low surface brightness galaxies, as well as the problem of simultaneously matching the galaxy luminosity function and the Tully-Fisher zero-point.

In a joint collaboration with Y.P. Jing (Shanghai Astronomical Observatory, the partner group of MPA) and Y. Chu (Center for Astrophysics, Hefei, China) we have used the conditional luminosity function to populate dark matter halos in large, cosmological N-body simulations with galaxies of different luminosities and different types. Stacking simulation boxes of $100h^{-1}$Mpc and $300h^{-1}$Mpc with 512^3 particles each we construct Mock Galaxy Redshift Surveys with a depth comparable to the 2dFGRS and with a mass resolution that guarantees completeness down to $0.01L^*$ (see Figure 2.10). We use these mock surveys to investigate various clustering statistics. The projected two-point correlation function, the two- and three-point redshift space correlation functions, and the quadrupole-to-monopole ratios are all in remarkably good agreement with data from the 2dFGRS. Modeling the "finger-of-God" effect, we find that the standard ΛCDM model predicts pairwise velocity dispersions that are almost 30 percent too high. Either galaxies move significantly slower than dark matter particles within the same halo, with a velocity bias $b_{\rm vel} \equiv \sigma_{\rm gal}/\sigma_{\rm dm} \sim 0.75$, or $\sigma_8 \simeq 0.8$ instead of 0.9. Given the cosmological constraints described above, and given the new results from WMAP, the latter seems the more likely explanation.

In the coming years, new large redshift surveys, such as the Sloan Digital Sky Survey, in which the Max-Planck Institute for Astrophysics is involved, will dramatically improve both the quantity and quality of data on the distribution of galaxies. The conditional luminosity function technique described here will hopefully proof a useful tool in extracting important information regarding cosmology and galaxy formation from these new data (F. van den Bosch, H. Mo).

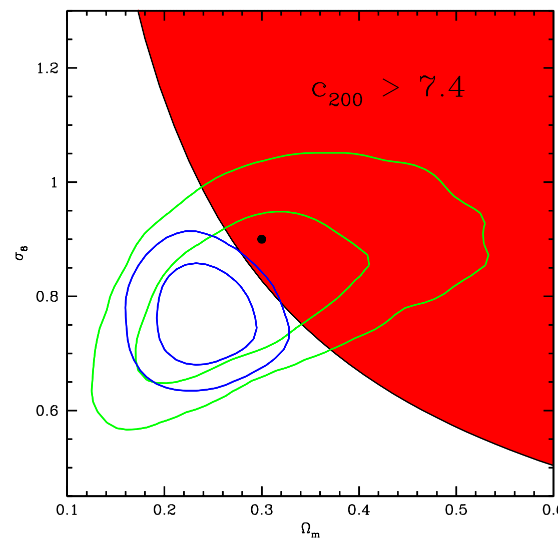

Figure 2.9: The green contours correspond to the 68 and 95 percent confidence levels of the likelihood that the current, pre-WMAP CMB data originates from a flat ΛCDM cosmology with given Ω_m and σ_8. Blue contours indicate the same confidence levels, but this time for the likelihood based on the combined data sets of the CMB, the clustering properties from the 2dFGRS, $\langle M/L\rangle_{\rm cl} = (350 \pm 70)hM_\odot/L_\odot$, and $\beta = 0.49 \pm 0.09$. These additional constraints significantly tighten the confidence levels, and both Ω_m and σ_8 are now well constrained. The red area corresponds to the region of (Ω_m, σ_8) parameter space for which dark matter halos with virial masses $M_{200} = 10^{12}h^{-1}M_\odot$ have a halo concentration parameter $c_{200} > 7.4$, which is ruled out from detailed observations of the rotation curves of low surface brightness galaxies. The solid dot indicates the location of the so-called concordance model with $\Omega_m = 0.3$ and $\sigma_8 = 0.9$. Note that this model (i) predicts halo concentrations that are (slightly) too large and (ii) is inconsistent with our new constraints (blue contours) at more than 95 percent confidence level.

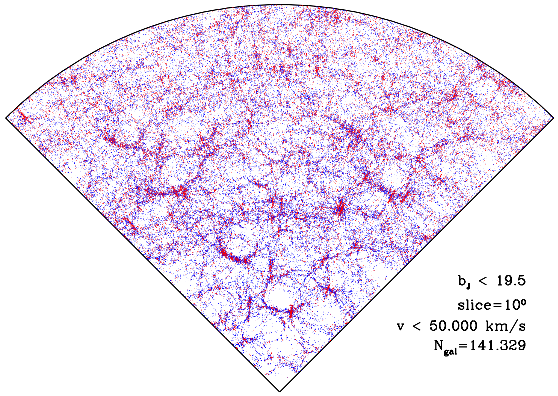

Figure 2.10: A redshift cone diagram for one of our Mock Galaxy Redshift Surveys, constructed from numerical simulations of structure formation in a ΛCDM concordance cosmology in which the dark matter halos are populated with galaxies of different luminosities and different types using our conditional luminosity function. Radial distance corresponds to redshift, extending from $z = 0$ in the origin to $z = 0.17$. All model galaxies with an apparent magnitude $b_J < 19.5$ and located within a slice with opening-angles of 90° and 10° are included in this mock survey (yielding a total of 141.329 galaxies). Red and blue dots correspond to early- and late-type galaxies, respectively. Note how the early-type galaxies are more strongly clustered, due to the fact that they predominantly occupy more massive haloes.

2.5 Lessons about Galaxy Formation from 100,000 SDSS Spectra

The Sloan Digital Sky Survey (SDSS) is using a dedicated 2.5 metre wide-field telescope at the Apache Point Observatory in New Mexico to conduct an imaging and spectroscopic survey of about a quarter of the extragalactic sky. The SDSS is the largest and most ambitious survey of local galaxies ever carried out and when it is complete, spectra will have been obtained for about 600,000 galaxies and 60,000 quasars selected uniformly from the imaging data.

The MPA joined the SDSS project in 2001. Together with collaborators at the Johns Hopkins University in Baltimore, MPA scientists have been focusing their efforts on understanding and interpreting the information available from the galaxy spectra. By design, the SDSS spectra are of unusually high quality and are well-suited to the determination of the principal properties of the stars and the ionized gas in galaxies. The rich stellar absorption-line spectrum provides unique information about the ages, metallicities and motions of the stars. The nebular emission lines can be used to derive estimates of the rates at which stars are forming within molecular clouds. The also provide information about the abundance of heavy elements and dust in the interstellar medium. By studying how the ages, metallicities and star formation rates of galaxies depend on parameters such as galaxy mass and morphology, and also on the environment of the galaxy, the MPA/JHU group hopes to gain insight into the host of complex physical processes that determine how galaxies form and how they evolve over cosmological timescales.

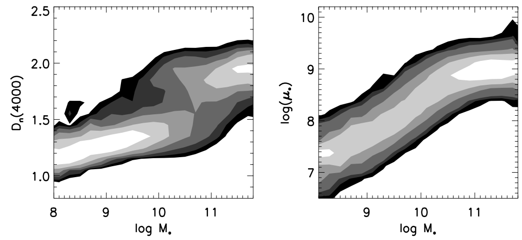

Figure 2.11: **Left**: The mean stellar age of a galaxy , as measured by the strength of the 4000 Å break index $D_n(4000)$ is plotted as a function of the logarithm of the stellar mass of the galaxy. **Right**: The relation between stellar surface mass density and stellar mass. Note that the relations in both panels exhibit an abrupt transition at a stellar mass of $3 \times 10^{10} M_{\odot}$.

In 2002, the MPA/JHU group developed a novel method of estimating the stellar mass of a galaxy using two key stellar aborption features in its spectrum. When they applied the method to the data, they discovered that there was a characteristic mass scale –3×10^{10} solar masses– where many properties of galaxies underwent an abrupt transition. Galaxies less massive than $3 \times 10^{10} M_{\odot}$ were found to have low densities and young stellar populations. A substantial fraction of low mass galaxies had strong Balmer absorption line equivalent widths, indicating that they had experienced recent short-lived episodes of strong star formation (termed starbursts). Above a mass of $3 \times 10^{10} M_{\odot}$, there was a transition to high densities and old stellar populations (see Fig.2.11). >From the data, it was apparent that star formation had terminated in the majority of massive galaxies a long time ago.

The fact that high mass galaxies appear older than low mass galaxies is a genuine puzzle to theoreticians. According to the standard paradigm for structure formation in the Universe, galaxies form in a *hierarchical* fashion thrugh the merging of small objects to form larger and larger structures. The theory predicts that the most massive galaxies in the Universe are the last to assemble, yet observations show that they contain the oldest stars.

One interesting clue to solving this conundrum lies in the fact that almost all massive galaxies contain a spheroidal "bulge" component, whereas low mass galaxies are usually dominated by rotationally-supported disks. It is often hypothesized that disk formation occurred slowly over many billions of years, but that bulge formation was violent and rapid and was characterized by a short period of very intense star formation. Many theorists believe that bulges were created by the merger of two or more galaxies. Numerical simulations show tha as galaxies interact, they exert strong tidal forces on each other. Much of the gas in the galaxies flows inwards, where it reaches high densities and forms stars very rapidly. It is now known that all galaxies with bulges contain supermassive black holes at their centers and some theorists have speculated these may have been formed during the same merging event that created the bulge. One interesting question that then follows is which of the processes associated with bulge formation is primarily responsible for shutting off star formation in the majority of massive galaxies?

To shed some light on this issue, the MPA/JHU group has been searching for young bulges in the SDSS data. Although rare at the present day, such systems could provide clues as to how how most bulges may have formed at earlier epochs. The MPA/JHU group believe that they have found a population of such objects among galaxies with strong active galactic nuclei (AGN).

It is commonly believed that an AGN is produced when gas accretes onto a supermassive black hole located at the centre of a galaxy. As the gas falls towards the black hole, it emits ionizing radiation which produces characteristic emission line signatures in the galaxy spectrum. The MPA/JHU group has now identified a sample of over 20,000 AGN based on the properties of their emission lines (see Fig.2.12) and is currently studying the properties of their host galaxies. They find that the most powerful AGN in their sample reside in a very unusual galaxies. Their hosts are massive and dense, but they are exhibit clear signatures of *young* stellar populations and recent star formation. Up to now, this so-called "starburst-AGN connection" has been a source of substantial controversy in the field, because the samples of AGN studied up to now have been very small – typically a few hundred objects at most. The new work of the MPA/JHU group demonstrates conclusively that the most powerful AGN reside in

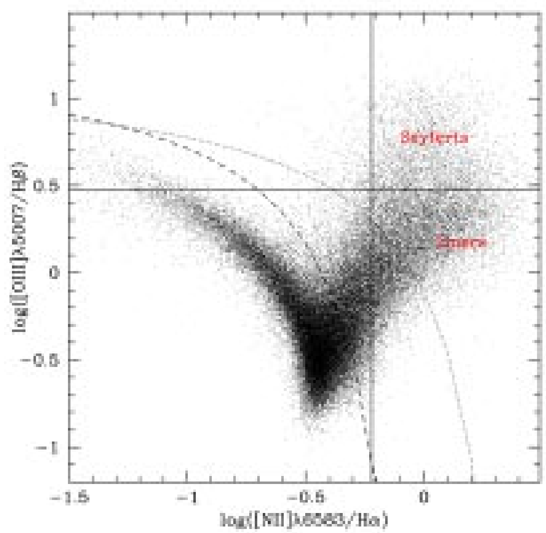

Figure 2.12: The so-called BPT diagram (Baldwin, Phillips and Terlevich 1981), which allows one to distinguish galaxies in which the line emission is coming from an active nucleus from galaxies where the lines are excited by ionizing radiation from young stars. Galaxies lying above the dashed line with high values of [OIII]/Hβ and [NII]/Hα are AGN.

massive young bulges. The group has also examined images of these systems (Fig.2.13) and find that a large fraction them either have very close companions or show clear signs of recent mergers or interactions. The results strongly support the hypothesis that the formation of black holes and galactic bulges occurred simultaneously as galaxies merged with each other in the early Universe.

Having located a large sample of young bulges, the MPA/JHU group would like to understand the influence the environment of a galaxy has determining how massive galaxies form their stars and how frequently they host an active nucleus. For example, mergers are thought to occur most often in small galaxy groups. Further analysis of the SDSS data set will allow the group to ascertain whether this hypothesis is correct, and to come to a more detailed understanding of the observational results they have obtained (G. Kauffmann).

2.6 The history of cosmic star formation

The currently most successful theory for the formation of galaxies in the universe is based on the

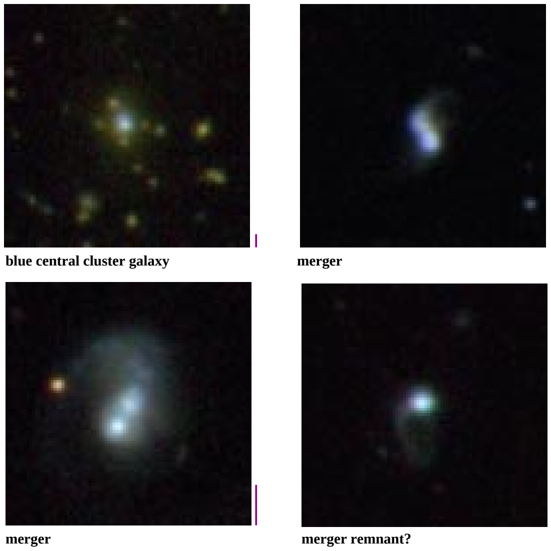

Figure 2.13: Some example images of powerful AGN that are merging/interacting.

so-called ΛCDM model, where the dominant mass component in the universe consists of *cold dark matter*, probably in the form of elementary particles that have not been detected directly so far. Ordinary baryons, on the other hand, make up for only about 13% of all the mass. In addition, there appears to be a non-vanishing cosmological vacuum energy density which actually dominates over the combined energy densities of dark matter and baryons at the present day.

Over the last two decades, computer simulations have greatly helped to understand the formation process and the properties of galactic halos in the ΛCDM model, as well as their distribution and motion in space. This part of the structure formation process is now comparably well understood. However, cosmological simulations that try to include star formation in order to allow for a direct comparison of the theoretical models with the luminous properties of observed galaxies have been met with substantially more difficulty, and are therefore theoretically still much more uncertain.

One generic problem of these studies has been that the radiative cooling of gas appears to proceed too efficiently, such that a substantial luminosity excess of the simulated galaxies compared to the real universe results. It is believed that this failure to account for the data is likely caused by an incorrect modelling of the physics of star formation and its associated feedback processes, like supernova explosions or stellar winds. If however feedback effects could be properly taken into account, the *overcooling problem* might be resolved. Unfortunately, the physical mechanisms that potentially provide efficient feedback are only very poorly understood. In addition, attempts to directly include them in simulations are met with substantial numerical difficulties.

In light of these problems, V. Springel and L. Hernquist (Harvard-CfA) proposed a new simulation method to account for the regulation of star formation by supernovae in the dense interstellar medium (ISM). Using an analytic sub-resolution model for the physics of the ISM on unresolved scales, their method successfully circumvents some of the main numerical problems usually encountered in simulations of galaxy formation. In this model, collapsed gas at very high overdensity becomes available for star formation, which in turn creates a complex multi-phase structure in the ISM. Star formation is assumed to occur in cold clouds that form by thermal instability out of a hot ambient medium, heated by supernova explosions. The supernovae also evaporate clouds, thereby establishing a tight self-regulation cycle for star formation in the ISM.

Motivated by observational evidence for strong galactic outflows in actively star-forming galaxies, Springel & Hernquist also for the first time included a novel description for feedback by *galactic winds*. Figure 2.14 shows the velocity field of the gas in a forming disk galaxy when such a wind is included. In the small galaxy shown here, the wind can actually escape from the galaxy, transporting both gas and heavy elements, that were synthesized in stars, out of the galaxy. As a result, the amount of gas available in the galaxy for star formation becomes much smaller. However, despite this strong effect on the luminosity of the forming disk, its morphological properties are still broadly consistent with observed spiral galaxies.

Galactic winds have a particularly strong influence on the star formation rate of small galaxies, where winds are able to escape from the gravitational pull of their parent dark matter halos. However, in large systems, the winds are confined, such that they are not efficient in suppressing star formation. Feedback by winds hence primarily reduces the star formation activity in small galaxies, which is just what appears to be required to improve the agreement between observations and predictions based on the ΛCDM model. This is one of the reasons why galactic winds receive a lot of attention in current theoretical studies. Another interesting effect of winds is that they transport metals into the intergalactic medium, thereby poten-

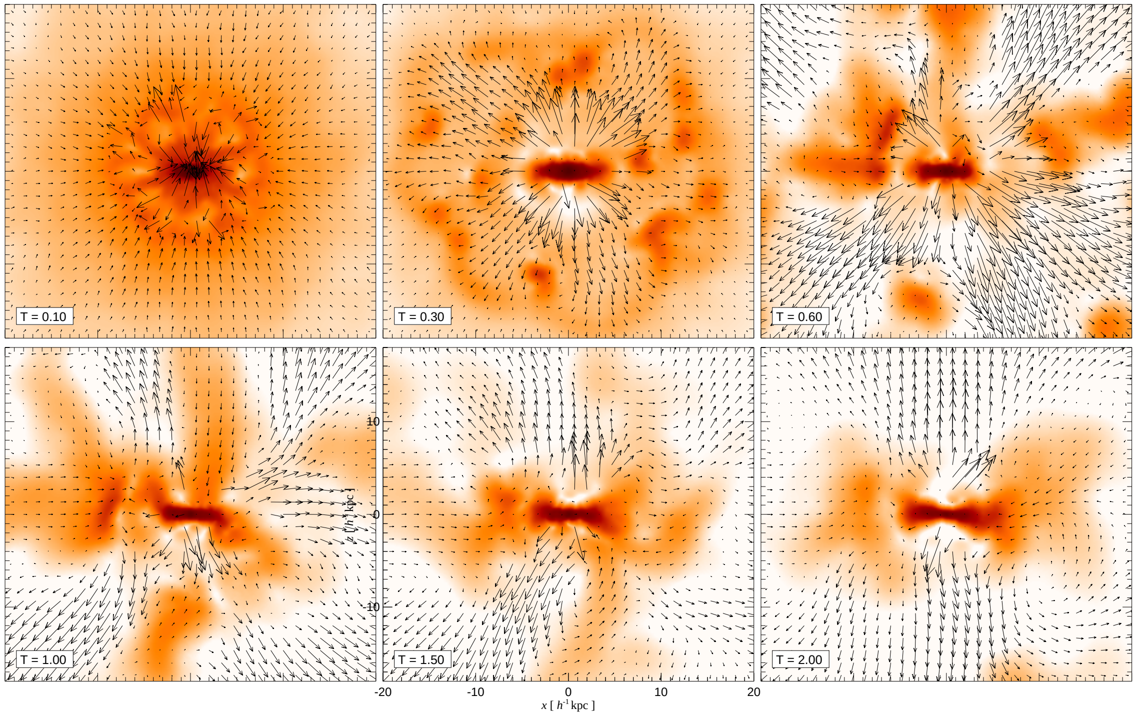

Figure 2.14: The velocity field of the gas in the halo of a small forming galaxy. Due to gas cooling, a centrifugally supported disk develops at the halo center, which is here seen edge-on. In the rapidly growing gaseous disk, star formation drives a powerful galactic wind which is able to escape from the galaxy.

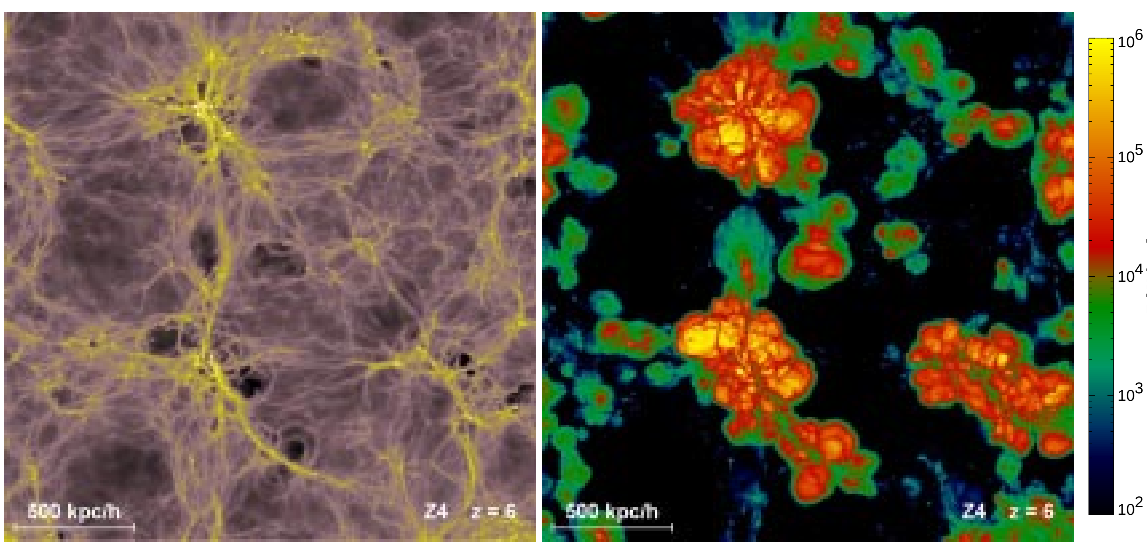

Figure 2.15: Galactic outflows seen at high redshift. On the left, the projected gas density around some of the first star-forming galaxies is shown, at a time when the universe was only about 1 billion years old. The dense white knots mark the positions of galaxies that undergo active star formation, driving winds into the intergalactic medium. They are generating bubbles filled with hot gas, as seen in the temperature map on the right.

tially explaining why heavy elements are observed in the low density gas that resides in intergalactic space, as probed by absorption line studies of quasar spectra.

