Max-Planck-Institut
für
Astrophysik

Annual Report 1998

Front cover: The MPA building in summer. In this season the institute's location in a wooded research park close to the river Isar is at its most appealing. Some scientists even cycle to work regularly from the centre of Munich – 17km through parkland along the banks of the river.
Back cover: The evolution of structure in a Cold Dark Matter universe. This image is a view along the past light-cone of an observer positioned at the "knot" of the tie. The end of the tie is at redshift 4.6 and the growth of structure as one moves from the end towards the observer is very obvious. The wide-angle part of the tie shows a region similar in size to the largest galaxy redshift surveys so far completed. This "Hubble Volume" simulation was carried out by the Virgo Supercomputing Consortium on the Garching T3E. It followed the motion of one billion computational particles in order to represent the evolution of structure in a cubic region 12 billion light-years on a side.

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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 more than 70 autonomous research institutes within the Max-Planck Society. 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 Max-Planck Society. 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 headquarters of the European Southern Observatory (ESO) came to Munich from Geneva, and as part of the resulting reorganisation 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. Simon White is acting as Managing Director until the end of 1999.

Research at MPA is devoted to a broad range of topics in theoretical astrophysics. Major concentrations of interest lie in the areas of stellar evolution, stellar atmospheres, nuclear astrophysics, supernova physics, astrophysical fluid dynamics, high energy astrophysics, radiative processes, galaxy structure, formation and evolution, gravitational lensing, the large-scale structure of the Universe, particle astrophysics and cosmology. For many years the MPA had a strong group in General Relativity, but in mid-1995 most of this group moved to the newly founded MPI für Gravitationsphysik in Potsdam near Berlin. Their departure allowed a consolidation of MPA activities in extragalactic astrophysics, as well as an expansion in a new area, high energy astrophysics. While most MPA research addresses theoretical issues, the neighbouring 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 infrared and is currently commissioning the VLT, the largest optical telescope in the world.

At any given time the MPA has about 30 scientists working on long-term positions at post-doctoral level and above, up to 10 foreign visitors brought in for periods of varying length under a vigorous visitor programme, and about 20 graduate students. The students are almost all enrolled for degrees in one of the two large universities in Munich, the TUM and the Ludwig-Maximilians-Universität (LMU). A number of the senior staff at MPA have teaching affiliations with one or other of these universities. Ties with the Institute of Astronomy and the Observatory of the LMU are particularly close because the observatory director (Rolf-Peter Kudritzki) is also a Scientific Member of the MPA.

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, two of which are coordinated from the MPA. Interaction with local institutions is enhanced by a Special Research Area funded by the German Research Foundation in the field of astroparticle physics. Other participants in this programme include the physics departments of the two universities, the observatory of the LMU, and the MPI für Physik.

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 focussed plan is very effective at encouraging interaction between scientists and makes for a pleasant and stimulating research environment. Part of the ground floor and most of the basement of the building is currently occupied by the infrared group of the MPE, and this proximity significantly enhances the possibilities for interaction with this large and active observational/instrumental group.

The MPA and the MPE share a large and fully stocked astronomical library which is housed in the MPA building. All major astronomical books and periodicals are available. The library staff can also provide access to a variety of online archives and are currently extending this capability. Further library material is available at ESO which in addition maintains a complete collection of optical sky maps and photographic sky surveys. Other large data analysis facilities are available at the MPE which is the European data centre for the ROSAT satellite and is providing a data centre for the ISO satellite mission.

The MPA has always placed considerable emphasis on computational astrophysics and has therefore ensured access to forefront computing facilities. The current in-house system is based on a central cluster of about 10 IBM RS6000 workstations, with additional SGI graphics workstations for graphics applications. Users have free access to all workstations and are in general connected via large-screen X-window terminals or desk-top workstations. For larger computing tasks MPA scientists use the facilities of the central computing centre of the Max-Planck Society (known as the RZG). This is part of the MPI für Plasmaphysik and is located a few hundred metres from the MPA. Current facilities at the RZG include a 748-processor CRAY T3E, an 18-processor IBM SP2, a 3-processor NEC SX-5, a large cluster of high-end workstations and a Terabyte mass storage system. MPA scientists have free access to the RZG and are among the top users of the facilities there. 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. 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.

1.3 1998 at the MPA

This year was one of consolidation and broadening of the initiatives started at MPA over the last few years. Work began in earnest on MPA's contribution to the ESA Planck Surveyor mission, and by year's end work primarily in collaboration with ESTEC in Holland had produced preliminary versions of many parts of the software framework within which the Planck project will operate its distributed mission simulation and data processing pipelines. The next few years will see further expansion of this effort, as well as the definition of MPA's specific responsibilities for science exploitation within the Planck Consortia.