Numerical predictions for the full star formation history of the universe are also especially challenging because galaxies form hierarchically in the cold dark matter theory, i.e. small objects form first and then gradually grow by accretion or merger events to become ever more massive systems. A complete inventory of all star-forming galaxies therefore requires that simulations simultaneously resolve galaxies on all relevant mass scales. This amounts to a very substantial demand for high dynamic range in these simulations. In addition, the feedback processes mediated by galactic winds are particularly important in galaxies of small mass, which adds to the difficulty of these computations, because these galaxies are typically close to the resolution limit, yet an accurate treatment of the winds is essential to correctly describe the suppression of star formation by feedback. In a single simulation, the required mass resolution can presently not be achieved in volumes large enough to be representative for the universe at all epochs. However, using a special simulation strategy, Springel & Hernquist have been able to largely work around this problem. By combining results for a number of different simulation volumes they were able to drastically extend the dynamic range over which their numerical model for galaxy formation could be probed. They also carried out extensive numerical convergence tests, thereby validating the simulation methodology.

At high redshift, the first star forming galaxies begin to drive violent outflows into the intergalactic medium, as seen in Figure 2.15, where the gas density in one of the high-resolution simulations is shown at redshift $z = 6$. When the galactic winds are stopped by shocks, they lead to the generation of bubbles in the intergalactic medium, which are filled with hot metal-enriched gas. Due to the 'loss' of baryons in such galactic outflows, the star formation in small galaxies is strongly suppressed.

In Figure 2.16, the history of cosmic star formation predicted by the composite simulation set is shown, both as a function of redshift, and in a cumulative form as a function of time. The star formation density is predicted to peak already quite early in the history of the universe, at a redshift of about $z = 5.5$. Note that about half of the stars are found to have been in place already about 10 billion years ago. The total fraction of baryons that end up in long-lived stars is predicted to be

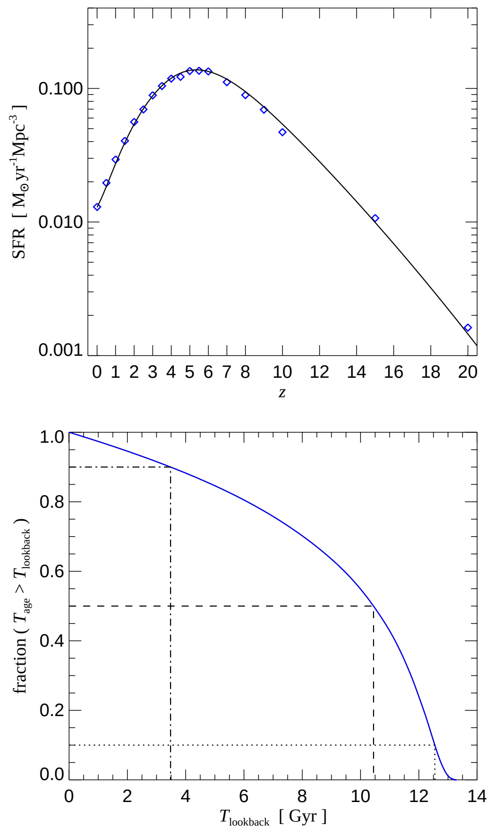

Figure 2.16: The history of cosmic star formation as a function of time. The top panel shows the evolution of the star formation rate density as a function of redshift. The blue symbols are measurements from the simulations, while the solid line is an analytic fit to the results. The maximum of the comoving star formation activity is already reached by redshift $z \sim 5.5$, at a time when the universe was only about 1 billion years old. The panel on the bottom shows the fraction of stars at the current epoch that are older than a given age. It is seen that about half the stars today are older than about 10 billion years.

only about 10%, which is consistent with observational data. Without the inclusion of galactic winds, this number would have been substantially higher, in conflict with a number of observational constraints.

This numerical study is probably the most comprehensive attempt thus far to use hydrodynamical simulations of cosmic structure formation to compute a reliably converged prediction for the full star formation history from high redshift to the present. Before, this could only be achieved with semi-analytic models of galaxy formation, which however are not able to treat the hydrodynamics self-consistently. Direct simulations of galaxy formation are hence becoming an ever more powerful tool for studying cosmological galaxy formation. (V. Springel)

2.7 Cosmic Rays from Microquasars

The Milkyway Galaxy is filled with cosmic rays. These high energy particles travel with relativistic velocities, approaching the speed of light, guided by the tangled mesh of magnetic field lines that permeates the Galaxy. While the most energetic cosmic rays carry more energy than a boxer's punch, the bulk of them travels at more moderate energies, a few times that of their own rest mass energy, $e = m\,c^2$ (about 100 billion times less than the most powerful cosmic rays observed).

It is believed that most of these cosmic rays are created in the powerful shocks surrounding the expanding remnants of supernova explosions. Particles can be accelerated to relativistic energies by crossing this shock many times, each time picking up a little bit of extra energy. However, there are other sources of relativistic particles in the Galaxy. One type of source, which had not previously been considered when making estimates of the contribution to the Galactic cosmic ray spectrum, are the so called microquasars. Microquasars are a type of X-ray binary star that produces powerful collimated, relativistic outflows, called jets.

The name microquasar originates from the comparison with active galactic nuclei, often called called quasars, which can also produce such relativistic jets. The quasar jets are much more powerful because the black hole at the heart of the creation of such quasar jets is much bigger and more massive than the black hole or neutron star at the center of microquasars. But just as in the giant quasars, the jets in microquasars can inherit a large fraction of the total amount of energy released by accretion of gas onto the central object. Thus, microquasar jets can travel large distances — up to several light years — before the interaction with the interstellar matter finally stops their advance.

Because these jets move with relativistic speed with respect to the stationary interstellar medium, the particles they contain are essentially already cosmic rays. In other words: relativistic jets are nothing but collimated bulk flows of cosmic rays, tied up into a neat package by magnetic field lines and their own inertia. All that is needed to convert them into regular cosmic rays is a way to disperse them, i.e., to randomize their individual motion. Such a disruption of the flow can easily take place in the interface of the jet with the surrounding interstellar medium (ISM). No further energy gain is required to make true cosmic rays out of these particles. This process of producing cosmic rays is therefore very efficient compared to the multi-step process occurring in supernova remnants. Thus, relativistic jets provide ideal sources for cosmic ray particles (see Fig. 2.17 for a cartoon of this scenario).

The fact that relativistic particles are produced in the violent interface of the jet with its environment, called the terminal shock, is, in fact, well known from the observations of so called radio lobes in active galaxies and in microquasars. These diffuse bubbles filled with relativistic electrons are the depository of the particles randomized in the terminal shock. The only relativistic particles directly visible in these lobes are relativistic electrons, observable through their radio synchrotron emission in the magnetic fields carried by the jets. This bright radio emission proves that relativistic particles are indeed produced in microquasars. However, electrons are only one part of the mixture of Galactic cosmic ray particles, while the bulk of the particles detected in the solar system are heavy particles, mostly protons. The presence of such other species of particles around microquasars is not directly detectable. As a result, the contribution of such heavy particles to the cosmic ray spectrum had not been considered before.

As shown by Heinz & Sunyaev, such a contribution of heavy particles must be produced in the relativistic shock that forms the interface between the jet and the interstellar matter. Moreover, relativistic shocks are not only efficient in producing cosmic ray particles, they can also produce interesting spectral features: each time a particle crosses such a shock, it can potentially gain a large amount of

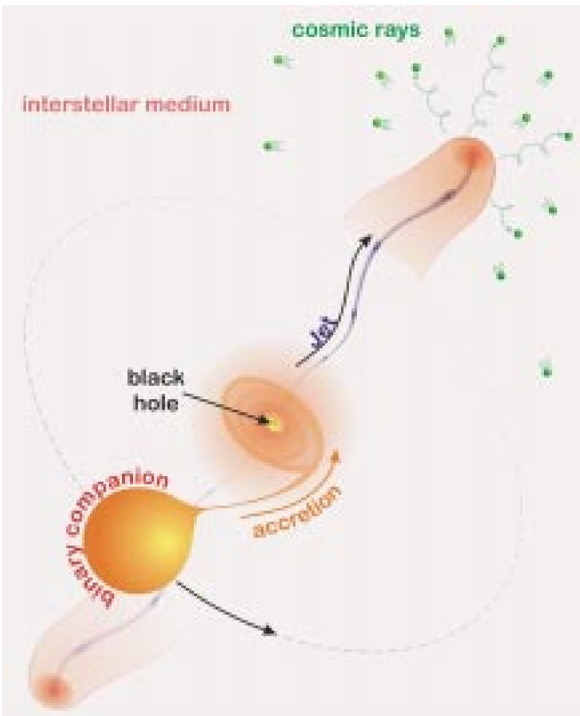

Figure 2.17: Cartoon of the production of cosmic rays in microquasars: Jets from Galactic black holes or neutron stars carry relativistic particles through the interstellar medium. Upon interaction with this medium, the organized bulk motion of these particles is broken, kinetic energy is converted into energy of individual and independent particle. The random motion of the particles carries them through the Galaxy as so-called cosmic rays.

energy. The spectral distribution of particles having crossed the shock several times should therefore bear a signature of these large energy increases in the form of spectral peaks shown in Fig. 2.18. Each of these peaks corresponds to an integer number of shock crossings. The largest and most powerful peak should be the one corresponding to particles which have crossed the shock only once. In fact, the fundamental requirement of energy conservation implies that, on average, the cosmic rays released by the shock carry exactly as much energy in all the random directions they are traveling after passing the shock, as they did carry in well organized kinetic energy before they passed the shock. This implies that the energy of this first peak is simply given by the kinetic energy per particle in the beam of the jet. Measuring such a peak would, in fact, be a unique signature of the jets initial velocity, something which has alluded astronomers for many decades now.

Because the cosmic ray spectrum produced by supernova remnants is smooth, the production of spectral features in the relativistic shocks of microquasars offers the possibility of searching for such a contribution. In order to estimate the relative strength of such a contribution, one would need an accurate measure of the energy released by microquasar jets into the Galaxy. At the current state of our knowledge of microquasar jets, such a measurement is impossible. However, based on the observed radio luminosity emitted by microquasar jets in the Galaxy, we can extrapolate from the few sources where we have a good idea of how much power they emit, to arrive at a rough estimate for the integrated energy input into the Galaxy by microquasars. Since the efficiency for cosmic ray production by this energy release is rather high, this, then, provides an estimate for the total cosmic ray power released into the Galaxy.

This estimated total luminosity released by microquasar jets lies between 0.1% and 10% of the total Galactic luminosity in cosmic rays. Thus, with sufficiently sensitive instruments, it should be possible to probe the cosmic ray spectrum for any contribution from microquasars. Current instruments have not been able to find any spectral traces indicating an origin in relativistic shocks of microquasars. Because the cosmic ray signal will be stronger the closer the source of the cosmic rays is, we can use this limit to exclude that any microquasar jet with an average power larger than $10^{38}\,\mathrm{ergs\,s^{-1}}$ (which is about 50000 times the power released by the sun) was active within a distance of about 3000 light years during the past 15 mil-

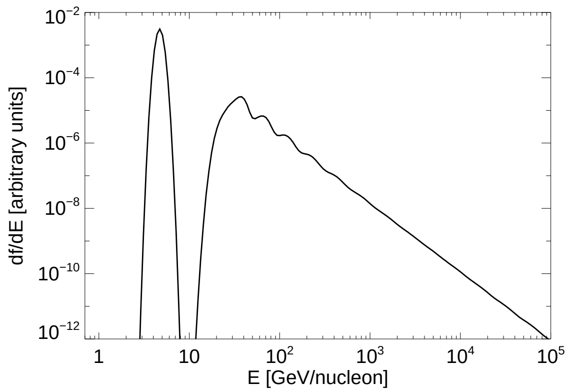

Figure 2.18: Sketch of the possible microquasar contribution to the Galactic cosmic ray spectrum - note the possibility of producing spectral features in relativistic shocks, the position of which contains information about the bulk velocity of the jet plasma.

lion years. All known powerful microquasars are located much further away than this limit and are therefore not in conflict with this measurement. The planned AMS 02 instrument on the International Space Station will feature an improved sensitivity and it will fly during the solar minimum, reducing the influence of the solar wind and its magnetic field with the cosmic rays traveling through the solar system. This combination will make it much easier to search for small but very peculiar contributions from microquasars.

Another possible way of detecting these high energy particles released by microquasars is through their interaction with the particles of the interstellar matter. The collision of high energy particles with other heavy particles can lead to the creation of elementary particles called pions. These pions themselves further decay into two gamma-ray photons. These gamma-ray photons can then be detected by gamma-ray telescopes of the the GLAST space craft planned for launch by NASA.

Because this process is most efficient if there are a lot of heavy particle targets around for such collisions, the gamma-ray signal will be strongest from sources that are located in dense environment, such as are found in molecular clouds and star forming regions. Coming generations of gamma-ray instruments will be able to detect this signal. This will provide an independent way to measure the energy released by relativistic jets into the Galaxy. It will also be proof of the proposed microquasar contribution to the Galactic cosmic ray spectrum. (S. Heinz, R. Sunyaev)

2.8 Magnetically powered Gamma-ray Bursts

Since the discovery of the first gamma-ray burst 30 years ago the cause of these events has been a main source of debate in astrophysics. It was proven in 1997 that the sources of the bursts are very far away. To be visible across half of the universe an object must release an enormous amount of energy. From the large energy, the rapid variability and the energy spectrum of the radiation follows that compact objects (black holes, neutron stars) must be involved. The gamma radiation itself originates from outflowing material which approaches us with more than 99.995% of the speed of light. A model for gamma-ray bursts must answer two critical questions: How is the matter accelerated to such extreme velocities? How is the radiation generated? Accelerated matter does not radiate by itself. An additional process must generate the high energy emission.

The high speed of the flow implies that the energy released by the source of the burst is dissipated in a small amount of mass, of the order 10^{-4} solar masses. Diluting the energy over, say, one solar mass would instead produce something resembling a supernova. The amount of energy is similar in both cases, but in the case of supernovae it is radiated away over months instead of seconds. This so-called baryon-loading constraint is perhaps the most telling clue about the physics in the inner regions of the central engines of GRB. One possibility is that the energy is transferred from the central compact object to a low-density region outside it by neutrinos. This has perviously been investigated in some detail at MPA by Ruffert and Janka. It is not quite clear at the moment if neutrinos can power a sufficiently strong burst (about $3\,10^{50}$ erg is needed), and if it can take place without blowing off too much mass (in the form of a 'neutrino driven wind').

A second possibility is rotating magnetic fields: the most realistic candidates for the central engine all involve a rapidly rotating compact object in the form of a (proto-) neutron star or a torus of matter orbiting in the gravitational field around a black hole. Differential rotation in these objects will generically produce very strong ($\sim 10^{15}$G) magnetic fields, and their rotation produces a powerful electromagnetic field. The Poynting flux of this field can travel in vacuum, hence is an ideal means of transporting the central energy outward with a small amount of mass involved. Together with their plausible creation in the central engine, this is the major attraction of a magnetic fields as the primary carriers of the GRB energy.

It turns out, however, that a magnetic field has three more properties that makes it a compelling candidate as the main energy carrier in GRB. In his PhD thesis G. Drenkhahn (supervisor H. Spruit) finds that the acceleration of the flow to high Lorentz factors, as well as the prompt nonthermal radiation are both natural consequences of the dissipation of magnetic energy in the outflow. Finally, the spectrum of the nonthermal radiation, inferred from the observations to be synchrotron radiation, is a natural result of the strong magnetic field.

The key to these properties is that an electromagnetic wave loaded with plasma can decay into heat, unlike a pure vacuum EM wave. For typical GRB parameters, the magnetic field is 'relativistic', that is its energy density is larger than the rest mass energy density of the plasma, and hence the Alfvén speed close to the speed of light. By instabilities regions in which the field orientation is different can come close to each other, and in a relativistic B-field this happens with a substantial fraction of the speed of light (as seen in a frame comoving with the bulk flow). By magnetic 'reconnection' the magnetic energy of the opposing fields is released and transfered to the plasma (see Fig. 2.19).

The time scale on which this reconnection takes place, as measured in the rest frame of the central engine, is of the order $\Gamma^2 P$, where P the rotation period of the central engine and Γ the Lorentz factor of the outflow. Due to the relativistic nature of the flow, $\Gamma \sim 100 - 300$, this is so slow that much of the reconnection takes place at a substantial distance from the source, outside the photosphere of the flow. The energy can thus be radiated away directly, and is likely to be nonthermal, its spectrum reflecting the dominant radiation process.

The dissipation process is automatically associated with a strong *acceleration* of the flow. A decrease of magnetic energy with distance neccessarily sets up a magnetic pressure gradient which accelerates the matter carried with the field outward. This is perhaps somewhat confusing: if the magnetic energy flux is dissipated into radiation, how can it at the same time accelerate the flow? The solution is found by noting that the (MHD) Poynting flux $vB^2/(4\pi)$ is actually twice the flux of magnetic energy $vB^2/(8\pi)$. The remaining half can be interpreted as $p\mathrm{d}V$ work, done on the outflow by the central engine. The magnetic energy can dissipate entirely, while the '$p\mathrm{d}V$ part' of the Poynting flux accelerates the flow. Hence, if the magnetic energy all dissipates outside the photosphere and is radiated away, exactly half of the Poynting flux is converted into radiation, the other half into kinetic energy of the flow.

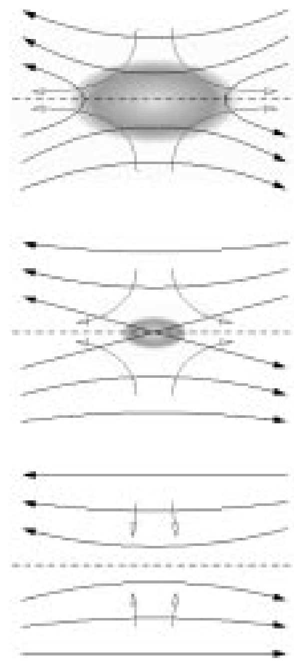

Figure 2.19: Simplified 2-dimensional sketch of the magnetic field decay. Differently aligned magnetic fields (black arrows) are brought together by the plasma flux (red arrows). At the meeting point in the middle the fields annihilate and magnetic energy is released locally heating up the matter (yellow-orange indicated). More realistic are 3-dimensional processes will be less ordered than this.

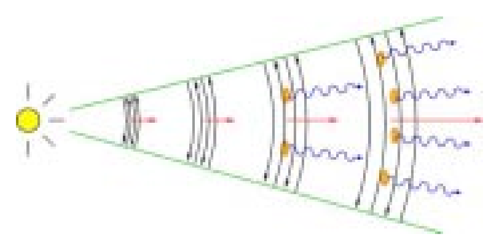

Figure 2.20: Schematic picture of magnetic fields in a GRB explosion. The central source (yellow) generates oppositely aligned magnetic fields (black arrows). Due to the magnetic field decay the outflow gets accelerated (red arrows) and high energy radiation is emitted (blue wiggles).