1998's Biermann Lecturer was Roger Blandford from Caltech. He spent three weeks at the MPA in July and filled the Hörsaal to the limit for his series of three lectures on astrophysical black holes. His stay proved stimulating for many of the MPA's research programmes, and this overlap in interests undoubtedly proved useful to him in his other offical MPA role as chair of the institute's Fachbeirat (Visiting Committee).

The Fachbeirat returned to MPA in late September for their biennial visit. Sudden illness prevented Catherine Cesarsky and Bohdan Paczynski from attending, while Immo Appenzeller was required in Chile for commissioning of his group's instrument on the VLT. As a result only Jim Truran and Nigel Weiss were able to come with Roger Blandford on the committee's two–day visit. This proceeded as usual with a report from the Managing Director, a morning of scientific presentations, informal discussions with the directors and selected staff members and, of course, the traditional parties. The Fachbeirat was apparently happy with what it saw and in due course sent a very positive report to the MPG President.

In early August the MPA and ESO organised the first of what is intended to be an annual series of joint workshops. The MPA/ESO workshop on "Large–Scale Structure from Recombination to Garching" attracted 120 registered participants, filling ESO lecture theatre to capacity. Posters were displayed in the MPA foyer and the regular walk from talks at ESO to coffee/posters at MPA seemed beneficial to the participants' concentration as well as to their health. A beery conference dinner in the Löwenbräu brewery went down well with the participants but was, perhaps, less successful in preparing them for the following morning's talks. The 1999 ESO/MPA workshop will be devoted to "The First Stars".

The institute also made good use in 1998 of the unique facility offered by Schloß Ringberg, the Max–Planck Society's castle in the Bavarian mountains. The by–now traditional winter Nuclear Astrophysics workshop took place there in March, a cosmology meeting was organised in June, and in December the Sonderforschungsbereich (Special Research Area) on Particle Astrophysics again used the castle for its annual meeting.

International collaborations at the MPA continued to be supported by a variety of formal and informal agreements. The institute currently plays a major role in three European TMR (Training and Mobility of Researchers) Networks, acting as coordinating node for two of them. These networks bring additional foreign postdocs and graduate students to MPA and greatly enhance exchanges with the partner institutes. In 1998 they also provided the basis for a number of successful proposals by MPA staff in the first competition for time on the VLT. These networks continued to be some of the major joint research efforts within the European Association for Research in Astronomy (EARA) the grouping which links the MPA to the Institute of Astronomy in Cambridge, the Leiden Observatory and the Institut d'Astrophysique de Paris. At the end of 1998 discussions with the Instituto Astrofisica de Canarias, the largest astronomical institute in Spain and the institution which runs the Canary Island observatories, led to its inclusion within EARA.

Another international collaboration which captured some headlines this year was the Virgo Supercomputing Consortium. This Anglo–German–Canadian group used the new T3E at the RZG to carry out several "Hubble Volume Simulations", attempts to follow the growth of structure in a large fraction of the entire observable universe. Since each simulation generated almost a Tbyte of data, follow–up data analysis (apart from media–friendly graphics such the ubiquitous "Tie" — see the back of this report) has been a major task in its own right.

An international collaboration of a different kind was set up this year by MPA and Fermilab scientists with the financial support of the German American Academic Council. The Young Scholars Institute on Astroparticle Physics brought together 30 carefully selected young scientists – 15 from Germany and 15 from the US – together with eight more senior "convenors" for an intense two–week discussion of problems at the interface between cosmology and particle physics. In 1998 the group met at the Aspen Center for Physics in Aspen, Colorado. In 1999 they will come together again for two follow–up weeks in Munich/Garching and at Schloß Ringberg.

Another international initiative which approached fruition in 1998 was an effort with the Shanghai Astronomical Observatory to set up a research group in cosmology at the SAO under a general cooperation agreement between the MPG and the Chinese Academy of Sciences. A cosmology workshop in Shanghai improved contacts between MPA and Chinese astrophysicists and provided an opportunity to sort out many of the details of the research group which will eventually comprise up to ten scientists and graduate students and will receive supplemental funding directly from the Max–Planck Society.

A new outreach project took shape in 1998 out of contacts with the Deutsche Museum in Munich (the "German Museum" — actually a world–class museum of science and technology). A permanent exhibit of MPA–related science is under construction based on computer animation of topics such as supernova explosions, stellar collisions, gravitational lensing and cosmological structure formation. The exhibit should be ready to go on display in 1999.

A significant preoccupation during the year has been the pioneering of new routes from the MPA to the cafeteria; construction for the MPE's new building has blocked off many of the traditional paths. Despite some fears the MPA and its computer system survived the minor earthquakes caused by the sinking of the foundations and by the end of 1998 the walls were two stories high. Summer 1999 should see the end of exterior construction and so the return of peace to the campus (at least until the subway builders arrive in 2001). The "Big Move" with its attendent ramifications for the MPA will not, however, take place for another year.

1.4 How to reach us

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  user-id@mpa-garching.mpg.de
  (initial + last name
  will reach most people,
  e.g. swhite for Simon White.)

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

  anonymous ftp:
  ftp.mpa-garching.mpg.de

- MPA (reference) library:

  phone: +49-89-3299-3305/6
  FAX: +49-89-3299-3235
  email: lib@mpa-garching.mpg.de
  URL: http://www.mpa-garching.
  mpg.de/libris.html
  homepage: only local access

2 Scientific Highlights

2.1 Where are the solar neutrinos?

Despite the postulation of the neutrino by Pauli 70 years ago the properties of this elementary particle still remain a mystery. Since neutrinos interact weakly with matter it is very difficult to determine their properties directly by experiments. In the standard model for the electromagnetic and weak interactions between particles, neutrinos do not carry any charge and are massless. Three types ("flavours") of neutrinos are known, the electron(e)-, muon(μ)- and tau(τ)-neutrino, each of which is associated within a "lepton"-family with the electron, muon or tauon. The neutrality of neutrinos has been tested to a very high precision, but it is not yet known if neutrinos have mass. Currently the mass of an e-neutrino is measured to be at least hundred thousand times less than the mass of an electron. Since the present standard model for electro-weak interactions treats neutrinos as massless, the discovery of even a tiny neutrino mass would demand an extension of this model.

Interestingly, the Sun provides a laboratory for improving our knowledge about neutrinos. As other stars the Sun shines because helium is created by nuclear burning of hydrogen in its core. In this process produces e-neutrinos which leave the Sun almost unimpeded because of their weak interaction with the solar matter. By measuring the neutrino flux at Earth one can thus obtain information about conditions (e.g. the temperature) in the solar core.

A number of experiments around the world have been developed during the last 30 years to measure solar neutrinos of various energies, among them *Homestake* in the USA, *GALLEX* in Europe, *SAGE* in Russia and *Super-Kamiokande* in Japan. Because neutrinos interact with matter extremely rarely their detection requires huge and long-running experimental facilities. Theoretical solar models calculated by MPA scientists and others are able to predict the flux of neutrinos; knowing the detector properties one can thus predict the number of events each experiment should see. All experiments do indeed measure neutrino events directly confirming that nuclear reactions are taking place at the center of the Sun. However, they find that the measured event rate is significantly smaller than predicted by theory (see Fig. 2.1). In the Homestake-experiment only about one third of the expected neutrinos are seen, while in GALLEX and SAGE, which measure the same part of the spectrum, only about one half of the expected flux is detected. The discrepancy between the measured and predicted numbers of neutrinos is called the "solar neutrino problem" and challenges the theoretical models.

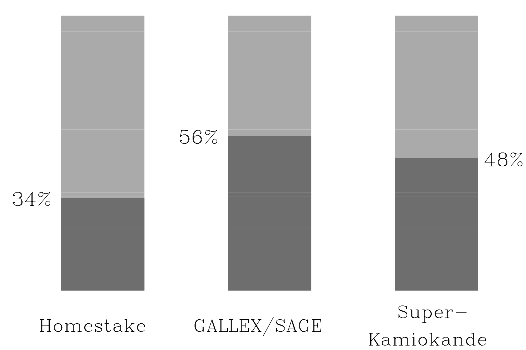


Figure 2.1: The dark shaded areas show how many neutrinos are measured in the experiments compared to the expected rates (light shaded).

A possible solution to this problem is that the solar model calculations are not correct. However, the detection of the 5-minute oscillation of the solar photosphere provided a new way to test the validity of these models to a high precision: "helioseismology". Acoustic waves which arise at the surface of the Sun travel through the interior, stimulating the Sun to oscillate at certain well-defined frequencies Since waves of different frequencies penetrate to different depths in the Sun, the solar oscillations provide information about the interior. This is similar to geoseismology, where small explosions are induced on the surface of the Earth to obtain data about the Earth's crust and mantle, for example, to locate the position of oilfields deep in the ground. The results obtained from helioseismology confirm the structure of the MPA solar model to better than 0.3%. This means that the predicted neutrino production must be nearly correct.