Detailed calculations of these processes yield the flow speed, magnetic field strength and amount of radiation emitted as a function of distance, including the transition between optically thick and thin regimes. As an example of the results, Fig. 2.21 shows the fractions of optically thick (thermal) ra-

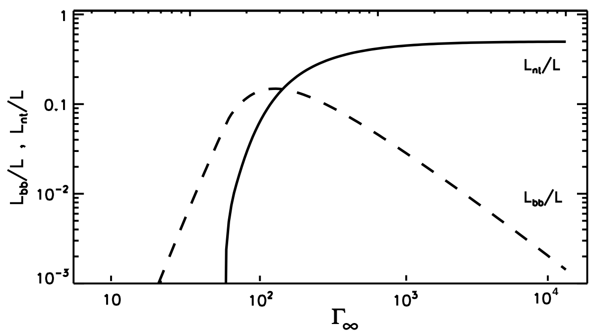

Figure 2.21: Thermal (photospheric, dashed) and nonthermal (solid) contributions to the prompt GRB emission predicted from the magnetic dissipation model, as a function of the asymptotic Lorentz factor of the flow. At large baryon loading (small Γ_∞) prompt emission is inefficient and most of the total energy released is converted into kinetic energy. For Γ_∞ around 100, X-ray flashes or X-ray-rich GRB result. For $\Gamma_\infty \gg 100$, 50% of the total energy is emitted as prompt emission and 50% ends up as kinetic energy.

diation produced at the photosphere and the optically thin (nonthermal) radiation, as functions of the amount of mass carried with by flow (as measured by the asymptotic Lorentz factor).

At low baryon loading, a GRB results, with mostly nonthermal radiation. At higher loading ($\Gamma_\infty \sim 100$), the (quasi-)thermal contribution of the photosphere becomes noticeable, consisting of lower energy photons. In this case the result is an 'X-ray flash'.

The magnetic dissipation model thus explains a whole set of key elements of the GRB phenomenology: the low baryon loading, the efficient acceleration of the flow and efficient prompt emission, the efficient production of synchrotron radiation and the transition between GRB and X-ray flashes at $\Gamma_\infty \sim 100$. (G. Drenkhahn).

3 Research Activities

3.1 Stellar Physics

The Sun and the Solar System. H. Spruit showed that the 'torsional oscillation' pattern, a small time and latitude-dependent variation in the Sun's rotatation, can be understood as a geostrophic flow associated with a pressure reduction in the active latitude zones (like a low pressure system on earth). This low pressure is a surface effect caused by the enhanced cooling due to the small scale magnetic fields at the surface (the opposite of the reduce energy loss in sunspots).

H. Spruit has made observations of the center-to limb variation of the magnetic flux ratio in the lines Fe 5250, 5247 with the McMath telescope at Kitt Peak, in collaboration with W.C. Livingston (NSO Tucson). He is involved as associated scientist with the project 'Sunrise' (led by MPAe Lindau), a balloon-borne solar observatory under constr uction with funding from DLR.

U. Anzer and P. Heinzel (Ondrejov,Czech Rep.) studied the extended solar filaments which have been observed in EUV spectral lines. In this context they developed a method to calculate the vertical extension of these structures. On the basis of these results they constructed magnetic models which can explain the observed configurations. They also continued their modelling attempts for prominence-corona transition regions.

Single stars. A. Weiss and collaborators (M. Salaris and H. Schlattl, Liverpool John Moores University; S. Cassisi, Osservatorio Collurania, Teramo) performed detail numerical models of core helium Population III stars in order to reproduce the observed high carbon and nitrogen overbundances in extremely metal-poor galactic halo stars. A similar event appears to occur in Population II stars, provided the envelope has been lost by stellar winds during the first giant branch ascent. In this case, a delayed helium flash happens after the star has already starting its white dwarf cooling and results in a reappearance as an extremely blue horizontal branch star with strong helium enrichment. Such stars are observed, and the models might be able to unveil their up to now unknown origin. – Together with M. Salaris (Liverpool John Moores University) A. Weiss continued work on age determinations of globular cluster, providing the largest homogeneous sample of 55 determined cluster ages. The oldest age is about 12 Gyr, almost independent of cluster metallicity, with an increasing spread in age down to 7 Gyr for the most metal-rich clusters. – The use of the Sun in connection with high-precision solar models as a laboratory for basic physics becomes more and more attractive, but is not possible in all cases. A collaboration between M.P. di Mauro (University of Catania), H. Schlattl (Liverpool John Moores University), A. Weiss, and J. Christensen-Dalsgaard (Aarhus University) showed that the Sun cannot – contrary to earlier work published in the literature – be used to constrain Newton's constant (G), mainly because the solar mass itself depends on G, and only the product $GM_\odot$ is determined with high accuracy from Kepler's third law. This work also showed that uncertainties in the seismic inversion of measured solar oscillation frequencies are larger than the small influence of G-variations.

Binary Systems. Low–mass stars, brown dwarfs and giant planets are still the focus of numerous theoretical and observational studies, and computing the internal structure and evolution of such objects is still a non–trivial task because of the numerous problems associated with the equation of state, the opacities, and the stellar atmospheres. The problem gets even more complicated if one considers such objects as near companions to comparatively luminous stars where external irradiation of the atmosphere is important. In this context I. Baraffe together with F. Allard, G. Chabrier (Ecole Normale Supérieure de Lyon), T. S. Barman (University of Georgia, Athens) and P. H. Hauschildt (University of Georgia, Athens and Hamburger Sternwarte) have calculated evolutionary models for cool brown dwarfs and extrasolar giant planets with special emphasis on the case of HD 209458. Furthermore, in collaboration with H. Ritter, the application of such calculations to the donor stars of compact binary systems has been investigated. In cataclysmic variables for example, the impinging flux due to accretion luminosity of the white dwarf companion could significantly affect the structure of a low-mass secondary.

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 A. King (University of Leicester) has investigated the formation of low–mass and intermediate–mass X–ray binaries with massive stellar mass black holes, i.e. $M_{\rm BH} \approx 10 - 15 M_\odot$. It is found that the formation of systems like the long–period low–mass binary V1487 Aql = GRS 1915-05 requires a high–mass primary star ($M \gtrsim 60 M_\odot$) with substantial wind mass loss prior to the first mass transfer, a relatively large value of the common envelope efficiency parameter of $\alpha_{\rm CE} \approx 0.3 - 0.5$, and substantial, but not too much wind mass loss from the primary's He–star remnant. Wind mass loss from the He–star is a necessity for widening the orbit of the post common envelope system and thus allowing the (second) mass transfer from the low–mass secondary to start not before it has become a giant or subgiant.

As a service to the community working on compact binaries H. Ritter has continued compiling the data for the "Catalogue of Cataclysmic Binaries, Low–Mass X–Ray Binaries and Related Objects", and, in collaboration with U. Kolb (Open University, Milton Keynes), has finished the preparatory work for a new (electronic) version of this catalogue due to be released early in 2003.

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. Büning and H. Ritter have carried out numerical calculations of the long-term evolution of cataclysmic binaries with mass transfer from evolved and unevolved donor stars, including the feedback on the mass transfer caused by irradiating the donor star with accretion luminosity. These calculations are the first involving full stellar models and irradiation feedback. In line with earlier analytical results, it is found that irradiation feedback can force the mass transfer to go through a limit cycle in which phases of high, irradiation-driven mass transfer alternate with phases of low or vanishing mass transfer. But contrary to earlier analytical results, it is not the systems with a giant donor which are most susceptible to irradiation feedback, but those with a low-mass main sequence donor of $\sim 0.5 M_\odot$. By means of a simple analytical model, it can be shown that the stability of systems with a giant donor with respect to irradiation feedback is a consequence of a) the systematically larger atmoshperic pressure scale height and b) the significantly deeper reaching superadiabatic convection zone.

Supernovae. K. Kifonidis, T. Plewa (ASCI FLASH Center, University of Chicago), H.-Th. Janka and E. Müller have continued their studies of hydrodynamic instabilities in neutrino driven core collapse supernovae. They have completed a study of the interaction between neutrino-driven convection, nucleosynthesis, and Rayleigh-Taylor instabilities. The results are being published in Astronomy & Astrophysics.

L. Scheck, K. Kifonidis, H.-Th. Janka, E. Müller and T. Plewa (ASCI FLASH Center, University of Chicago) have continued their studies of the coupling between neutrino transport and neutrino-driven convection in core collapse supernovae. In the framework of the PhD thesis of L. Scheck, commonly supervised by H.-T. Janka and E. Müller, a new characteristics-based neutrino transport scheme was coupled to their PPM hydrodynamics based supernova code. The new transport schemes takes into account the back reaction of matter onto the neutrino flux, and thus is superior to the light bulb approximation used in previous simulations. In particular, the scheme considers the additional neutrino flux generated by mass accretion during the neutrino heating phase. First 2D supernova models show the dominance of large-scale modes of convection, which may result in large neutron star "kick" velocities. The study will also involve simulations of 3D models to investigate whether the commonly used assumption of axial symmetry is justified.

M. Rampp and R. Buras in his PhD work, supervised by H.-Th. Janka, performed one- and two-dimensional supernova simulations of massive stars with varied progenitor models, neutrino physics, and grid resolution. Although convective regions develop inside the neutrinosphere and in the neutrino-heating region behind the stalled shock, no explosions could be obtained in the most complete simulations. Omitting the velocity-dependent terms in the neutrino momentum equation leads to significant changes of the transport solution between the neutron star and the supernova shock, although the fluid velocities in this region are at most a few percent of the speed of light. In fact, a weak explosion could be obtained in this case. This demonstrates the strong sensitivity of the dynamics on “smaller” effects in the neutrino transport. In most recent calculations we include the effects of rotation and of initial fluctuations in the progenitor core, which can grow in the layers of supersonic collapse.

K. Kifonidis, T. Plewa (ASCI FLASH Center, Chicago) and H.-Th. Janka performed two-dimensional simulations of the evolution of convective overturn processes in the neutrino-heating region behind the stalled supernova shock. Neutrino cooling and heating between the neutron star (as the inner boundary condition) and the shock were included. The computations demonstrate that convective bubbles merge to large-scale structures when the shock expands slowly and the onset of the supernova explosion is delayed for 100 or more milliseconds. A tendency to a dominant contribution of the $(l = 1, m = 0)$ mode in an advanced phase of the simulations was discovered. This may have important consequences for observable asymmetries of supernova explosions and for the explanation of measured pulsar proper motions. L. Scheck in his PhD work, supervised by H.-Th. Janka, K. Kifonidis and E. Müller, repeats such simulations and performs also three-dimensional calculations with a significantly improved description of the neutrino physics. Different from the previous “light bulb” simplification the modifications of the neutrino fluxes due to neutrino emission and absorption in the cooling and heating layers are now taken into account.

Relativistic stars. H. Dimmelmeier, E. Müller and J.A. Font have studied the gravitational collapse of general relativistic, axisymmetric, rotating polytropes modelling stellar cores. The collapse was simulated within the framework of the Wilson approximation to General Relativity. In this approximation the general relativistic hydrodynamic equations are integrated together with the Einstein field equations within the (3+1) ADM formalism describing the curvature of the three–geometry by a position–dependent conformal factor times a flat–space Kronecker delta (conformally flat gauge condition). They calculated the gravitational wave signature of the events and compiled a publicly available catalogue of gravitational wave signals. This wave template catalogue is intended to be used by the data analysis community of the current gravitational wave interferometers.

H. Dimmelmeier, J.M. Martín García (University of Southampton, UK), and J.A. Font (University of Valencia, Spain) have developed a general relativistic hydrodynamics code for studying critical phenomena in the collapse of ideal fluids. Critical phenomena are a currently very active field of research in mathematical and numerical general relativity, and describe the evolution of spacetimes towards naked black hole singularities. The investigation includes the first simulations ever performed of a critical collapse with nonzero initial angular momentum. The results will enhance the knowledge about the mathematical conditions for black hole formation.

3.2 Nuclear and Neutrino Astrophysics

In order to improve our knowledge of type Ia supernovae, a group of European astronomers, led by W. Hillebrandt, organized as a team and proposed for a Research Training Network funded by the EU which has started in July, 2002. The idea was that accurate observations and modelling of relatively nearby SNe is the only way to understand their nature and the causes of their range of properties. Participants to the RTN include German, British, Italian, French, Spanish and Swedish institutes. Researchers involved have begun the programme by successfully applying for joint observing time on most major European telescopes, thus maximizing and optimizing the amount of telescope time allocated for SN studies. In the short time since its beginning, the RTN has already collected very accurate data on three nearby SNe Ia: SNe 2002bo, 2002dj, and 2002er.

First results were obtained for using MPA’s 2- and 3-dimensional numerical simulations of thermonuclear (type Ia) supernovae as input into computations of synthetic spectra and lightcurves. In a collaboration with the group of A. Pauldrach (USM) PhD student D. Sauer worked on numerical calculations of synthetic spectra of type Ia supernovae in early phases. For this purpose the stellar atmosphere code, that is developed at USM is adopted to the different physical conditions in supernovae. This code provides a detailed solution of the NLTE rate equations and the radiative transfer in spherical symmetry. The objective is to gain understanding for the spectral formation in these objects and derive synthetic spectra on the basis of the hydrodynamic explosion models.

First colour and bolometric lightcurves were calculated S. Blinnikov and E. Sorokina (ITEP, Moscow) during their visit at MPA, using 3D hydrodynamic explosion models as input. The agreement between the essentially parameter-free models and observed lightcurves, e.g. of SN1994D, is amazing and demonstrates that deflagrations of Chandrasekhar-mass carbon-oxygen white dwarfs are most likely the correct models.

The data obtained from the 3D hydrodynamic type Ia models have been "post-processed" by C. Travaglio to predict detailed elemental and isotopic abundances of the supernova ejecta. This is a crucial test since nuclear abundances are very sensitive to both densities and temperatures during the explosion. Again, the first results look promising and do not seem to be in conflict with observations. Moreover, they predict that unburnt low-velocity carbon and oxygen should become visible at late times, a prediction that can be tested by future observations.

Further observational aspects of type Ia supernovae are investigated in Diploma and PhD theses. Supervised by W. Hillebrandt and P. Mazzali (Trieste), M. Stehle is analyzing observed spectra of nearby explosions in order to link them to physical properties of the models. This is done by means of synthetic fits based on an extension of the Lucy/Mazzali spectral code. M. Stritzinger, in a thesis supervised by W. Hillebrandt and B. Leibundgut (ESO), computes bolometric lightcurves of well-observed Type Ia's, including the RTN-sample, and searches for the physical reason behind the observed luminosity/lightcurve-shape relation that is crucial for their use in cosmology. Also, by calculating the true luminosity and nickel mass of many type Ia supernovae one hopes to determine the major stellar evolutionary channels, which lead to these events. T. Behrens, in a Diploma thesis supervised by J. Niemeyer (now U. Würzburg) and P. Mazzali (Trieste), has looked at alternative correlations. Among others, he found a correlation between decline rate of type Ia supernovae and the velocity of the ejecta as measured by silicon and iron.

S. Inoue, together with N. Iwamoto, M. Orito and M. Terasawa (National Astronomical Observatory, Japan) explored the possibility of nucleosynthesis in baryon-rich outflows which are generically expected to accompany GRBs. Utilizing detailed reaction network codes in the context of the fireball model, it was found that appreciable amounts of heavy neutron capture elements can be produced, which should be observable in the companion stars of black hole binary systems and in the most metal-poor stars. S. Inoue, in collaboration with W. Aoki, S. Kawanomoto, T.K. Suzuki (National Astronomical Observatory, Japan), S.G. Ryan and I.M. Smith (The Open University), observationally determined the abundance of the element ^{6}Li in the metal-poor star HD140283 using the Subaru Telescope High Dispersion Spectrograph, resulting in a low upper limit. This data strongly constrains supernova cosmic ray production models of ^{6}Li, and may be more consistent with the structure formation shock scenario proposed earlier by Suzuki and Inoue (2002), provided that depletion effects have not been significant in this star.

C. Travaglio, K. Kifonidis and E. Müller have investigated the numerical requirements necessary for the calculation of reliable nucleosynthetic yields in Eulerian simulations of neutrino-driven core collapse supernova models. For this purpose a marker particle integrator was coupled to the Eulerian supernova code HERAKLES. The temperature and density histories of the marker particles, which are passively advected with the flow in the course of the Eulerian simulation, are used to compute the nucleosynthesis in a post-processing step. In collaboration with F.-K. Thielemann (Basel) and M. Limongi (Rome) two nuclear network codes are currently being evaluated for this purpose. Subsequently, the method will be extended to study nucleosynthesis also in multidimensional flows, like those expected due to the mixing induced by neutrino-driven convection behind the shock wave and/or due to the asphericity of the shock itself.

C. Travaglio developed a series of studies aimed at interpreting and modeling the evolution of light and heavy elements in the interstellar medium of our Galaxy. In particular, she focused on one of the lightest element of cosmological interest, i.e. Lithium, and on elements produced by slow and and rapid neutron capture nucleosynthesis, i.e. elements from Copper and Zinc, and heavier from Strontium up to Lead and Bismuth.

The evolution of Li and the main stellar sources are still not completely understood. In this study C. Travaglio considered the interplay among the different stellar sources required to account for the Pop.I Li abundance. Moreover, in order to put stringent constraints on theoretical models C. Travaglio developed in collaboration with J. Lattanzio (Monash University, Australia) and D. Galli (Observatory of Florence). She has undertaken an observational campaign to determine Li and metallicity in a selected sample of Pop.I stars, including field and evolved stars, in collaboration with C. Abia (University of Granada, Spain) and S. Randich (Observatory of Florence Italy).

A quantitative understanding of the Galactic evolution of nuclei heavier than iron has been so far a challenging problem. Although some of the basic tools of this task have been presented several years ago, both from an observational and a theoretical point of view, only recently the observations have grown sufficiently in number and precision to allow a direct comparison with theoretical predictions. From the observational and theoretical point of view (thanks to the collaborations with observers as well as theoreticians) C. Travaglio tried to recontruct the chemical evolution of: Cu and Zn, in collaboration with M. Busso (University of Perugia, Italy) and T. Mishenina (Odessa Astronomical Observatoy, Ukraine); Mg and Ba, in collaboration with L. Mashonkina (Department of Astronomy, Kazan State University, Russia) and T. Gehren (University of Munich, Germany); the most rare isotope ^{180}Ta, in collaboration with R. Gallino (University of Turin, Italy), F. Kaeppeler (Forsschungszentrum Karlsruhe, Germany); and the light-heavy elements Sr-Y-Zr, in collaboration with R. Gallino (University of Turin, Italy) , John Cowan (University of Oklahoma, USA), Chris Sneden (University of Texas, USA).

In collaboration with M. Keil and G. Raffelt (both MPI for Physics, Munich) H.-Th. Janka and M. Rampp investigated, for the first time in the context of stellar core collapse and supernova explosions, the effects of muon and tau neutrino pair creation by the annihilation of electron neutrinos and antineutrinos and the corresponding scattering reactions. The neutrino emission and shock dynamics are significantly changed by these processes, which therefore should be included in hydrodynamical simulations. In a related project, M. Keil (MPI for Physics, Munich) studied as part of his PhD work, jointly supervised by G. Raffelt (MPI for Physics, Munich) and H.-Th. Janka, the influence of different weak interactions on the spectra formation of the neutrinos that are emitted from a forming neutron star. His Monte Carlo transport simulations showed that the electron antineutrino and muon and tau neutrino spectra become more similar than previously thought when nucleon recoil, nucleon-nucleon bremsstrahlung, and the newly considered neutrino-neutrino processes are taken into account.

M. Rampp and H.-Th. Janka investigated the consequences of electron captures by nuclei on stellar core collapse and supernova shock formation. For this purpose new rate tables of the capture rates, integrated over the distribution of nuclei in nuclear statistical equilibrium, were provided by K. Langanke and J. Sampaio (both Univ. Aarhus, Denmark). With these rates included, electron captures on free protons turned out to be dwarfed to insignificance. The electron fraction and the shock formation radius are somewhat reduced compared to the conventional treatment where the effects of nuclei were effectively neglected.

3.3 Numerical Hydrodynamics

The work on modeling thermonuclear combustion fronts and type Ia supernova explosions was continued. The group, consisting of W. Hillebrandt, J.C. Niemeyer and M. Reinecke, and PhD students F. Roepke, W. Schmidt, and L. Iapichino investigated questions concerning the nature of subsonic turbulent burning fronts in the flamelet as well as in the distributed burning regime, various hydrodynamic and flame instabilities, and numerical methods to model them.

In particular, the level set method used by the group in the flamelet regime was extended by F. Röpke to allow for full reconstruction of thermodynamic quantities in grid zones cut by the front. His special treatment of flame/flow coupling allows the treatment of the flame as a sharp discontinuity in the state variables. A parallelized code incorporating the new techniques was developed and tested successfully. The goal was to study the flame evolution under the influence of the Landau-Darrieus instability and its counteracting nonlinear stabilization mechanism. The numerical simulations were consistent with expectations on the flame propagation in the linear and nonlinear regime. The growth rate of the amplitude of perturbations as predicted by Landau could be reproduced, as well as the stabilization of the flame in a cellular structure at later stages of the evolution. Studies to estimate the effects of the interaction of the flame with turbulent flows are under way.

A new subgrid-scale (SGS) model to estimate the boost of the flame propagation speed due to turbulence at unresolved scales was investigated by W.

Schmidt. In contrast to the SGS model that has been implemented in Prometheus so far, the new model is based on a dynamical procedure to determine the free parameters of the subgrid kinetic energy equation from structural properties of the resolved flow. This method utilizes the self-similarity of fully developed turbulence over a range of scales in which neither energy production nor viscous dissipation are significant. In order to test explicitly the self-similarity assumptions used for the dynamical model, he has performed several high-resolution direct numerical simulations of isotropic turbulence. In these simulations, stochastic stirring is used to force turbulence and the evolution of the system is computed over sufficiently long time to obtain fully developed turbulence in a statistically stationary regime. To make the new SGS model applicable to supernova simulations some issues remain to be tackled: Firstly, the treatment of cells intersected by the flame surface is not clear yet. Secondly, the dynamical procedure requires a an equidistant grid. For this reason, it would be necessary to implement a homologously expanding grid in Prometheus to follow up the enlargement of scales as the white dwarf expands in the course of the explosion.

Following up on their earlier work M. Reinecke, W. Hillebrandt and J.C. Niemeyer presented an improved set of numerical models for simulations of white dwarfs exploding as type Ia supernovae. Full 3D simulations were carried out for different ignition conditions, besides the initial composition the only remaining parameters of the models, and successful explosions were found in all cases. All models gave results comparable to observed SN Ia in terms of released energy and production of ^{56}Ni. In contrast, the distribution of freshly synthesized chemical elements in velocity space turned out to be quite different for different initial conditions, opening the possibility to determine them from comparisons with observed high-resolution spectra.

An attempt has been started to model also the last few minutes in the life of a white dwarf prior to thermonuclear runaway and to determine the ignition conditions in a more rigorous way by means of multi-dimensional numerical simulations. L. Iapichino, in a PhD thesis supervised by W. Hillebrandt and J.C. Niemeyer, is comparing different numerical schemes that seem, in principle, to be able to tackle this problem, including a version of the Chicago "Flash Code". First results look promising. Numerical solutions of white dwarfs have been found which are stable on time-scales much larger than the sound-crossing time.

T. Leismann developed in the course of his PhD thesis, supervised by M.A. Aloy and E. Müller, a 2D special relativistic hydrodynamics code suited for the simulation of relativistic magnetized jets. The code involves staggered grids in order to avoid the numerical generation of magnetic monopoles. The advection is implemented via an approximate Riemann solver.

K. Kifonidis has developed a parallel, time-dependent photoionization code targeted for parallel computers with vector as well as superscalar processors. In collaboration with T. Plewa (ASCI FLASH Center, University of Chicago) the code will be coupled to PPM hydrodynamics schemes, including adaptive mesh refinement. It will be applied to the problem of planetary nebula evolution and for modelling the ring structures around SN 1987A.

As final part of his PhD supervised by E. Müller, J.A. Font (University of Valencia) and Philippos Papadopoulos (University of Portsmouth), F. Siebel studied axisymmetric supernova core collapse with his fully relativistic hydrodynamical code based on the characteristic formulation of general relativity. Modelling the iron core as a relativistic polytrope, and using a model equation of state which takes into account the stiffening at supra-nuclear densities and the thermal heating due to shocks, he studied the dynamics of collapse, neutron star formation and shock propagation. Covering the spacetime up to infinity, he also extracted the gravitational wave signals with no approximation required.

M.A. Aloy, in collaboration with J.A. Miralles and J.M. Ibáñez (University of Valencia) and V. Urpin (A.F. Ioffe Institute of Physics and Technology), has performed an analytic study of the stability of ultrarelativistic jets in the collapsar model for gamma–ray bursts. His numerical simulations show the presence of a strong shear in the bulk velocity of such jets. This shear can be responsible for a very rapid shear–driven instability that arises for any velocity profile. This conclusion has been confirmed both by numerical simulations and theoretical analysis. The instability leads to rapid fluctuations of the main hydrodynamic parameters. The characteristic growth time of the instability is much shorter than the life time of the jet and, therefore, may lead to a complete turbulent beam. In the course of the non-linear evolution, these fluctuations may produce internal shocks which can be randomly distributed in the jet. If internal shocks in a ultrarelativistic outflow are responsible for the observed phenomenology of gamma-ray bursts, the proposed instability can well account for the short-term variability of gamma-ray light curves down to milliseconds.

M.A. Aloy, H.-T. Janka and E. Müller have started a new line of work concerned with neutron star mergers as progenitors of gamma–ray bursts. They are interested in exploring under which conditions a successful ultrarelativistic jet or wind is formed in this scenario, and whether these jets may explain the properties of the short gamma-ray bursts. Their model assumes that the jet (or wind) is initiated by the release of energy due to the annihilation of neutrinos and anti-neutrinos produced in the accretion disk resulting from the merger process. Their preliminary results indicate the possibility of obtaining extremely smooth, highly collimated, ultrarelativistic outflows with a very low baryon pollution in a fraction of a millisecond.

M.A. Aloy and E. Müller, in collaboration with J.M. Martí and J.M. Ibáñez (University of Valencia) and J.L. Gómez (Instituto de Astrofísica de Andalucía) have performed numerical simulations of relativistic jets in order to disentangle the effects of curvature, helical motions and light travel time delays on the morphologies observed in parsec scale jets. In particular, they performed a three-dimensional, relativistic, hydrodynamic simulation of a precessing jet into which a compact blob of matter is injected. A comparison of synthetic radio maps computed from this hydrodynamic model with those obtained from observations of actual superluminal sources shows that the variability of the jet emission is the result of a complex combination of phase motions, viewing angle selection effects, and non-linear interactions between the perturbations and the underlying jet and/or the external medium. These results question the hydrodynamic properties inferred from observed apparent motions and radio structures, and unveil that shock-in-jet models may be over-simplistic.

R. Buras in his PhD work, supervised by H.-Th. Janka and M. Rampp, updated the collision integral in their new Boltzmann neutrino-hydrodynamics code (named VERTEX for one-dimensional and MuDBaTH for multi-dimensional simulations) by adding neutrino-neutrino interactions. The treatment of the low-density equation of state in this code was improved and extended for nuclear burning and a simplified description of composition changes due to shifts of nuclear statistical equilibrium. The code was also extended by lateral neutrino advection and neutrino pressure terms, which turned out to be indispensable for performing multi-dimensional simulations. K. Kifonidis provided important input with respect to parallel matrix inversion techniques and upgrades of the PROMETHEUS hydrodynamics code. By the joint effort of M. Rampp and R. Buras, with significant support by R. Hatzky (Rechenzentrum Garching), the coupled Boltzmann neutrino transport and hydrodynamics program was adapted for high-performance and efficient computations on single nodes of the new IBM "Regatta" supercomputer of the Rechenzentrum Garching.

In a collaboration with M. Liebendörfer (CITA, Toronto) and A. Mezzacappa (Oak Ridge Nat. Lab., Tennessee), the new neutrino-hydrodynamics program was tested against the Oak Ridge-Basel code AGILE-BOLTZTRAN. Both codes use very different methods to solve the hydrodynamics equations and the neutrino transport. Applying them to well defined one-dimensional core collapse problems with Newtonian and relativistic gravity, we found good agreement for all phases of the supernova evolution.

F. Miniati, has worked in collaboration with P. Ricker (ASCI center U. of Chicago, now at University of Illinois at Urbana-Champaign) and the ASCI center on the implementation of a numerical module that allows the capability of following collisionless, particle-like components in the FLASH Adaptive Mesh Refinement code. The new code will be suitable for the investigation of a variety of problems. In particular it will allow high resolution cosmological simulations which will take advantage of the several physics modules already available in FLASH, such as MHD and radiative cooling, etc. This will make it possible to carry out numerical investigation of several new problems of great interest in the community.

The equilibrium and evolution of 'fossil' magnetic fields in stars (magnetic A-stars and white dwarfs) was studied with numerical simulations by J. Braithwaite (EARA fellow, PhD project supervised by H. Spruit). The first results show that nonaxisymmetric field configurations of the 'linked poloidal-toroidal' type evolve naturally as end-products of the decay of random initial fields, and that these can be long-lived (stable on Alfvén time scales).

3.4 High Energy Astrophysics

The nearby black holes are much less luminous than active galactic nuclei in distant galaxies. T. Di Matteo, in collaboration with S. Allen and A.C. Fabian (Cambridge University), and A.S. Wilson and A.J. Young (University of Maryland), on the massive black hole in M87 has provided a definitive answer as to why the nearby black holes appear so dim. I have shown that, with its excellent resolution *Chandra* is able to image the hot X-ray emitting gas down to the gravitational capture radius of the central $3 \times 10^9 M_\odot$ black hole in M87. By measuring the density and the thermal state of the gas in this region I was able to derive a direct and reliable estimate of the Bondi mass accretion rate, $\dot{M}_\mathrm{B}$, in M87. Although, $\dot{M}_\mathrm{B}$, is well below the Eddington rate (the accretion rate typical of quasars), it cannot explain the extremely low luminosity of this nucleus. The X-ray luminosity of the active nucleus of M87 is much less than the predicted nuclear luminosity, $L \sim 0.1\dot{M}_\mathrm{B}c^2$. This firmly establishes that accretion must occur in a radiatively inefficient mode.

The nature of the cosmic dark matter is one of the mysteries of the present standard models of cosmology and particle physics. In many particle physics scenarios the dark matter decoupled from the primordial fireball at the so called freeze-out-epoch in the very early universe. In these scenarios the observed dark matter mass density is fixed by the self-annihilation cross-section of the dark matter particles. This indirect information on the cross-section allows to search for radiation due to dark matter annihilation in regions of high dark matter density, as the Galactic centre or nearby galaxy clusters. A collaboration of C. Böhm (Oxford), T. Enßlin, and J. Silk (Oxford) used this in order to constrain the particle physics parameter space of light (MeV-GeV mass) bosonic dark matter candidates.

High mass X-ray binaries and star formation. H.-J. Grimm, M. Gilfanov and R. Sunyaev studied population of high mass X-ray binaries (HMXB) and their relation to the star formation. Based on recent X-ray observations of the Milky Way, Magellanic Clouds and nearby starburst galaxies they suggested that the number and/or the collective X-ray luminosity of HMXBs can be used to measure the star formation rate (SFR) of a galaxy. The data in the $\lg(L_X) \sim 36-40$ luminosity range are broadly consistent with existence of a universal luminosity function of HMXBs which can be roughly described as a power law with differential slope of ~ 1.6, a cutoff at $\lg(L_X[erg/s]) \sim 40.5$ and the normalization proportional to the star formation rate. The high luminosity part of this distribution corresponds to the ULX sources found in many starburst galaxies. They pointed out that statistical properties of the probability distribution of the collective luminosity of HMXBs lead to non-linear relation between SFR and the X-ray luminosity of a galaxy at low values of the star formation rate. Based on Chandra obseravtions the Hubble Deep Field North they showed that the calibration of the X-ray luminosity as SFR indicator derived from the local sample agrees well with the data for starburst galaxies located at intermediate redshifts, $z \sim 0.2-1.2$.

Comptonization and reflection in Seyfert galaxies and X-ray binaries. M. Gilfanov, M. Revnivtsev and A. Zdziarski P. Lubinski (N. Copernicus Astronomical Center) studied correlations between spectral properties of accreting black holes (Seyferts and black-hole binaries) with particular emphasis on the correlation between X-ray spectral index and strength of Compton reflection (R-Γ correlation). Critically evaluating the evidence for R-Γ correlation and considering in detail statistical and systematic effects that can affect it, they concluded, that the existence of global correlation between these two parameters can be established beyond any reasonable doubts. They showed that R-Γ correlation is a natural consequence of coexistence of cold media (e.g. accretion disk) and the hot Comptonizing cloud in the vicinity of the black hole and discussed it's implications for the accretion models.

S. Heinz and R. Sunyaev derived the non-linear relation between radio flux and black hole mass in core dominated jets. They were able to show that this relation is independent of the assumed jet model. Only the input conditions at the base of the jet, provided by the accretion disk, determine this relation. This explains the strong non-linear correlation found between jet emission from microquasars and from AGN jets. S. Heinz showed that such a scale invariant comparison between jets from black holes of different mass is only possible for the cores of jets. He showed that the environment of AGN jets provides a much stronger barrier into which the jets propagate than the environment of microquasar jets, even though microquasar jets are situated in denser gas. Heinz showed that the dynamical evolution of ejections in the sources GRS 1915+105 and GRO J1655-40 prove that their environment must be much less dense than typical interstellar matter, which is evidence for the existence of a low density halo of radio plasma from previous ejections, i.e., and undetected radio lobe.

Turbulent cores of the galaxy clusters. E. Churazov in collaboration with W. Forman, C. Jones (CfA) and H. Böhringer (MPE) studied the X–Ray emission from the core of the Perseus cluster using XMM-Newton data. The complicated substructure of the surface brightness and the gas temperature distributions can be explained as a consequence of propagation of acoustic waves through the cluster core, generated by a accreting subroups at the outskirts of the cluster. The gas in the core is shown to be turbulent with a typical velocities at the level of a half of the sound speed.

F. Miniati has also computed in detail, based numerical simulations, the spatial and spectral properties of gamma-ray emission from shock accelerated CRs in clusters of galaxies. It is shown that different CR components can contribute the emission of diffuse gamma radiation at a comparable level. Particularly, both inverse Compton emission and decay of neutral pions make appreciable radiation flux above 100 MeV. The measurement of this flux is targeted to estimate the CR-proton content in galaxy clusters. It is shown, however, that the two emission processes originate in spatially separate regions and that instruments with sufficient spatial resolution should be able to discriminate among them. It is pointed out that such measurements, if successful, will allow direct detection of the accretion shocks. In addition, it is pointed out the importance of such spatially resolved observations for correct estimates of intracluster magnetic fields.

T. Enßlin proposed that the circular polarised radio emission of many quasars is Faraday converted synchrotron emission in a helical field geometry, as it is naturally expected to be present in relativistic jets launched from rotating accretion discs. If Faraday rotation is suppressed in the jet, a unique relation between the accretion disc and the polarisation rotational senses is given. This would explain the long term persistence of the observed circular polarisation sign of individual sources, and would allow to measure the rotational sense from quasar central engines. For Sgr A* this scenario would predict that the accretion disc is counter-rotating with respect to the Galaxy, but co-rotating with the population of hot stars in its vicinity, which were proposed to feed the central galactic black hole with their winds.

S. Inoue with M. Nagashima (National Astronomical Observatory, Japan) have developed semi-analytic methods to investigate nonthermal particle acceleration and emission in merger/accretion shocks due to large scale structure formation, by constructing Monte Carlo merger trees and accounting for the distribution of merger mass ratios and shock Mach numbers. The inverse Compton gamma-ray emission from shock-accelerated electrons were shown to be dominated by strong shocks in minor mergers rather than weak shocks in major mergers, and their integrated emission can account for a significant fraction of the observed gamma-ray background. Future deep gamma-ray observations may constrain the unknown efficiency of nongravitational heating/cooling processes in the intergalactic medium.

Recent X-ray observations have shown evidence for exceptionally broad and skewed iron Kα emission lines from several accreting black hole systems. The lines are assumed to be due to fluorescence of the accretion disk illuminated by a surrounding corona and require a steep emissivity profile increasing in to the innermost radius. This appears to question both standard accretion disc theory and the zero torque assumption for the inner boundary condition, both of which predict a much less extreme profile. Instead it argues that a torque may be present due to magnetic coupling with matter in the plunging region or even to the spinning black hole itself. Discussion so far has centered on the torque acting on the disc. In a work done in collaboration with A.C. Fabian (Institute of Astronomy, Cambridge), A. Merloni argued that the crucial determinant of the iron line profile is the radial variation of the power radiated in the corona in magnetized accretion discs and studied the effects of different inner boundary conditions on the coronal emissivity and on the profiles of the observable Fe Kα lines. They argued that in the extreme case where a prominent high redshift component of the iron line is detected, requiring a steep emissivity profile in the innermost part and a flatter one outside, energy from the gas plunging into the black hole is being fed directly to the corona.

M. Revnivtsev, M. Gilfanov, E. Churazov and R. Sunyaev continued to study enigmatic transient source high mass X-ray binary. There were analyzed a collections of X-ray observations and it was shown that they broadly support the hypothesis (previously claimed by these authors) that giant September 1999 outburst was associated with an episode of super-Eddington accretion onto the black hole. During the outburst an extended optically thick envelope/outflow has been formed around the source making the observational appearance of V4641 Sgr in many aspects very similar to that of SS433. These results suggest that objects like V4641 Sgr and SS433 indeed represent the class of objects accreting matter at a rate comparable or above Eddington value and the formation of an envelope/outflow is a generic characteristic of supercritical accretion. When the accretion rate decreased the envelope vanished and the source short term variability and spectral properties started to resemble those of other galactic black hole candidates accreting at a rate well below the Eddington value. Interestingly that during this phase the source spectrum was very similar to the Cygnus X-1 spectrum in the low state inspite of more than order of magnitude larger X-ray luminosity.

Long term observations of X-ray transients could reveal a lot of new information about binary systems and shed a light on a mechanism of their transient behavior. However, it is very hard to perform such observations. M. Revnivtsev in collaboration with N. Aleksandrovich, V. Aref'ev and A. Emel'yanov (Space Research Institute, Moscow) succeeded to combine more that 10 years of observations of TTM telescope and RXTE/ASM all sky monitor to study neutron star binaries KS1731-260 and 4U1724-307 (in globular cluster Terzan 2). They have shown that KS 1731-260 during some episodes of his 10 years outburst demonstrated high amplitude quasi regular variations, that could be interpreted as a influence of predicted limit-cycle instability. This result could be used to estimate the accretion disk viscosity. Analysis of the lightcurve of 4U1724-307 showed that this source showed very unusual graduate increase and then graduate decrease of its flux on a time scale of 10 years. Authors discuss several scenarios to explain this behavior, including the evolution of mass outflow rate from the donor star surface due to the passage of a third star close to the binary system 4U1724-307 (the binary system is located inside the core of a globular cluster that has extremely high star density).

M. Revnivtsev in collaboration with S. Trudolyubov and K. Borozdin (Los Alamos National Laboratory) published a list of bright X-ray sources detected during a set of CHANDRA observations of 6 globular clusters: NGC6440, NGC 6441, NGC 6624, Terzan 1, Terzan 2, Terzan 6

The Galactic ridge emission was discovered in 1972 and since then various satellites were used to study this emission: HEAO1, EXOSAT, Tenma, GINGA, ASCA. Now Rossi X-ray Timing Explorer provides unique capabilities to study this emission with relatively high sensitivity and uniform coverage of central 10 degrees. M. Revnivtsev analyzed large set of scanning observations of RXTE/PCA of the Galactic center field (approximately 700 ksec total exposure time) to study the distribution of Galactic ridge emission parameters. He showed that at Galactic latitudes 2<b<10 degrees the brightness profile could be well described by an exponential model with e-folding size 3.3 degrees, and that the spectral parameters of the ridge emission almost do not change over studied field. These results could be very important for any model of the origin of the Galactic ridge emission.

Resonant scattering can distort the surface brightness profiles of galaxy clusters in X-ray lines. S. Sazonov, E. Churazov and R. Sunyaev demonstrated that the scattered line emission should be polarized and possibly detectable with future X-ray polarimeters. Spectrally resolved mapping of a cluster in polarized X-rays could provide valuable information on the physical conditions, in particular element abundances and the characteristic turbulence velocity, in the intracluster gas. The expected degree of polarization is of the order of 10% for richest regular clusters (e.g. Coma) and clusters whose X-ray emission is dominated by a central cooling flow (e.g. Perseus or M87/Virgo). Most nuclei of giant elliptical galaxies in the nearby universe are surprisingly dim at present. Continuing the above theme, S. Sazonov, R. Sunyaev and C. Cramphorn studied the feasibility of constraining the past (up to 10^6 years ago) X-ray luminosity of the nucleus of a cluster dominant galaxy by measuring the contribution of scattered radiation from the central source to the surface brightness of the intracluster gas. Resonance X-ray lines present an advantage over the adjacent continuum because the relative contribution of the scattered component is larger in the line case by a factor of 3–10. Estimates were made for the nearby M 87 and Cygnus A active galaxies. A similar method can be applied to distant powerful quasars (at redshifts $z > 1$). Their surface brightness profiles in the X-ray continuum above $\sim$ 10 keV $\gg kT/(1+z)$ (where T is the gas temperature) should be dominated by redshifted scattered radiation from the quasar. Therefore, measurements with forthcoming mirror-optics hard X-ray telescopes could give information on the lifetime of quasars and parameters of the hot gas around them.