Thus we are left with the question: What happens to the neutrinos on their way from the Sun to the Earth? Is it possible that some of the e-neutrinos produced in the Sun are transformed into μ- or τ-neutrinos on their way to the Earth? Muon- and tau-neutrinos cannot be measured in existing detectors, so the number of detections caused by the remaining e-neutrinos would be smaller than expected.

Transformations between neutrino families, known as "neutrino oscillations", in non-standard extensions of the electro-weak theory. In order for this to happen, the neutrinos of different flavours must have masses. The relative strength of the mixing is described by the quantity $\sin^2 2\Theta$; for instance $\sin^2 2\Theta=1$ means maximal possible mixing, $\sin^2 2\Theta=0$ no mixing at all. The path length for the oscillation of, for example, e- into μ-neutrinos during their propagation depends on the difference of their squared masses (Δm^2) and their energies. These parameters, the $\sin^2 2\Theta$'s and Δm^2's, are not specified by the theory and the aim is to determine them using results from solar neutrino experiments.

In order to do so, our MPA solar model was taken and, for a variety of values of these parameters, we determined what fraction of the original e-neutrinos are still of e-type when they reach Earth. From this information we calculate the expected event rates for the various neutrino experiments. For some choices the expected and actual measured rates agree in all experiments at the same time. The grey areas in Fig. 2.2 show the parameter combinations where this is the case. It was assumed that the e-neutrino mixes only with one other neutrino type, either μ- or τ-neutrino. This is the standard approach. As shown in Fig. 2.2 there are several regions in the parameter plane which are consistent with the measurements. Presently it is not possible to reduce the solutions to a single region, so new experiments are needed to get an unambiguous solution.

There is a second source of detectable neutrinos which, as in the solar case, points to the "disappearance" of neutrinos: In the Earth's atmosphere energetic cosmic rays interact with the air, producing various secondary particles, among them neutrinos of e- and μ-type. These neutrinos have different energies than the neutrinos emitted by the Sun, and can therefore be discriminated from the latter in detectors like Super-Kamiokande. As in the case of solar neutrinos, the experiments measure too few atmospheric neutrinos. In contrast to the solar e-neutrino deficit, a part of the atmospheric μ-neutrinos disappears. The Super-Kamiokande collaboration concluded that some of the μ-neutrinos oscillate into τ-neutrinos. This implies that oscillations between all three types of neutrinos may happen, and thus one has to reconsider the solar case to include all possible oscillations. The aim is to resolve the solar and the atmospheric neutrino problems simultaneously.

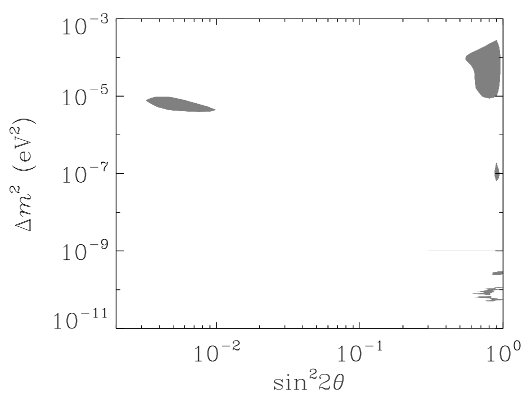


Figure 2.2: The regions in mixing strength ($\sin^2 2\theta$) and difference of squared masses (Δm^2) in which the transition from e- into either $\mu-$ or $\tau-$ neutrinos could explain the measured rates in the solar neutrino experiments Homestake, GALLEX, SAGE and Super-Kamiokande. For comparison, the electron mass is about 511 000 eV.

An MPA analysis of the three flavour oscillation case for the solar neutrinos was therefore started taking into account the results found for the atmospheric neutrino anomaly. Consistent solutions for the mixing parameters were indeed found, which agree with the solar and atmospheric neutrino experiments and are not obtained in the simpler two-flavour mixing scenario studied previously. However, several possible solutions still remain. To determine the correct properties of neutrinos, new experiments are needed which measure parts of the neutrino energy spectrum, which are presently poorly known. In the near future two experiments will help to clarify the whole solar neutrino problem, BOREXINO and SNO. The latter will be able to measure not only the solar e-neutrino-flux, but also the combined μ- and τ-neutrino rate. SNO will therefore be an "appearance" experiment in which certain events will happen only if e-neutrinos have changed into another type. Thus it should decide whether oscillations between neutrino families occur in nature. Together with the other experiments it should determine the correct oscillation parameters. (Helmut Schlattl)