Further developing the general method of using scattered X-ray signal for studying astrophysical objects, S. Sazonov and R. Sunyaev considered a popular scenario in which gamma-ray bursts originate in molecular clouds in distant galaxies. If this is true, one could detect a significant flux of GRB prompt and early afterglow X-ray radiation scattered into our line of sight by the molecular and atomic matter located within tens of parsecs of the GRB site long after the afterglow has faded away. The scattered flux directly measures the typical density of the GRB ambient medium. Furthemore, if the primary emission is beamed, it should be possible to estimate the collimation angle of a burst from the light curve of its X-ray echo and a measured value of the line-of-sight absorption column depth. Detection of such an echo is for the brightest GRBs just within the reach of the Chandra and XMM-Newton observatories.

S. Sazonov, J. Ostriker (Institute of Astronomy, Cambridge, UK) and R. Sunyaev computed the characteristic spectrum and the Compton equilibrium temperature, T_c, of the emission of the average quasar in the Universe. Using 1) measurements of cumulative AGN light at various wavelengths, 2) data on composite quasar spectra and 3) the measured local mass density of massive black holes, the average T_c was constrained to a narrow range around 2×10^7 K. This value is interestingly close to typical temperatures of gas in the cooling flows of elliptical galaxies and clusters of galaxies and above the virial temperatures of lower mass galaxies. A number of applications of these results will be considered in future work. In particular, the average spectrum and Compton temperature obtained will be applied to the model of Ciotti and Ostriker that considers radiative feedback from the central massive black hole to the X-ray halo of a giant elliptical galaxy as a means to regulate the accretion growth of the black hole.

G. Drenkhahn (superviser H. Spruit) defended his thesis at the University of Amsterdam on 11 June, on "Magnetically powered Gamma-ray Bursts". His work shows that for typical GRB parameters the Poynting flux produced by a nonaxially symmetric rotating magnetic field (as invoked in several types of central engine model) dissipates gradually over a considerable distance. In this way, it simultaneously powers most of the acceleration of the flow to high Lorentz factors, produces the nonthermal emission outside the photosphere, and provides the strong magnetic field needed for efficient synchrotron emission. This makes magnetically powered outflows a strong alternative to the standard internal shock model for prompt GRB radiation.

N. Sibgatullin (Moscow State University) showed that the inclination of low-eccentricity orbits significantly affects orbital parameters, in particular, the Keplerian, nodal precession, and periastron rotation frequencies, which are interpreted in terms of observable quantities. A Taylor expansion in terms of the Kerr parameter was derived for the nodal precession and periastron rotation frequencies of low-eccentricity orbits in a Kerr field. The particle radius, energy, and angular momentum in the marginally stable circular orbits were calculated as functions of the Kerr parameter j and parameter s in the form of Taylor expansions in terms of j to within $O[j6]$. Compact approximation formulas were presented for the nodal precession frequency of the marginally stable circular orbits at various s in the entire range of the Kerr parameter.

V.V. Zheleznyakov and S.A. Koryagin (Institute of Applied Physics, Russian Academy of Sciences) investigated the problem of determining the plasma composition of relativistic jets in blazars and microquasars from the polarization frequency spectra of their synchrotron radiation. They analytically calculated the polarization spectra of the synchrotron radiation for simple models of jets with a uniform magnetic field and with a magnetic-field shear. They pointed out the characteristic features of the polarization spectra which allow to differentiate between the synchrotron radiation from an admixture of relativistic particles in a cold plasma and the radiation from a relativistic plasma. Only radioastronomical studies with high angular and frequency resolution will make it possible to determine the content of relativistic plasma (electrons or electron-positron pairs).

3.5 Accretion

Accretion is one of the central topics in modern astrophysics. At MPA much effort has been devoted to the understanding of accretion processes. This includes systematic, analytical studies of the accretion flow as well as short time variability and the analysis of spectra. The objects studied reach from protoplanetary disks around young stars, cataclysmic variables, neutron stars and stellar black holes in X-ray binaries to the Galactic Center and Active Galactic Nuclei (AGN). Additional topics are wind accretion flows and the evolution of massive accretion tori as remnants of mergers of compact binary stars.

C.P. Dullemond has developed a 2-D self-consistent model for irradiated protoplanetary disks around intermediate mass pre-main-sequence stars. In this model, the temperature of the gas and the dust at every location in the disk is computed through 2-D continuum radiative transfer, and the density structure is solved from the equation of hydrostatic equilibrium in vertical direction. This is the first self-consistent 2-D model for such disks to date, and it reveils various new aspects of irradiation that have not been seen in models using the standard 1+1D (annulus by annulus) splitting of the problem. Using this model, and a semi-analytic approximation of it, various stars have been analyzed. Predictions have been made for the upcoming SIRTF mission (space infrared telescope facility) and the MIDI instrument on the VLTI (mid-infrared interferometry), both of which should come on-line in 2003. Much of this work is done in collaboration with C. Dominik and L. Waters (University of Amsterdam, the Netherlands), A. Natta (Arcetri, Italy) and E. van Dishoeck (University of Leiden, the Netherlands).

A. Merloni carried on a systematic, analytical study of geometrically thin, optically thick accretion disc solutions for magnetized turbulent flows, with an α-like viscosity prescription. Under the only assumptions that (1) Magneto-Rotational instability (MRI) generates the turbulence that produces the anomalous viscosity needed for accretion to proceed, and that (2) the magnetic field amplified by the instability saturates due to buoyant vertical escape, he was able to self-consistently solve the disc structure equations including the fraction of power f that is carried off by vertical Poynting flux. In doing so, a new stable, radiation pressure dominated solution is found for high viscosity discs, characterized by $f \sim 1$ and appearing only above a critical accretion rate (of the order of few tenths of the Eddington one). This newly discovered thin disc solutions, possibly accompanied by powerful, magnetically dominated coronae and outflows, should be relevant for models of black holes accreting close to (or above) the Eddington rate.

F. Meyer and E. Meyer-Hofmeister continued work on a model for super-Eddington X-ray sources. F. Meyer and Y. Osaki (Nagasaki University) showed that evidence for increased mass overflow in outbursts of dwarf novae and models based on it are flawed by misinterpretation and inconsistencies. A refined thermal-tidal instability model without increased mass transfer successfully explains the multitude of very different outburst behaviours in these systems including the case of the ER UMa subclass of SU UMa systems that up to now have remained a mystery.

M. Revnivtsev, M. Gilfanov and S. Molkov (IKI, Moscow) studied origin of short term variability in luminous low mass X-ray binaries. Based on the RXTE observations of GX340+0 and 4U1608-52 they found that the energy spectra of aperiodic variability do not depend upon Fourier frequency at $f1$ Hz. This fact, combined with high degree of coherence and nearly zero phase lags between different energies implies that observed variability results from oscillations of the same emission component associated with the same, distinct component of the accretion flow. Importantly, these results indicate that the kilohertz QPO originate in the same region as the bulk of the aperiodic variability and intermediate frequency QPO. The energy spectrum of this oscillating component is significantly harder than the average spectrum, is inconsistent with simple models of the accretion disk emission and can be roughly described by a Comptonized blackbody emission with $kT \sim 2$ keV. It was demonstrated, that the variable component originates the boundary layer near the surface of the neutron star. The emission of the accretion disk has softer energy spectrum, is significantly less variable and contributes to observed flux variation at low frequencies only.

EARA-fellow D. Giannios (supervision H.C. Spruit and N. Kylafis) started the development of a model for the quasi-periodic oscillations of black hole X-ray transients. It assumes the 'truncated disk' accretion geometry developed earlier by Deufel, Spruit and Dullemond (see report 2001). The interaction between an inner ion-supported accretion flow (ISAF) and the truncated disk leads to excitation of radial oscillations of the ISAF at a frequency of the order of the Kepler frequency of the inner edge of the disk.

For Gamma Ray Bursts (GRB) most popular models invoke a binary merger or a collapse leading to the formation of a black hole with a debris torus or disk around it. In these scenarios, the black hole is accreting at sufficiently high rates (a few solar masses per second) that the disk becomes dense and hot enough in the inner regions to cool via neutrino emission. T. Di Matteo with R. Perna and R. Narayan (Harvard University), has worked on deriving dynamical solutions of neutrino dominated accretion flows. I have improved on previous calculations by including a simple prescription for neutrino transfer and neutrino opacities in these disks. I have shown that at very high accretion rates, neutrinos are sufficiently trapped that energy advection becomes the dominant cooling mechanism in the flow. These results imply that, neutrino annihilation in hyperaccreting black holes is an inefficient mechanism for liberating large amounts of energy. Extraction of rotational energy by magnetic processes remains the most viable mechanism for liberating energy.

Using Chandra observations of the neutron star 4U 2129+47, M. Nowak (MIT), S. Heinz, and M. Begelman (CU) investigated the structure of the X–ray emission region. The lightcurve exhibits total eclipses and sinusoidal modulation in the powerlaw component of the spectrum, which is interpreted as interaction of the accretion stream and a small accretion disk. They show that the 0.1" X-ray astrometry of the X-ray source is consitent with the claim that the system is a hierarchical triple.

N.I. Shakura (Sternberg Astronomical Institute, Moscow) and R. Staubert (IAAT, Tuebingen) organized a multi-wavelength campaign of X-ray (Ginga and RXTE data) and optical observations of the 35-day cycle in Hercules X-1. The phase evolution of the X-ray pulse profile of Hercules X-1 was analysed. Free precession of the neutron star was shown to be the clock mechanism underlying the observed long-term stability of the 35-day cycle. The complex behaviour of the X-ray pulse shape evolution with time requires additional emitting regions (apart from the standard magnetic poles) on the surface of the neutron star with a more complex, horses-like geometry around the magnetic poles.

N.A. Inogamov (Landau Institute for Theoretical Physics, Russian Academy of Science, Moscow) and R.A. Sunyaev continued their theoretical study of the boundary layer of the neutron star accretion disk. Specifically, the "neck" region, in which the accretion disk transforms into a boundary layer, was carefully analysed. While in the preceding work the main attention was given to the latitude dependence of parameters of the boundary layer, now both the radial and latitude structure of the boundary layer were studied simultaneously. As a result, a more complete picture of disk accretion onto a neutron star was obtained.

The interaction of ion supported accretion flows with a surrounding 'truncated cool disk' (see report 2001) was studied by C. Dullemond and H. Spruit. Spectra and time dependence of this interaction yield promising new interpretations of the spectra and variability of black hole accreters.

G.V. Lipunova and N.I. Shakura (Sternberg Astronomical Institute, Moscow) fitted the X-ray and optical light curves of two X-ray novae (Nova Monocerotis 1975 = A 0620 and Nova Muscae GS 1991 = 1124–683) by a non-steady-state accretion-disk model. The inferred accretion rate decreases as a power law. The estimates for the non-dimensional turbulence parameter α are similar: 0.2–0.4 for A 0620-00 and 0.45–0.65 for GS 1124–683. Also, the distances to these systems were derived as a function of the compact object mass. A model for the secondary maxima in the X-ray nova light curves was suggested: a zone of partial ionization develops near the outer edge of the disk, which temporarily increases α. An analytic qualitative calculation of the light curve at the secondary maximum was made, suggesting that the partial ionization zone propagates inward.

H. Spruit and G. Kanbach (MPE) analyzed the relation between X-rays and optical emission from the black hole transient KV UMa (=XTE J1118+480). From detailed analysis of the variability of the cross-correlation they concluded that the curious 'premonition dip' (see see report 2001) is in fact an integral part of the optical light curve, and probably caused by the same physical mechanism. The search for a good explanation of this remarkable optical behavior, which may be common among black hole accreters in the 'hard' state, is in progress in collaboration with D. Giannios and J. Malzac (IoA Cambridge).

H. Spruit and G. Kanbach (MPE) used the Rossi X-ray timing explorer (RXTE) and Kanbach's fast optical photometer OPTIMA for two campaigns of coordinated observations of the black hole candidate Cyg X-1. A stringent upper limit could be set on any optical emission correlated with X-rays, significantly lower than observed earlier in the black hole transient KV UMa. Unforunately, during these observations Cyg X-1 was in a 'soft' X-ray state which is less likely to produce the interesting X-ray/optical correlations. Further observations are planned after the source has returned to its normal hard state.

S. Nayakshin proposed a new model explaining the extreme dimness of the black hole in our Galactic Center. As is well known, as much as $L \sim$ few $\times 10^{40}$ erg/sec is expected to be emitted because of the accretion of stellar wind captured by the black hole, and yet as little as $L \sim 10^{36}$ erg/sec is actually observed. One currently popular explanation is a radiatively inefficient accretion flow, which however makes certain unchecked assumptions about electron-proton interactions in the flow. S. Nayakshin pointed out that if there is a cold (inactive) accretion disk, then the hot flow may be cooled by thermal conduction. Via numerical simulations it was shown that if the wind has a relatively large angular momentum then the flow condenses onto the cold disk, releasing, as observed, no more than $\sim 10^{36}$ erg/sec. This therefore opens up a possibility that the black hole is not accreting at all at the present epoch.

In collaboration with J. Cuadra and R. Sunyaev, S. Nayakshin proposed that this model can also explain the recently observed X-ray flares from our Galactic Center. In these flares the X-ray emission increases up to a factor of 100, and the flares last only $\sim$ few kiloseconds. What is inexplicable in "traditional" models is that there seems to be no response to the flares in any other wavelength. In the model of Nayakshin et al., however, the X-ray flares are due to the stars passages through the inactive disk. Indeed, there are as many as $\sim 10^4$ stars in the central arc-second region, and this means that on average one star will pass through the disk per day. The star drives a very high Mach number shock into the disk material, which yields a flare with roughly observed duration and spectrum upon the exiting the disk. Because the emitting region size is roughly the star's radius, i.e. much smaller than in the other models, no response is expected in the radio, and only a weak one, if observable at all in the near infra-red and optical. The model makes a number of predictions that strongly differ from the other available models. The authors estimate that the disk mass is $\sim 1 - 100$ solar masses and its extent is less than few tenths of an arc-second.

F. Meyer and E. Meyer-Hofmeister investigated the possible modes of accretion in AGN (Active Galactic Nuclei). In the far outward regions around central black holes the accretion occurs via a thin disk. Observations, e.g. for low-luminosity AGN, show that further inward the thin disk is truncated and the gas accretes in form of a hot coronal flow. As could be shown in detailed computations the truncation happens at very different distances from the center depending on whether a dynamo works in the underlying thin disk or not. An application of the studies of the coronal flow in the innermost regions of luminous narrow-line Seyfert 1 galaxies was carried out together with Liu Bifang (Kyoto University). A recently developed new method for the determination of the radially extended corona above the cool disk and the gradual change over from disk accretion to coronal flow/ADAF can be seen as a step forward in the understanding of accretion flows onto stellar and supermassive black holes.

U. Anzer, G. Börner, I. Kryukov (Moscow) and N. Pogorelov (Moscow) calculated two-dimensional models for wind accretion flows onto magnetised stars. They used an idealised representation for the magnetosphere. Incorporating the relevant heating and cooling mechanisms into their numerical scheme they found that the very efficient cooling produced by the inverse Compton effect can substantially facilitate the accretion of material at the magnetic holes located at the poles.

M. Aloy, H.-Th. Janka and E. Müller investigated the formation of relativistic jets by energy deposition (e.g. due to neutrino-antineutrino annihilation or magnetic fields) in the vicinity of accretion tori around black holes as remnants of mergers between neutron stars or neutron stars and black holes. The relativistic hydrodynamical simulations showed that the flow is quickly accelerated to high and very high Lorentz factors, if the energy deposition rate is large enough. The outflows start collimated because of the presence of the dense torus matter, and lateron expand as highly collimated jets because of the interaction with the cocoon. The propagation of the relativistic ejecta turned out to be extremely sensitive to density perturbations along their path of motion.

In collaboration with M. Ruffert and S. Setiawan (both Univ. of Edinburgh, Scotland) H.-Th. Janka studied the evolution of massive accretion tori around black holes as remnants of mergers of compact binary stars. The three-dimensional simulations were performed by including shear viscosity effects in the torus and by using a pseudo-Newtonian potential for the black hole which allows to approximate the effects of relativistic gravity and black hole rotation. The tori develop central temperatures of several MeV and emit neutrinos with high luminosities. The three-dimensional simulations of neutron star black hole merging for different binary configurations, a project that was started two years ago, are now finished. In all investigated cases, with Newtonian and pseudo-Newtonian potential, a disk of some $0.1\,\mathrm{M}_\odot$ remains around the black hole.

3.6 Interaction of radiation with matter

Numerous astrophysical problems require a detailed understanding of the radiative transfer of photons into different environments, ranging from intergalactic and interstellar medium to stellar or planetary atmospheres. The solution of the complete radiative transfer equation is not practical in many of these cases, but several groups at MPA are attacking the problem with approximate schemes and different numerical methods. B. Ciardi, in collaboration with A. Ferrara (SISSA, Trieste), has developed the code CRASH, based on a Monte

Carlo method, to follow the propagation of ionizing photons into a given density field. The code, initially developed for the radiative transfer into a medium of pure hydrogen, has been extended (with A. Maselli of the OAA in Florence) to include the presence of helium.

P. Mimica has studied particle acceleration in blazar jets. This study is part of his PhD work supervised by M.A. Aloy, E. Müller and W. Brinkmann (MPE). He has incorporated a numerical treatment for the transport of nonthermally radiating particles into the relativistic hydrodynamics code GENESIS. Assuming that electrons are injected with a power-law energy distribution at internal shocks an analytical solver for the electron kinetic equation (continuity equation in momentum space) was developed. The analytic solver has been incoporated into GENESIS, including (up to now) only synchrotron radiation by electrons. The back reaction of the radiation onto the jet flow is modelled by an energy loss term in the energy equation. Effects caused by time delays are also taken into account.

T. Enßlin and C. Vogt investigated how Faraday rotation maps of extended polarised radio sources in or behind the magnetised plasma of a galaxy cluster can be used to measure the magnetic field strength and power spectrum. They demonstrated that under plausible conditions (statistical homogeneity and isotropy) this information can be extracted. In her PhD project C. Vogt is presently developing a computer program which performs such analysis on existing Faraday rotation maps and she is performing radio interferometric observations in order to obtain new high quality Faraday maps. C. Pfrommer and T. Enßlin studied nonthermal properties of clusters of galaxies in order to put constraints on the population of cosmic ray protons.

In collaboration with C. Done and E. Barrio of the University of Leicester, UK, S. Nayakshin compared theoretical models of photo-ionized X-ray reflection off the surface of an accretion disk with broad-band 3-200 keV spectra of Cygnus X-1, a black hole candidate. Earlier studies showed that the observed spectra may be equally well explained with either a hot geometrically thick flow in the inner region and a cold disk at larger radii, or a cold disk at all radii and magnetic flares above it with a fairly large freedom in parameters. However, it turns out that the highest energy part of the spectrum (i.e., $E > 50$ keV) yields important new constraints on the geometry of the accretion flow. In particular, the magnetic flare model can only explain the data if a significant fraction of reflected X-rays again re-enters the hot comptonizing region above the disk.

3.7 Galaxy evolution and the Intergalactic Medium

Galaxy properties of low z. G. Kauffmann studied the mass-dependence of the star formation histories and internal structure of 100,000 galaxies in the Sloan Digital Sky Survey. In collaboration with T. Heckman (JHU, Baltimore), S. Charlot and S. White, a new method was developed to constrain the star formation histories, dust attenuation and stellar masses of galaxies. It was demonstrated that galaxies divide into two distinct families at a characteristic stellar mass of $3 \times 10^10 M_\odot$. Lower mass galaxies have young stellar populations, low surface mass densities and the low concentrations typical of disks. A significant fraction of the lowest mass galaxies have experienced recent starbursts. At stellar masses larger than $3 \times 10^10 M_\odot$, there is a rapidly increasing fraction of galaxies with old stellar populations, high surface mass densities and high concentrations.

The same group has also been studying the properties of the host galaxies of a sample of 20,000 active galactic nuclei (AGN) drawn from the same sample. AGN are found to reside in massive galaxies with structural properties that are very similar to ordinary early-type galaxies, but with stellar populations that are typically much younger. A significant fraction of the most powerful AGN have experienced a recent starburst.

J. Brinchmann has developed code for quantitiative estimation of emission lines in galaxies and applied this to 200000 galaxies from the Sloan Digital Sky Survey to provide a comprehensive account of the physical properties of galaxies in the local universe. This research has been done as part of the SDSS collaboration at MPA (S. Charlot, G. Kauffmann, S. D. M. White) and with collaboration with C. Tremonti and T. Heckman (Johns Hopkins Univeristy) and has allowed the construction of distribution functions for star formation rate, metallicity, dust attenuation and other physical properties of local galaxies as a function of mass and galactic properties. In a separate study J. Brinchmann developed a method to accurately simulate the appearance of simulated galaxies with a variety of present and up-coming instrumentation in a collaboration with R. Abraham and J. Dubinski (University of Toronto). The methodology and software are being developed in order to help the design and construction of next generation of instrumentation and telescopes.

S. Shen, as part of team in the SDSS collaboration, used galaxies in the survey to analyze the size distribution of galaxies.

Stéphane Charlot, in collaboration with G. Bruzual (CIDA Venezuela), M. Fall (STScI, USA), M. Longhetti (OAB Milan), and M. Liu and J. Graham (UC Berkeley) developed new models of the spectral evolution of galaxies including the effects of stars, gas, and dust. The spectral resolution of these new models is 10 times higher than achieved in the past. The models are designed to interpret observed galaxy spectra in a physically consistent way in terms of physical parameters such as age, star formation history, metallicity and dust content. The models were first applied to constrain the star formation rates of a sample of 705 galaxies drawn from the Stromlo-APM redshift survey, in collaboration with L. Tresse (LAM Marseille), G. Kauffmann and S. White (MPA) and S. Maddox (U. Nottingham). Work in collaboration with J. Brinchmann, H. Mathis, C. Möller and C. Haydn (MPA) has led to the development of new techniques to analyse efficiently the shear number of spectra gathered by modern spectroscopic galaxy surveys such as the SDSS, and of new diagnostics of the star formation properties of galaxies based on their ultraviolet and far-infrared spectra.

In his diploma thesis C. Haydn explored an automated method for extracting physical parameters from galaxy spectra, using Artificial Neural Networks (ANNs). He trained an ANN, using a large library of mixed population model spectra with stochastic star formation histories. The ANN method was used to estimate light-weighted ages, light-weighted metallicities, and dust absorption optical depths, for a sample of galaxies with any star formation history. The accuracy of this method is typically greater than 90% for the estimates of ages and dust absorption optical depths, and greater than 70% for metallicity estimates. The results to the age and metallicities obtained in this way are better than those obtained from fits of single stellar population spectra.

F. van den Bosch, together with M. Milosavljević and D. Merritt (both Rutgers University) and A. Rest (UW, Seattle) used the surface brightness profiles of early-type galaxies, as obtained from observations with the Hubble Space Telescope, to compute the three-dimensional density distributions. These are used to test the hypothesis that the cores of elliptical galaxies and bulges are created from the binding energy liberated by the coalescence of supermassive binary black holes during galaxy mergers. F. van den Bosch, in collaboration with R. Swaters (JHU), B. Madore (OCIW) and M. Balcells (IAC) analyzed the high resolution, Hα rotation curves of a sample of dwarf and low surface brightness galaxies, in order to derive limits on the slopes of the central mass distributions. In the ongoing debate on whether the rotation curves of dwarf and LSB galaxies are consistent with predictions for a CDM universe, we argue that current data provide insufficient evidence to rule out halos with a central cusp.

X. Kong, in a collaboration with A. Weiss, S. Charlot and F.Z. Cheng (USTC), investigated the star formation rates, stellar components, metallicities, and star formation histories of blue compact galaxies (BCGs). They observed 97 high signal-to-noise ratio BCG spectra with the BAO 2.16m telescope. Using an empirical population synthesis method, they found, BCGs are old galaxies, in which star formation occurs in short intense burst separated by long quiescent phases. Combining with nebular emission lines Hα, [O II]3727, the IRAS IR and 1.4 GHz radio luminosities, they calculated the star formation rates and interstellar gas consumption time scales of BCGs, the star formation rates range 10^{-2} to $10^{2} M_{\odot}$, the typical gas depletion time scale is a few Gyr. In addition, metallicity indices show trends with galaxy absolute magnitude and attenuation by dust, faint, low-mass BCGs have lower metallicity and color excess; subtracting the underlying stellar absorption from emission lines is very important to measure the color excess and star formation rate of BCG. This study will be useful as a benchmark for studies of emission line galaxies of SDSS.

H. Arp has undertaken along term study of associations on the sky of diverse extragalactic objects. Cataloguing of evidence for the physical association of different kinds of cosmic objects such as galaxies, quasars and clusters of galaxies is underway. Where it most critical new observations have been undertaken personally and in collaboration with other researchers. The material is being readied for publication in a Catalogue.

Structure of the Milky Way. P. Popowski in collaboration with K. Cook from the Lawrence Livermore National Laboratory (LLNL, USA) and A. Becker from Lucent Laboratories (USA) produced a $(V-R)$-based reddening map of about 43 square degrees of the Galactic bulge/bar. The map was constructed using photometry from the MACHO microlensing survey, contains 9717 resolution elements, and is based on $(V-R)$-color averages of the entire color-magnitude diagrams (CMDs) in 4 by 4 arc-minute tiles. The conversion from the observed color to the reddening follows from an assumption that CMDs of all bulge fields would look similar in the absence of extinction. Consequently, the difference in color between different fields originates from the differences in the disk extinction between different lines of sight. The average CMD $(V-R)$ colors correlate very well with the visual extinction derived by Stanek (1996) in Baade's Window. A dusty disk obeying cosec$|b|$ extinction law provides a good approximation to the extinction toward the MACHO bulge/bar fields.

In a follow-up project, A. Kunder and P. Popowski from MPA in collaboration with K. Cook from LLNL selected a set of RR Lyrae stars from the MACHO Survey of the Galactic bulge. They determined the color excesses of almost 3000 RR Lyrae stars, and they checked that these color excesses correlated well with the CMD-based reddening map described above. They derived the selective extinction coefficient $R_{VR} = A_V/E(V-R)$ for the MACHO RR Lyrae sample and calibrated the relation between extinction, A_V, and average CMD color. They identified fundamental RR Lyrae pulsators in the Sgr dwarf galaxy, and carried out a period analysis. For Sgr members, the average periods are 0.567 days and for the Galactic bulge members, 0.540 days.

Galaxy evolution. G. Rudnick has measured the rest-frame optical luminosity density, rest-frame optical color, and stellar mass density of all massive galaxies at $0 < z < 3$ using ultra-deep Near Infrared (NIR) data of the Hubble Deep Field South (HDF-S) from ISAAC at the VLT taken as part of the Faint InfraRed Extragalactic Survey (FIRES). This data were taken in collaboration with I. Labbe (Leiden Observatory), M. Franx (Leiden Observatory), N. M. Forster Schreiber (Leiden Observatory), P. van der Werf (Leiden Observatory), H. Rottgering (Leiden Observatory), L. van Starkenburg (Leiden Observatory), A. van de Wel (Leiden Observatory), K. Kuijken (Leiden Observatory), H.-W. Rix (MPIA), A. Moorwood (ESO), E. Daddi (ESO), P. G. van Dokkum (CalTech). Using this data set and a photometric redshift technique developed by G. Rudnick, galaxies in this sample are studied in constant rest-frame optical wavelengths out to $z \lesssim 3.2$, allowing a direct comparison with local samples and a systematic study of the whole redshift range. By considering the integrated properties of the entire galaxy population, e.g., rest-frame luminosity density and rest-frame color, the evolution of stellar mass in the universe can be modeled with simple star formation histories (SFH) models. This makes far fewer assumptions than the modeling necessary to describe the SFHs of individual galaxies.

V. Springel proposed a new hybrid multi-phase model for the regulation of star formation in the interstellar medium, and he implemented this model in a new version of the parallel hydrodynamical simulation code GADGET. In collaboration with L. Hernquist (Harvard University, Cambridge), he applied this code to numerically study the star formation history of the ΛCDM universe, using a large set of cosmological simulations of structure formation. Supported by extensive resolution tests that established the numerical reliability of their techniques even in the presence of strong feedback by galactic outflows, they were able to make a converged prediction for the full star formation history within this theoretical model. Interestingly, the global baryon fraction locked up in stars was reduced to about 10% by the feedback processes included in the simulations, which is broadly consistent with observational constraints. The predicted star formation rate density peaks early in the history of the universe, at redshift $z \simeq 5$, and then falls by an order of magnitude to the present time. The resulting shape of the star formation history can be understood quite accurately by combining analytic models for the gravitational growth of structure with simple analytic models for radiative cooling and star formation processes within dark matter halos.

H.J. Mo and S.D.M. White investigated the abundance and clustering of dark haloes in the standard Lambda CDM cosmogony and used the results to understand structure formation in the Universe at high redshift.

F. van den Bosch in collaboration with T. Abel (Cambridge), R. Croft (CfA), L. Hernquist (CfA) and S. White (MPA) used numerical simulations of structure formation, including non-radiative gas, to compute and compare the angular momentum distributions of the gas and dark matter in CDM halos. It is found that the dark matter and gas acquire virtually identical angular momentum distributions, in good agreement with standard predictions, but that the detailed distributions differ from that of galaxies, implying angular momentum transport during disk formation. In a follow up study with T. Abel and L. Hernquist, the effects of pressure forces on the angular momentum of protogalaxies were investigated, using both analytical and numerical techniques. It is shown that preheating of the IGM may significantly reduce the angular momentum of the gas in protogalaxies.

G. Kauffmann and M. Haehnelt (IoA, Cambridge) studied the interaction rates of supermassive black holes in galactic bulges as predicted by hierarchical models of galaxy formation. The number of low-mass black holes that can interact with the central object is predicted to be a strong function of galaxy luminosity. In most faint ellipticals, no black holes fall into the centre of the galaxy after the last major gas accretion event, but in the most luminous ellipticals, an average of 10 low-mass black holes interact with the central supermassive object after this time. Multiple black holes in galactic bulges thus provide a natural explanation for the strong systematic trends in the observed central density profiles of ellipticals as a function of luminosity.

G. Kauffmann, A. Kaviani (Imperial College, London) and M. Haehnelt (IoA, Cambridge) modelled SCUBA source counts in a Lambda-CDM cosmology. They showed that the counts are easily reproduced in a model in which the bulk of the sub-millimetre emission comes from extended, cool dust in objects with star formation rates of 50-100 solar masses per year

Lyman-alpha forest. Using a novel multi-resolution analysis method, T. Theuns (IoA Cambridge), S. Zaroubi (MPA), T.-S. Kim (ESO), P. Tzanavaris (IoA), and R.F. Carswell (IoA) have studied the thermal evolution of the intergalactic medium from the observed Lyman-α forest and found strong evidence of a marked jump in the temperature, with 99% significance, at the mean density, T_0, of 60 per cent around a redshift z=3.3, which have been attributed to reionization of Helium II. In an extension of this work T. Theuns (IoA Cambridge), J. Scahye (IAS), S. Zaroubi (MPA), T.-S. Kim (ESO), P. Tzanavaris (IoA), and R.F. Carswell (IoA) have used the thermal evolution of the intergalactic medium from the observed Lyman-α forest to extrapolate the IGM temperature back in time and put an upper limit on the epoch of Hydrogen I reionization to redshift less than 9.

H.J. Mo, in collaboration with M. Viel, S. Matarrese (both from Padova), M. Haehnelt and T. Theuns (both from Cambridge), studied the possibility of using high-resolution N-body simulations of dark matter distribution to model the intergalactic medium and the Lyman alpha forest at high redshift.

Reionization. The application of the Gunn-Peterson test to QSOs absorption spectra suggests that the IGM is completely reionized by z 6. As the known population of quasars and galaxies provides 10 times fewer ionizing photons than are necessary to keep the observed IGM ionization level, additional sources of ionizing photons are required at high redshift, the most promising being early galaxies and quasars. B. Ciardi, F. Stöhr and S. White have studied the reionization process produced by an early population of pregalactic stellar objects. This is obtained combining the high-resolution simulations run at the MPA, for the galaxy distribution and emission properties, with the code CRASH, for the radiative transfer of photons. The process has been studied for a variety of parameters, and has been tested against the effect of the environment, the mass and grid resolution.

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. In collaboration with P. Madau (Santa Cruz, OAA Florence), B. Ciardi has estimated the radio emission expected from the neutral hydrogen distribution derived by the above simulations. They find that the warm, neutral IGM produces brightness temperature fluctuations relative to the average that could be detected by the planned telescope SKA or LOFAR at $z > 10$.

A highly uncertain parameter in these calculations is the fraction of emitted ionizing photons which is able to escape out from a galaxy, f_{esc}. B. Ciardi, in collaboration with S. Bianchi (OAA, Florence) and A. Ferrara (SISSA, Trieste), has calculated f_{esc}, for a Milky Way type galaxy, via 3D numerical simulations, using the code CRASH to follow the photon propagation. They find values of the escape fraction in the range 2-50%, depending on the total ionization rate and the density field, confirming the high uncertainty of the parameter.

In addition to their local effects (i.e. ionizing the surrounding medium), the first objects will also produce UV radiation which could introduce long range feedbacks on nearby collapsing halos. Particularly relevant is the soft UV background in the Lyman-Werner bands, which can dissociate the H_2 responsible for the cooling and collapse of small mass objects. This implies the existence of a population of "dark objects", galaxies which are not able to collapse and efficiently produce stars. Recently, this population of dark galaxies has received an increasing attention. For example B. Ciardi, in collaboration with X. Hernandez (Universidad National Autonoma de Mexico) and A. Ferrara (SISSA, Trieste), has derived the expected number counts of dark objects based on a combination of the extended Press-Schechter formalism and the mentioned feedback effects.

Observations of QSOs and galaxies at $z > 6$ has 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), is collecting the available studies into a Review paper on the subject.

3.8 Cosmic structure from z=0 to the Big Bang

Galaxy clusters. As part of a large international consortium led by S. White an MPA group (G. Rudnick, G. De Lucia, G. Kauffmann, S. Charlot) has been carring out the ESO Distant Cluster Surving (EDisCS), an ESO Large Programme on the VLT and NTT telescopes. Deep photometry has been obtained in the optical and near infrared for a sample of 2D distant galaxy clusters and follow up spectroscopy is about 40% complete.

With S.D.M. White, M. Bartelmann investigated what can be learned from the ROSAT All-Sky Survey about the X-ray emission of galaxy clusters found in ongoing and future wide-area surveys. A significant measurement of the mean flux of cluster subsamples can be obtained by stacking cluster fields. The mean X-ray luminosity of moderately massive clusters selected from the Sloan Digital Sky Survey should be measurable out to redshift unity with high signal-to-noise. A suitably chosen hardness ratio allows the mean temperature of such clusters to be estimated with reasonable accuracy.

With H. Ohno, M. Takada and N. Sugiyama (Mitaka, Tokyo), K. Dolag and M. Bartelmann constructed a method for extracting information on intracluster magnetic fields from measurements of the Faraday rotation on the Cosmic Microwave Background polarisation, combined with possible observations of the Sunyaev-Zel'dovich effect and X-ray emission for the same clusters. The feasibility of the method was demonstrated using detailed numerical cluster simulations.

T. Enßlin and H. Röttgering estimated the redshift dependent radio luminosity function of so called galaxy cluster radio halos in order to be able to make predictions for upcoming sensitive radio telescopes like LOFAR, ATA, and EVLA. Their estimate is based on the observed radio halo to cluster X-ray luminosity correlation, and an extended Press-Schechter description of the statistics of clusters which have undergone a recent strong merging event, as a prerequisite for the presence of a cluster radio halo. They found that upcoming telescope should be able to detect 10^3 to 10^4 radio halos, depending on the search strategy. Since cluster radio halos have steeply falling spectra, there should be a frequency range around several GHz in which the radio halo emission is compensated by the thermal Sunyaev-Zeldovich CMB decrement of the same cluster, which has a with frequency increasing strenght. The complex radio morphologies occurring in this frequency range were discussed by T. Enßlin, who argued that some existing high frequency measurements are already affected by this effect.

T. Enßlin and S. Heinz discussed the detectability of buoyantly rising bubbles of relativistic plasma released by radio galaxies within galaxy clusters. A numerical example of the hydrodynamically governed evolution of the radio luminosity and the X-ray contrast of such a bubble reproduces many of the features of observed X-ray ghost-cavities in galaxy clusters. In that context it may be noted, that T. Enßlin provided a detailed discussion of the escape mechanisms of relativistic particles from such relativistic bubbles into the surrounding inter-galactic medium.

B.M. Schäfer works with M. Bartelmann on the comparison of different cluster detection experiments. They simulate the observational signals in various windows, which are the thermal Sunyaev-Zel'dovic effect, gravitational lensing and X-ray as well as optical emission. The modelling relies on large scale structure formation simulations carried out by N. Yoshida.

Large scale structure. S. Zaroubi (MPA) has developed a novel Unbiased Minimal Variance

(UMV) estimator for the purpose of reconstructing the large–scale structure of the universe from noisy, sparse and incomplete data. Similar to the Wiener Filter (WF), the UMV estimator is derived by requiring the linear minimal variance solution given the data and an assumed prior model specifying the underlying field covariance matrix. The general application of the UMV estimator is to predict the values of the reconstructed field in un-sampled regions of space (e.g., interpolation in the unobserved Zone of Avoidance), and to dynamically transform from one measured field to another (e.g., inversion of radial peculiar velocities to over-densities).

S. Zaroubi (MPA), E. Branchini (Roma III), Y. Hoffman (Jerusalem) and L.N. da Costa (ESO) have used the UMV algorithm in order to reconstruct the uniformly smoothed large scale density and 3-D velocity from the galaxy peculiar velocity catalogs ENEAR and SFI. In this work they have compared the velocity and density to those obtained from PSCz redshift catalog. For the first time, the comparison of both fields is carried out in the same analysis framework. The study has yielded a value of the parameter $\beta = \Omega^{0.6}/b$ of ≈ 0.5 from both comparisons.

F. Miniati has investigated numerically the contribution of cosmic-rays (CRs) accelerated at intergalactic shocks to the cosmic gamma-ray background. The following processes were considered: decay of neutral pion generated in p-p inelastic collisions of CR protons with the nuclei of the intergalactic gas, inverse Compton emission of primary electrons and secondary electrons-positrons generated in the decay of charged pions (also created with neutral pions). The total flux is dominated by inverse Compton emission from primary electrons. Critical to that estimate is the acceleration efficiency of the latter. Expressed in terms of the fraction of shock ram pressure that is converted into CR electron pressure, this was constrained for the first time to be no more than 1 simulations to the existing upper limits for nearby clusters of galaxies. That implies a contribution of such CRs to the cosmic gamma-ray background no more than 20-25% of the measured level.

G. Hütsi and C. Hernandez-Monteagudo began to study the possibilities of how one could exploit the thermal and kinematic Sunyaev-Zeldovich effects to investigate the properties of the supercluster-void network.

F. van den Bosch, in collaboration with H.J. Mo and X. Yang (University of Science and Technology, Hefei, China) constructed a new method to link galaxies to dark matter halos. This method uses the observed luminosity function and clustering properties of galaxies to constrain the so-called conditional luminosity function, which specifies how many galaxies, on average, of a given luminosity, populate a halo of given mass.

G. Börner, H.J. Mo, and R. Casas-Miranda investigated the higher-order moments of the distribution of dark matter haloes constructed from theoretical, semi-analytical models, and tested against the predictions of numerical simulations.

Xi Kang from the MPA partner group at Shanghai Observatory together with Y. Jing (Shanghai), H.J. Mo, and G. Börner constructed an analytic model for the nonlinear redshift-space power spectrum.

D. Zhao from the MPA partner group in Shanghai together with Y. Jing (Shanghai), H.J. Mo and G. Börner realised that for dark matter haloes a scaling relation exists which connects a particular scale radius with the mass of a halo. This allows to compute the density profile of a halo from its mass accretion history. Various tests of the relation were carried out, both in numerical simulations and in semi-analytic models.

Early universe. J. Niemeyer, in collaboration with R. Parentani and D. Campo (Univ. Tours), continued to investigate the potential observational signatures of Planck scale physics during the epoch of cosmological inflation. Applying an adiabatic boundary condition on quantum modes with a fixed physical momentum, they derived the amplitude and shape of the correction to the primordial perturbation spectrum produced during inflation. Under very conservative assumptions, this result provides a lower bound on the expected signal from any theory with a fixed high energy cutoff.

3.9 Gravitational Lensing

B. Ménard and M. Bartelmann continued investigating higher-order terms in QSO-galaxy cross-correlations induced by gravitational lensing. With Y. Mellier (IAP Paris), they demonstrated that the three-point correlator between QSOs and galaxy pairs can be used jointly with the two-point correlator to break degeneracies between cosmological parameters, and that the Sloan Digital Sky Survey will provide sufficient data for a significant measurement. With T. Hamana (Mitaka, Tokyo) and N. Yoshida (CfA, Cambridge), they showed that previously neglected higher-order terms in the two-point correlator can be a substantial correction.

Brice Ménard and Céline Péroux (Trieste) investigated statistical lensing effects due to absorber systems along quasar lines-of-sight and detected them by analysing one thousand quasar spectra from the 2dF survey.
In collaboration with Thomas Erben (IAEF, Bonn) and Yannick Mellier (IAP), Brice Ménard used a deep I-band observation of the galaxy cluster Abell 2029 and mapped its dark matter distribution using a gravitational shear analysis.

With M. Bartelmann and L. Moscardini (Padova), M. Meneghetti (MPA and Padova) continued working on theoretical models for the statistics of giant luminous arcs in galaxy clusters. They showed that analytic lens models are generally inadequate for quantitative studies of arcs statistics, and that cD galaxies in cluster centres change their strong-lensing cross sections only weakly.

With F. Perrotta and C. Baccigalupi (LANL Berkeley and SISSA Trieste), M. Bartelmann studied how properties of dark-matter haloes change in cosmological models with quintessence rather than a cosmological constant. They found that haloes are more concentrated in such models because they form earlier, but this effect is partially compensated by the a necessarily lower power-spectrum normalisation. Quintessence thus has only a moderate effect on weak-lensing counts of dark-matter haloes.

The same team, plus M. Meneghetti (MPA and Padova) and L. Moscardini (Padova) studied how arc statistics is expected to change in quintessence compared to cosmological-constant models. They found that arcs are more probable by a factor of a few in quintessence models, but not by the order of magnitude required to explain observations.

With M. Bartelmann and L. Moscardini (Padova), M. Maturi (Padova) studied whether the microwave background data expected from the Planck satellite will suffice to detect the lensing signal in stacked samples of cluster images. They found that it should be possible with Planck to quantify the deflection-angle profiles of clusters.

X. Yang (a student from Hefei supported by the CAS-MPG exchange program), H.J. Mo, G. Kauffmann and Y. Chu (from Hefei) used galaxy catalogs constructed from semi-analytic models of galaxy formation to understand the results of galaxy-galaxy lensing obtaind from recent SDSS survey.

P. Popowski made a new evaluation of the optical depth toward the Galactic bar from Difference Image Analysis (DIA) of the MACHO collaboration. First, he presented supplementary evidence that MACHO field 104 located at $(l, b) = (3^\circ\!.11, -3^\circ\!.01)$ is anomalous in terms of event duration distribution. He argued that both event durations and very high optical depth of field 104 are not representative, and, therefore, excluded this field as an outlier. In addition, he eliminated field 159 at $(l, b) = (6^\circ\!.35, -4^\circ\!.40)$ based mainly on its separate location, but also on unexplained statistical properties of event durations. The remaining six DIA fields formed a very homogeneous and spatially compact set that was very suitable for averaging. The weighting of the optical depth values for these six DIA fields resulted in a total optical depth $\tau_{\rm tot} = 2.01^{+0.34}_{-0.30} \times 10^{-6}$ at $(l, b) = (2^\circ\!.22, -3^\circ\!.19)$. If a fraction of all sources, $f_{\rm disk}$, assumed to be in the disk, does not contribute to microlensing, then the optical depth toward the sources in the bar is $\tau_{\rm bar} = 2.23^{+0.37}_{-0.33} \times 10^{-6}\,[0.9/(1 - f_{\rm disk})]$. When taken together with $\tau_{\rm bar} = 1.4 \pm 0.3 \times 10^{-6}$ at $(l, b) = (3^\circ\!.9, -3^\circ\!.8)$ from clump giants, this new result suggested that all popular models of the Galactic bar were consistent with the current observational constraints.

P. Popowski in collaboration with C. Alcock from the University of Pennsylvania (USA) entertained the idea that robust theoretical expectations could become a tool in removing hidden observational biases. They illustrated this approach for a specific problem associated with gravitational microlensing. Using the fact that a group is more than just a collection of individuals, they derived formulae for correcting the distribution of the dimensionless impact parameters of events, $u_{\rm min}$. They referred to the case when undetected biases in the $u_{\rm min}$-distribution could be alleviated by multiplication of impact parameters of all events by a common constant factor. They showed that in this case the general maximum likelihood problem of solving an infinite number of equations reduced to two constraints, and they found an analytic solution. Under the above assumptions, this solution represents a state in which the "entropy" of a microlensing ensemble is at its maximum, that is, the distribution of $u_{\rm min}$ resembles a specific, theoretically expected, box-like distribution to the highest possible extent. They also showed that this technique did not allow one to correct the parameters of individual events on the event by event basis independently from each other.

P. Popowski participated in several investigations performed by the MACHO Collaboration. The MACHO Group reported on the discovery of likely black hole candidates among lenses of the events seen toward the Galactic bulge. The masses of the best candidates are $M/M_\odot = 6^{+10}_{-3}$ and and $M/M_\odot = 6^{+7}_{-3}$. In another investigation, MACHO presented a method for solving the light curve of an eclipsing binary system that contains a Cepheid variable as one of its components as well as the solutions for three eclipsing Cepheids in the Large Magellanic Cloud (LMC): 6.6454.5, 78.6338.24, and 81.8997.87. In the next development, MACHO announced 47 spectroscopically-confirmed quasars discovered behind the Magellanic Clouds identified via photometric variability in the MACHO database. Thirty-eight quasars lie behind the LMC and nine behind the SMC, more than tripling the number of quasars previously known in this region. The quasars cover the redshift interval $0.2 < z < 2.8$ and apparent mean magnitudes $16.6 < V < 20.1$.

3.10 Cosmic Microwave Background Studies

Non-Gaussianity Studies. Work has continued on methods to investigate and quantify non-Gaussian signals present in CMB data. A. J. Banday together with H. K. E. Eriksen (Oslo, Norway) and K. M. Gorski (ESO, Garching), an algorithm to determine the 3- and 4-point correlation functions for various geometries of the spherical triangles or quadrilaterals has been developed. Application to the COBE-DMR data has demonstrated consistency with the hypothesis that the observed temperature fluctuations are cosmological in origin and Gaussian in nature. Work is continuing to extend the algorithm to spin-2 fields (ie. the Stokes Q and U parameters for CMB polarisation maps), and particular emphasis is being placed on making such analyses tractable for the forthcoming large data sets from MAP and Planck. A. J. Banday in collaboration with L. Cayon E. Martínez-González, F. Argüeso (Santander, Spain) and K. M. Górski, the Mexican Hat wavelet has been used to place constraints on the non-linear coupling parameter for a quadratic term in the gravitational potential of slow-roll type inflation. Analysis of the COBE-DMR data set constrains this parameter to be less than 1100 at 68% c.l., a lower limit than one set previously by a bispectrum study, made in collaboration with E. Komatsu, D. Spergel, B. Wandelt (Princeton, USA) and K. M. Górski.

Foreground studies. A. J. Banday in collaboration with K. M. Gorski (ESO, Garching), G. Giardino K. Bennett, J. Tauber (ESTEC, Nordwijk) and J. Jonas (HRAO, South Africa), have continued to study the nature of the Galactic radio continuum emission and in particular, based on analysis of polarisation data and the corresponding power spectra, estimated the likely foreground contamination of the polarised CMB signal to be measured by Planck. Simulations of this polarised foreground emission at high resolution have been made available as part of the Planck Level-S simulations efforts coordinated locally. Ongoing studies with C. Dickinson, R. D. Davies, and R. Davis (Jodrell Bank, UK) consider the application of Galactic surveys of H_α emission as a tracer of free-free emission in the microwave frequency range. Preliminary studies are very promising. In particular, application to studies of the COBE-DMR data help to disentangle such emission from an anomalous component of Galactic dust emission, which has a free-free like spectrum. The now unambiguously identified anomalous dust component has been compared spectrally to predictions for a rotational dust emission mechanism.

C. Pfrommer, M. Bartelmann, T. Hamana and S.D.M. White studied the cosmological weak lensing effect of the cosmic microwave background (CMB) by large scale structure using a ray tracing approach applied to large simulations of the dark matter distribution in the Universe.

B.M. Schäfer, C. Pfrommer, V. Springel and M. Bartelmann were simulating all-sky Sunyaev-Zel'dovich maps (thermal and kinematic SZE) using line of sight projections of high resolution SPH cluster simulations serving as templates and Hubble volume cosmological N-body simulations as a cluster catalogue. The primary application of this work would be a realistic simulation of the CMB fluctuations as seen by the PLANCK satellite.

Component separation studies. A method for component separation based on the Fast Independent Component Algorithm (FastICA) has been developed and applied to simulated Planck resolution simulations by a group comprising A. J. Banday in collaboration with D. Maino, D., A. Farusi, C. Baccigalupi, F. Perrotta, L. Bedini, C. Burigana, G. De Zotti, E. Salerno and K. M. Górski (ESO, Garching) wth promising results. In particular, the CMB component is recovered to percent accuracy on all scales down to the beam resolution of the instrument. Current extension of this work is related to application of the method to the DMR data. With application to real data, we have found that the method is sensitive to differences in the noise properties of the input data sets. By including other data, specifically maps of Galactic dust emission from the COBE-DIRBE instrument, synchrotron measurements at 408 MHz and a tracer of the free-free emission based on surveys of the H_α spectral line, convolved to the DMR beam resolution, a reasonable separation of the CMB signal can be achieved.

A. Rubiño-Martín and R. Sunyaev have proposed a new method to distinguish between SZ galaxy clusters and point sources as responsible sources for excess of power in CMB maps at small angular scales. This method is based on the probability distribution function (PDF) of the temperature fluctuations, and is of special relevance for CMB experiments with very high angular resolution. A prediction for the values of these statistical quantities is done using a Press-Schechter prescription for modelling the cluster population.

HEALPix. A. J. Banday in collaboration with K. M. Gorski (ESO, Garching), E. Hivon (NASA-JPL, USA), M. Bartelmann and M. Reinecke continue to maintain and develop the HEALPix software package for the simulation and analysis of CMB anisotropy maps, version 1.2 will be publicly released in early 2003.

Radiative transfer effects. K. Basu, C. Hernandez-Monteagudo and R. Sunyaev are trying to propose a new method to look for the metallicity evolution of the universe through observation of Cosmic Microwave Background. The basic idea is to use resonant scattering of CMB photons by atoms and molecules as a source of frequency dependent opacity that will give rise to different signals (C_l-s) in different observing channels of an experiment. Since each line acts only in a limited range of redshifts, determined by the bandwidth of the experiment, one can put limit on the abundance of that particular atomic or molecular species at that epoch. With the very high sensitivity of forthcoming CMB experiments like Planck HFI, it will be possible to probe abundances as low as 10^{-4} Solar for atoms and ions of Oxygen, Carbon, Silicon, Iron etc. in the redshift range 1-100 through this method.

J. Chluba, S.Y. Sazonov and R. A. Sunyaev have been working on relativistic corrections to double Compton scattering in an isotropic, mildly relativistic thermal plasma. Approximate analytic expressions for the Boltzmann collision integral of double Compton scattering have been found using expansions of the integrand. The implications of relativistic corrections to Compton and double Compton scattering on the thermalization of small spectral distortions of the cosmic microwave background in the early universe will be studied in the future.

Further J. Chluba and K. Mannheim studied the kinetic Sunyaev-Zeldovich effect of a rotating cluster of galaxies. Using an isothermal beta-model for the electron gas distribution inside the cluster and assuming solid rotation, analytic expressions for the intensity change of the cosmic microwave background and the degree of linear polarization could be found.

Inversion techniques. C. Hernández-Monteagudo improved a method that inverts a CMB map into its power spectrum by studying the clustering properties of temperature fluctuations above/below a given threshold. This method performs in $10^{-2} - 10^{-4} N_{pix}^2$ operations, and behaves robustly under realistic conditions of foreground contamination and sky coverage. Its accuracy is about a factor 4-8 below standard methods. This work was performed in collaboration with A.Kashlinsky (GSFC) and F.Atrio-Barandela, (University of Salamanca).

3.11 Quantum mechanics of atoms and molecules, astrochemistry

The long-term efforts are continued to study basic exothermic binary reactions of astrophysical relevance, such as radiative association (or photodissociation) and ion-electron dissociative recombination. P. Soldan (University of Durham, UK) calculated rate constants for the single-state and two-states association formation of the $HeLi^+$ ion and he also started detailed quantum studies of radiative atom-ion charge transfer processes for various combinations of H(D), He and Li and their ions as reaction partners. These reactions proceed under fairly large photon emissions and can therefore provide large local cooling effects. An understanding and a detailed insight in the dynamics of these diatomic processes is of great help in dealing with the much more complex situation in triatomic associations. Apart from the enormous computational effort which has to be put into the high-quality calculation of the 3-dimensional potential energy surfaces, a further complication arises in this case from the additional degrees of freedom and the resulting higher density of quasi-bound rotation-vibrational states in the low-energy continuum of the reaction complex. The weakly-bound HeH_2^+ ion is used here as a convenient model system. F. Mrugala (University of Torun, Poland) has succeeded for the first time according to the relevant literature to evaluate in a rigorous quantum approach the reaction rate constant for the single-state radiative association for this triatomic system and she has extended now these studies to include also the first excited electronic state. For this two-state association process and the closely related radiative charge transfer reaction $He^+ + H_2 \rightarrow He + H_2^+$ Mrugala has recently obtained rate constants of the order of several 10^{-14} cm^3s^{-1}.

Whereas for the weakly-bound HeH_2^+ ion rigorous quantum calculations can still be managed, they become unfeasible for any more strongly bound triatomic. Studies of such systems (HCO^+ and HN_2^+) were recently started. W.P. Kraemer together with P. Neogrady (University of Bratislava, Slovakia) have developed a new computational approach to calculate on a multi-reference coupled-cluster level the relevant potential surfaces for the two lowest electronic states. V. Špirko together with M. Šindelka (Academy of Sciences, Prague, Czech Republic) are developing appropriate approximations for studying the reaction dynamics of these systems.

As an extension of the previous work on the dissociative recombination of the HeH^+ diatomic system, P.-A. Malmqvist (University of Lund, Sweden) has derived and implemented a new method for calculating vibronic coupling effects in triatomics and has started to apply this code to the recombination reaction of HeH_2^+ ions with low-energy electrons.

Recent advances in semiconductor technology has allowed the construction of new quantum systems, sometimes referred to as *artificial atoms*, also known as a *quantum dot*. An artifitial atom is essentially a number of electrons confined in a potential well. Similar systems may be obtained by confinig an atom, a molecule or several such objects. The development of new technologies and experimental techniques has triggered intensive theoretical studies on modelling spatially confined quantum systems.

The spectrum, the electron density distribution and the ground state correlation energy of two electrons confined by an anisotropic harmonic oscillator potential have been studied for different confinement strength ω by using the quantum chemical configuration interaction (CI) method employing a large basis set of cartesian anisotropic harmonic oscillator eigenfunctions to approximate the one-electron functions and a full CI wavefunction. The total energy and the spacing between energy levels increase in all cases with increasing ω. The electron density distribution becomes more and more compressed for increasing ω. The correlation energy of the ground state is comparable in magnitude to that of the helium atom. It increases for increasing ω. Similar studies have been performed for the three two electron quantum systems, namely the 2-electron quantum dot, the hydrogen negative ion and the helium atom. A large basis set of cartesian anisotropic harmonic oscillator eigenfunctions and cartesian anisotropic gaussian functions has been employed to approximate the one-electron functions of the hydrogen negative ion and the helium atom. The results for the three confined quantum systems have been compared with each other: In general, the absolute energies of the states and the interval between states increases with increasing confinement stength ω. The ordering of states may vary for different values of ω. The shape of the electron density distribution differs among the three systems. Its size increases in the order He $< H(^-) <$ 2-electron quantum dot. The ground state CI wavefunction of the hydrogen negative ion and the helium atom confined in a spherical potential are dominated by harmonic oscillator functions.

4 Publications and Invited Talks

4.1 Publications in Journals

4.1.1 Publications that appeared in 2002

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Ritter, H. and A. King: On the accretion efficiency of neutron stars in long–period binaries. In: The Physics of Cataclysmic Variables and Related Objects. Proc. A Conference on the occasion of Klaus Beuermann's 60th Birthday, Göttingen, 5 August- 10 August, 2001. Eds.: B.T. Gänsicke, K. Beuermann and K. Reinsch. Astron. Soc. Pac. Conf. Ser., Vol. 261, 531–532.

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Sauer, D. and A. Pauldrach: Model atmospheres for type Ia supernovae: Basic steps towards realistic synthetic spectra. In: Proceedings of the 11th Workshop on "Nuclear Astrophysics", Ringberg Castle, February 11-16th, 2002 Eds: Hillebrandt, W. and E. Müller MPA Garching 2002, 48–53.

Schlattl, H., S. Cassisi, A. Weiss and M. Salaris: The peculiar evolution of low-mass Pop. III stars. In: New Quests in Stellar Astrophysics: The link between Stars and Cosmology. Proc. of a workshop in Puerto Vallarta, Mexico, March 26–30, 2001. Eds.: M. Chavez, A. Bressan, A. Buzzoni and D. Mayya. Kluwer Academic Publisher, Amsterdam 2002, Vol. 55, in press.

Schmieder, B., N. Mein, P. Heinzel and U. Anzer: Spectral diagnostics of the magnetic field orientation in a round–shaped filament. In: Solar Variability: From Core to Outer Frontiers. Proc. 10th European Solar Physics Meeting, Prague, September 9-14, 2002. Ed.: A. Wilson. ESA SP-506, 469–472.

Spruit, H.C. and B. Deufel: Evaporation of the Inner Disk in Black Hole Candidates. In: Lighthouses of the Universe: The Most Luminous Celestial Objects and Their Use for Cosmology. Proc. MPA/ESO conference, Garching 6–10 August 2001. Eds.: M. Gilfanov, R. Sunyaev, E. Churazov Springer Berlin 2002, 479–485.

Travaglio, C., R. Gallino, & E. Arnone: Chemical evolution of Sr-Y-Zr: the puzzle of the stellar multisource origin. Proc. of the 11th Workshop on "Nuclear Astrophysics" Ringberg Castle, February 11 -16, 2002. Eds.: W. Hillebrandt and E. Müller, 218–223.

Travaglio, C., K. Kifonidis, & E. Müller: C and O explosive nucleosynthesis in SNII coupled to multidimensional hydrodynamics. Proc. CNO in the Universe, St. Luc, Switzerland, September 10–14, 2002. Eds.: C. Charbonnel, D. Schaerer & G. Meynet, ASP Conf. Ser., in press.

Utrobin, V.P. and N.N. Chugai: Ionization Freeze-out and Barium Problem in Supernovae 1987A. Proc. of the 11th Workshop on "Nuclear Astrophysics" Ringberg Castle, February 11 -16, 2002. Eds.: W. Hillebrandt and E. Müller, 136-144.

Weiss, A.: Key problems in stellar evolution. In: Stellar Structure and Habitable Planet Finding. Proc. 1st Eddington workshop, Cordoba, June 11–15, 2001. Eds.: F. Favata, I.W. Roxburgh and D.Galadi-Enriquez. ESA, Paris 2002, 57–64.

Welch, D.L., P. Popowski et al.: Frequency Analysis of a Subset of Fundamental Mode RR Lyrae Stars from the MACHO Project Large Magellanic Cloud Database. ASP Conference Proceedings: Radial and Nonradial Pulsations as Probes of Stellar Physics. Edited by Conny Aerts, Timothy R. Bedding, and Jørgen Christensen-Dalsgaard. San Francisco: Astronomical Society of the Pacific, 2002, Vol.259, p.412.

Wilms, J., N.A. Ketsaris, M. Kuster, I.E. Panchenko, K.A.Postnov, M.E. Prokhorov, P. Risse, R. Rotshild, W.A. Heindl, N.I. Shakura and R. Staubert: Observational Appearence of Non-Dipole Magnetic Field of Neutron Star in Hercules X-1. In: Magnetic Field and Turbulence in Space. Proc. Joint Seminar on Problem of Magnetic Fields and Turbulence in Space. Eds.: B.V. Somov and V.S. Prokudina. Izv. RAN, Ser. Fiz. 2003, Vol. 67, p. 310.

Wisshak, K., F. Voss, C. Travaglio, et al: An *s*-process origin of $^{180}\mathrm{Ta}^m$?. Proc. of the 11th Workshop on "Nuclear Astrophysics" Ringberg Castle, Febraury 11-16, 2002. Eds.: W. Hillebrandt and E. Müller, 88–94.

4.2.2 Publications available as electronic file only

Clarke, T. E. and T.A. Enßlin: Cluster mergers and diffuse radio emission in Abell 2256 and Abell 754. In: Clusters of Galaxies and the High Redshift Universe observed in X-Rays. Eds: D.M. Neumann and J. Tranh Thanh Van. Proc. XXXVIth Rencontres de Moriond, XXIst Moriond Astrophysics Meeting, Les Arcs, Savoie France, March 10– March 17 2001. `http://www-dapnia.cea.fr/Conferences/Morion_astro_2001/abs07/clarke.html`.

Cohen, A., N. Kassim, T.E. Clarke, T.A. Enßlin and D. Neumann: Low frequency VLA observations of Abell 754: evidence for a cluster radio halo and two possible radio relics. In: Clusters of Galaxies and the High Redshift Universe observed in X-Rays. Eds: D.M. Neumann and J. Tranh Thanh Van. Proc. XXXVIth Rencontres de Moriond, XXIst Moriond Astrophysics Meeting, Les Arcs, Savoie France, March 10– March 17 2001. `http://www-dapnia.cea.fr/Conferences/Morion_astro_2001/abs07/cohen.html`.

Downes, R.A., R.F. Webbink, M.M. Shara, H. Ritter, U. Kolb and H.W. Duerbeck: A catalog and atlas of cataclysmic variables: The living edition. `http://www-int.stsci.edu/ downes/cvcat/`

Enßlin, T. A. and M. Brüggen: Fossil radio plasma in cluster merger shock waves. In: Clusters of Galaxies and the High Redshift Universe observed in X-Rays. Eds: D.M. Neumann and J. Tranh Thanh Van. Proc. XXXVIth Rencontres de Moriond, XXIst Moriond Astrophysics Meeting, Les Arcs, Savoie France, March 10– March 17 2001. `http://www-dapnia.cea.fr/Conferences/Morion_astro_2001/abs07/ensslin.html`.

Nayakshin, S.: Kα lines (Theory) In: Black Holes: Theory Confronts Reality, Three Years Later, Santa Barbara, USA `http://online.itp.ucsb.edu/online/bhole_c02/nayakshin/`

4.3 Popular articles and books

Bartelmann, M.: Hintergründige Polarisation. Physik Journal, **1/12**, 18–20 (2002)

Börner, G.: "Kosmologie". S. Fischer Verlag, Frankfurt am Main, 2002, 128 pages.

Börner, G. and M. Bartelmann: Astronomen entziffern das Buch der Schöpfung. Physik in unserer Zeit, **33/3**, 114–120 (2002)

Diehl,R. and W. Hillebrandt: Astronomie mit Radioaktivität. Physik Journal, April-Heft, S. 47–53 (2002).

Gilfanov, M., Sunyaev, R. and E. Churazov (Eds.): Proc. of the MPA/ESO/MPE/USM Joint Astronomy Conference "Lighthouses of the Universe: The Most Luminous Celestial Objects and Their Use for Cosmology" 6-10 August 2001, Garching, ESO, 618 pages.

Hillebrandt, W. and E. Müller (Eds.): Proc. of the 11th Workshop on "Nuclear Astrophysics" Ringberg Castle, February 11 -16. MPA Garching 2002, 230 pages.

Hillebrandt, W. und K. Langanke: Astrophysik und Kernphysik - gemeinsam das Universum entschlüsseln. Physik Journal, Juni-Heft, S. 43–49 (2002)

Kauffmann, G. and F. van den Bosch: The Life Cycle of Galaxies. Scientific American, **286**, part no 6, 36–45 (2002).

Kauffmann G., and F.C. van den Bosch: Uber den Ursprung der Galaxienarten Spektrum der Wissenschaft, September 2002, 54–62

Kühnel, T. and M. Bartelmann: Die Grundlagen der Kosmologie. Sterne und Weltraum, **41/5**, 40–46 (2002)

4.4 Invited talks

Anzer, U.: Magnetic dips and the physics of quiescent prominences. In: Solar Variability: From Core to Outer Frontiers.

M. Bartelmann: "Kosmische Entwicklung im Spiegel der Galaxienhaufen" (wissenschaftliches Kolloquium, Heidelberg, 13.3.)

M. Bartelmann: "Strong and weak lensing by galaxy clusters" (Taipeh, 22.4.–26.4.)

M. Bartelmann: "Einstein's Telescope: Gravitational lensing as a cosmological tool" (wissenschaftliches Kolloquium, ESTEC, Noordwijk, 29.11.).

S. Charlot: SDSS Workshop on "Galaxy Spectra" (Tucson, USA, 14.1.–25.1.).

E. Churazov: Workshop “Matter and Energy in Clusters of Galaxies”, Taiwan (23.04.–27.04.).

E.Churazov: Workshop “CMB & Cosmology: Where Are We?”, Ringberg, Germany (02.12.–06.12.).

E. Churazov: Workshop “High Energy Astrophysics 2002”, Moscow, Russia (24.12.–26.12.).

B. Ciardi: Conference “Early Cosmic Structures Formation and the End of the Dark Ages” (Elba, 4.6.–7.6.)

B. Ciardi: 1st Joint Seminar Italy-Japan “Formation of the First Generation of Galaxies and Cosmological Implications” (Florence, 8.7.–10.7.)

T. Di Matteo: Black Holes: Theory Confronts Reality, Three Years Later “Observations and theory of non-radiative accretion flows” (Institute of Theoretical Physics, Santa Barbara USA, 25.2.–28.2.).

T. A. Enßlin: “Matter and Energy in Clusters of Galaxies” (Taipei 23.4.-27.4.)

M.Gilfanov: IAU Symposium No.214 “High Energy Processes and Phenomena in Astrophysics” (Suzhou, China, 6.08–10.08).

M. Gilfanov: “High Energy Astrophysics 2002” (Moscow, 24.12.–26.12)

W. Hillebrandt: “Nuclei in the Cosmos VII” (Fuji-Yoshida, Japan, 8-12 July).

W. Hillebrandt: Workshop on “Variability with Wide Field Imagers” (Lampedusa Island, Italy, 16 - 20 September)

H.-Th. Janka: Kolloquium, Univ. Giessen (Giessen, 7.2.)

H.-Th. Janka: Kolloquium, Univ. Heidelberg (Heidelberg, 13.3.–14.03)

H.-Th. Janka: 200th Meeting of the American Astronomical Society, (Albuquerque, New Mexico, 2.6.–6.6.)

H.-Th. Janka: Kolloquium, Univ. Stuttgart (Stuttgart, 18.7.)

H.-Th. Janka: ESO/MPA/MPE Workshop “From Twilight to Highlight: The Physics of Supernovae” (Garching, 29.7.–31.7.)

H.-Th. Janka: ECT* Collaboration Meeting on “Neutron Stars and Stellar Collapse” (Trento, Italy, 29.10.–31.10.)

H.-Th. Janka: 3rd SNSC Team Meeting (UCSC, Santa Cruz, 21.11.–23.11.)

H.-Th. Janka: Kolloquium, TU München (Garching, 4.12.)

G. Kauffmann: “Galaxy Evolution: Theory and Observations” (Cozumel, 8.4.–12.4.)

G. Kauffmann: “Star Formation through Time” (Granada, 24.9.–28.9.)

A. Merloni: 5th National Italian AGN Meeting “Inflows, Outflows and Reprocessing around Black Holes” (Como, Italy, 11.6–14.6)

E. Müller: Physikalisches Kolloquium (Basel, 18.1.)

E. Müller: Astrophysical Colloquium (Turino, 7.5.)

E. Müller: Physikalisches Kolloquium (Oldenburg, 13.5.)

E. Müller: 4th EU Network Meeting “Theoretical Foundations of Sources for Gravitational Wave Astronomy in the Next Century” (Palma de Mallorca, 26.-28.9.)

E. Müller: Workshop on Theoretical Plasma Astrophysics "The Flowing Universe - Dynamics of Astrophysical Flows" (Trieste, 11.-22.11.)

S. Nayakshin: International Conference "Black Holes: Theory Confronts Reality, Three Years Later" (Institute for Theoretical Physics, Santa Barbara, USA, 25.2.–28.2.)

S. Nayakshin: International Conference " Active Galactic Nuclei: From Central Engine to Host Galaxy", (Meudon, France, 23.7.–27.7.)

J. Niemeyer: "(Alternative) Dark Matter, Cosmic Structure, and the Early Universe" (Schloss Ringberg, 8.4.–12.4.)

J. Niemeyer: "From Twilight to Highlight: The Physics of Supernovae" (Garching, 29.7.–31.7.)

V. Springel: CMBnet Annual Meeting 2002 (Castle Ringberg, 2.12.–4.12.)

H.C. Spruit: 3rd Sakharov Conference on Physics and Astrophysics, (Moscow 24.6.–28.6.)

H.C. Spruit: NATO ASI "Turbulence, Waves and Instabilities in the Solar Plasma", (Budapest 16.9.–20.9.)

H.C. Spruit: IAU Symposium 215 on Stellar Rotation, (Cancun, Mexico 11.11.–15.11.)

R. Sunyaev: Three Scott lectures; Cavendish laboratory, (Cambridge University, 16.2.–24.2.)

R. Sunyaev: Bruno Rossi Lecture in Astrophysics , MIT (Cambridge, USA, 7.5.)

R. Sunyaev: 4th microquasar workshop; (Corsica France, 26.5.–1.6.)

R. Sunyaev: Plenary talk on Physical Processes near accreting black holes and neutron stars; Third Sakharov conference on physics (Moscow, 26.6.–29.6.)

R. Sunyaev: Two lectures on "Leonardo da Vinci" Summer Course on Space Science, Mission concept and payload design in X- and Gamma-Ray astronomy (Bologna, 30.6.–2.7.)

R. Sunyaev: Conference "Making Light of Gravity", (Cambridge, England, 7.7.–13.7.)

R. Sunyaev: Accretion Disks, Jets and High Energy Phenomena in Astrophysics, Centre for Theoretical Physics (Les Houches, 10.8.–18.8.)

R. Sunyaev: Plenary talk during High Energy Astrophysics-2002 conference (Moscow, 24.12.–26.12.)

F. van den Bosch: 3rd annual meeting of the RTN-IGM network "Feedback processes in the IGM" (Gargonza, Italy, 14.9.–18.9.)

R. Wegmann: Exploration of Small Solar System Objects: Past, Present and Future (Houston 14.10.–16.10.)

S. White: Moriond Astrophysics Conference "The Cosmological Model" (France, 16.3.–23.3.)

S. White: Cozumel workshop "Galaxy Evolution: Theory and Observations" (Mexico, 8.4.–13.4.)

S. White: Cambridge Summer Conference "MJR60: Making Light of Gravity" (U.K. 7.7.–12.7.)

S. White: UNESCO International Conference on Theoretical Physics "TH-2002" (France 22.7.–27.7.)

S. White: RTN Network Meeting "The Intergalactic Medium" (Italy, 14.9.–18.9.)

S. White: Maryland October Astrophysics Conference "The Emergence of Cosmic Structure" (U.S.A., 7.10.–9.10.)

S. White: Ringberg workshop "Galaxy Clusters" (Germany, 2.12.–4.12)

S. White: XXI Texas Symposium "Texas in Tuscany" (Italy, 8.12.–13.12)

S. White: Oxford Workshop "Extending Frontiers in Cosmology: Joe at 60" (Oxford U.K. 13.12.–15.12)

5 Personnel

5.1 Scientific staff members

Directors

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

Scientific Member

R.-P. Kudritzki (till Dec. 16)

External Scientific Members

R. Giacconi, R.-P. Kudritzki (since Dec. 17), W. Tscharnuter.

Staff

U. Anzer (till Jan. 1.) A.J. Banday, M. Bartelmann, G. Börner, S. Charlot, E. Churazov, H. Dimmelmeier, K. Dolag, K. Dullemond (since March, 1) T. Enßlin, M. Gilfanov, S. Heinz, A. Helmi (till July 14.), H.–T. Janka, G. Kauffmann, K. Kifonidis W.P. Kraemer, H.J. Mo, E. Müller, J.C. Niemeyer (till Oct. 30.), S. Nayakshin, P. Popowski, M. Rampp, M. Reinecke, M. Revnivtsev, H. Ritter, G. Rudnick, S. Sazonov, F. Siebel (since Dec. 1), V. Springel, H.C. Spruit, C. Travaglio, F. van den Bosch, A. Weiß, S. Zaroubi.

Emeriti

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

Scientists associated:

U. Anzer (since Febr. 1), H. Arp, G. Diercksen, E. Meyer–Hofmeister, J. Schäfer, H.-C. Thomas, R. Wegmann.

Sofja Kovalevskaja Programm

J. Brinchmann, S. Charlot (awardee) C. Möller

Alexander von Humboldt fellowships

Xu Kong (USTC, China), N. Sugiyama (Tokyo, Japan, 10.7.–30.9.).

DAAD–fellowships

N. Yoshida (Tokyo, Japan) till July 30.

EC–fellowships

A-M. Aloy Torás, S. Bertone (Aug. 29), J. Braithwaite, S. Bianchi (till March 22), B. Ciardi, S. Cora, K. Dullemond (till Feb. 28), D. Giannios (since Aug. 15), S. Inoue (since Aug. 1), L. King (till March 1), Ch. Kobayashi (since March 15), J.A. Rubiño-Martín (since Nov. 1), A. Wozna (since Oct. 1).

Ph.D. Students

R. Banerjee (till Nov. 15), J. Braithwaite, A. Büning, R. Buras, G. Drenkhahn (till Aug. 31), M. Flaskamp, H.-J. Grimm, H. Hämmerle (till Sept. 30), F. Hansen (till June 30), C. Haydn (since Oct. 1), L. Iapichino (since May 1), M. Jubelgas (since Sept. 1), T. Leismann, H. Mathis (till Sept. 30), B. Menard, A. Nickel (till Dec. 31), C. Pfrommer (since Sept. 1), F. Röpke, D. Sauer, B. M. Schäfer, L. Scheck, M. Schirmer (till March 31), W. Schmidt, F. Siebel (till Nov. 30), M. Stehle, F. Stoehr,

IMPRS Ph.D. Students

K. Basu, S. Bertone (since Oct. 1), J. Chluba, D. Croton (since July 15), J. Cuadra (since Aug. 20), G. DeLucia, L. Gao, G. Hütsi (since Aug. 1), P. Mimica, M. Stritzinger (since Sept. 3), L. Tasca, C. Vogt, S. Zibetti.

Diploma students

A. Arcones (since Nov. 5) T. Behrens, C. Haydn (till Sept. 30), V. Heesen (since May 15), M. Jubelgas (till Aug. 30), F. Kitaura (since Nov. 15), A. Marek (since Nov. 15), C. Pfrommer (till Aug. 30), O. Zahn (since April 10).

5.1.1 Staff news

H.-Th. Janka: Habilitation im Fachgebiet Theoretische Physik an der Technischen Universität München.

G. Kauffmann: Heinz Maier-Leibnitz-Preis

M. Reinecke: Otto-Hahn medal of the MPG (2002).

R. Sunyaev: Alexander Friedmann Prize in Gravitation and Cosmology from the Russian Academy of Sciences

5.1.2 Ph.D. theses 2002

R. Casas-Miranda: “Statistics of the Dark Matter Halo Distribution in Cosmic Density Fields”, Ludwig-Maximilians-Universität, München.

G. Drenkhahn: “Magnetically powered Gamma-ray Bursts”, Universität Amsterdam.

H. Hämmerle: “Cosmic shear measurements on small angular scales: The HST/STiS parallel survey” Universität Bonn.

F. Hansen: “Data analysis of the cosmic microwave background”, Ludwig-Maximilians-Universität, München.

H. Mathis: “Simulations numeriques de modeles gaussiens et non-gaussiens de formation des galaxies” University of Toulouse III.

F. Siebel: ”Simulation of axisymmetric flows in the characteristic formulation of general relativity”, Technische Universität, München.

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
I. Baraffe	(Lyon, France)	1.10.–30.11.
J. Bicak	(Prag)	17.1.-17.3.
S. Blinnikov	(ITEP, Moscow)	1.8.–30.9.
G. Bruzual	(Mérida, Venezuela)	1.8.–30.9.
I. Cenusak	(Bratislava, Slovak Republic)	24.6.–20.7.
D. Chen	(Shanghai, China)	since 4.12.
G. Chabrier	(Lyon, France)	1.11.–30.11.
R.A.C. Croft	(Carnegie Mellon Univ., Pittsburgh, USA)	1.6–30.6.
R. Dutt	(Santiniketan, India)	3.5.–26.5.
J.A. Font	(Valencia, Spanien)	4.5.–15.3.
W. Forman	(Cambridge, USA)	24.6.–31.7.
L. Girardi	(Trieste, Italy)	1.11.–30.11.
S.A. Grebenev	(Moskau, Rußland)	15.7.–25.8.
C. Halliday	(Padova, Italy)	1.1.–30.4.
P. Heinzel	(Ondrejov, Czech Rep.)	1.-31.5.
		1.-30.11.
N.A. Inogamov	(Moskau, Rußland)	3.6.–2.9.
S. Inoue	(Tokyo, Japan)	since 1.8.
Y. Jing	(Shanghai Obs.)	20.2.–3.3.
C. Jones	(Cambridge, USA)	20.7.–19.8.
X. Kang	(Shanghai, China)	till 30.10.
M. Karelson	(Tartu, Estland)	10.12.–21.12.
M. Kieninger	(Montevideo, Uruguay)	1.1.–31.1.
U. Kolb	(Milton Keynes, United Kingdom)	27.11.-31.12.
S. A. Koryagin	(Nizhny Novgorod, Russia)	30.3.–29.4.
I. Kryukov	(Moscow,Russia)	1.3.-30.4.
A. Kunder	(Willamette, USA)	22.07.–20.11.
Y. Lu	(Beijing, China)	20.10.–19.12.
P.-A. Malmqvist	(Lund, Sweden)	6.11.–6.12.
L. Mashonkina	(Kazan, Russia)	till 28.2.
P. Marigo	(Padua, Italy)	1.11.–30.11.
P. Mazzali	(Trieste, Italy)	19.6.–14.8.
M. Meneghetti	(Padova, Italy)	15.4.–31.7.
S. Molkov	(Moskau, Rußland)	5.7.–5.8.
F. Mrugala	(Torun, Poland)	1.9.–30.9.
D. Nadyozhin	(ITEP, Moscow, Russia)	25.6.–25.8.
R. Narayan	(CfA Harvard, USA)	16.6.–15.7.
P. Neogrady	(Bratislava, Slovakia)	6.11.–30.11.
N. Padmanabhan	(Princeton, USA)	1.7.–14.7.
N. Pogorelov	(Moscow,Russia)	1.3.-30.4.
P. Ruiz-Lapuente	(Barcelona, Spain)	9.1.–28.2.
		1.8.31.8.
A. Rubino-Martin	(Inst. Astr. de Canaries)	1.8.–30.9.

Name	home institution	Duration of stay at MPA
T. Sako	(Tokyo, Japan)	1.1.–31.12.
M. Salaris	(Liverpool, UK)	17.6.–30.7.
H. Schlattl	(Liverpool, UK)	25.6.–12.7.
N.I. Shakura	(Moskau, Rußland)	4.9.–4.10.
Z. Shao	(Shanghai, China)	since 23.10.
S. Shen	(Shanghai, China)	1.1.–31.12.
C. Shu	(Shanghai, China)	since 05.08.
N.R. Sibgatoulline	(Moskau, Rußland)	18.1.–22.2.
S. Sild	(Tartu, Estland)	5.12.–21.12.
M. Sindelka	(Prague, Czech Rep.)	21.5.–31.7.
P. Soldan	(Durham, England)	3.6.–3.7.
E. Sorokina	(Sternberg Inst. Moscow)	1.8.–29.8.
V. Spirko	(Prague, Czech Rep.)	17.6.–31.7.
K. Subramanian	(IUCAA, India)	2.4.–21.5.
P. Tissera	(Buenos Aires, Argentina)	31.5.–13.6.
M. Urban	(Bratislava, Slovak Republic)	24.6.–20.7.
V. Utrobin	(ITEP, Moscow, Russia)	3.1.–28.2.
O. Ventura	(Montevideo, Uruguay)	1.1.–31.1.
		12.7.–8.8.
S. Woosley	(UC, Santa Cruz, USA)	28.7.–28.9.
H. Wu	(Beijing, China)	since 04.10.
K. Yamamoto	(Hiroshima, Japan)	till 30.8.
X. Yang	(Hefei, China)	till 30.06.
D. Zhao	(Shanghai Obs.)	till 8.3.
V.V. Zheleznyakov	(Nizhny Novgorod, Rußland)	30.3.–30.4.