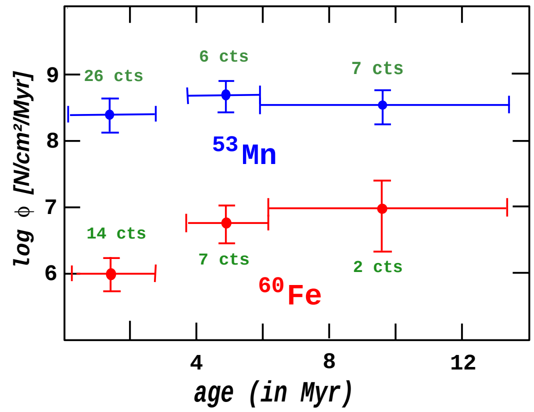


Figure 2.3: Fluxes of ^{60}Fe (lower points) and ^{53}Mn (upper points) as functions of age for the three layers of ferromanganese crust analyzed with AMS. The fluxes are obtained by assuming a constant flux during the time interval, corrected for radioactive decay. The ages of the samples have been determined by cobalt dating. "Counts" means the clearly identified ^{60}Fe (^{53}Mn) nuclei.

2.2 A search for radioactive ^{60}Fe in deep ocean sediments

Many speculations deal with the possibility that an occasional supernova might explode near the solar system and, among other things, have significant effects on the terrestrial biosphere. Although the number of supernova explosions observed in other spiral galaxies leads one to conclude that an explosion within, say, 10 pc is rather unlikely, perhaps one every 10^9 years or more, indirect evidence seems to indicate that such violent events did happen during geological and biological history. Of course, one would like to have direct evidence for a recent interaction between a supernova and the solar system. For example, the detection of radioactive elements on Earth which cannot be produced by other processes could provide a clear indication for a nearby supernova.

Several long-lived radio-isotopes are possible diagnostic tools for identifying such supernovae, but ^{60}Fe is the most promising candidate. In the absence of other significant production channels, its natural abundance is far below an expected supernova induced signal, and other isotopes which are similarly free of background are produced by supernovae in much smaller quantities. Moreover, ^{60}Fe has a half-life of 1.49 Myr, long enough to survive transport to Earth. Finally, accelerator mass spectrometry (AMS) provides a very sensitive method to detect it in minute concentrations.

For these reasons we have decided to carry out an AMS searching in ice cores and deep ocean sediments for radionuclides in particular ^{60}Fe which accreted onto Earth from space which have not yet decayed. The collaboration consists of a group at Munich Technical University (K. Knie, G. Korschinek, T. Faestermann, C. Wallner), the University of Kiel (J. Scholten) and the MPA (W. Hillebrandt). Our first experiments were done with a sample of ferro-manganese crust originating from Mona Pihoa in the South Pacific at a depth of about 1,300 m. These crusts have a formation rate of only a few mm/Myr and, therefore, concentrate the isotopes of interest. A ^{60}Fe and ^{53}Mn (half-life 3.7 Myr) depth profile of three layers was measured, corresponding to an age span of 0–2.8 Myr, 3.7–5.9 Myr, and 5.9–13.4 Myr. Although spallation reactions of cosmic rays with iron in extraterrestrial dust can produce a strong background for ^{53}Mn, one expects a significantly enhanced flux rate of ^{53}Mn in the case of a nearby supernova explosion as well.

Figure 2.3 shows the first results of our AMS measurements. Before the measurements all iron (manganese) was chemically extracted from the ferro-manganese crust. From this iron (manganese) negative FeO^- (MnO^-) were produced in a sputter ion source and accelerated by the Munich electrostatic Tandem accelerator as Fe^{11+} (Mn^{11+}) ions up to an energy of 155 MeV. At the end of the beam transport system, tuned to mass number 60 (53) and charge state 11^+, the interfering stable isobar ^{60}Ni (^{53}Cr) was separated by means of a 135^o magnet, filled with 6 mbar of nitrogen gas. Due to the interaction with the gas the ions get an average charge depending on their nuclear charge. Therefore isobaric ions exit the magnet at different positions. They then enter an ionization chamber where the ^{60}Fe (^{53}Mn) ions can be identified by their position, residual energy, differential energy loss, and angle.

Possible background rates due to different ion species have been determined with older crust samples and artificial ones treated in the same way as those from the sediments, but even the lowest ^{60}Fe flux value found in the ferro-manganese crust is more than one order of magnitude above the expected background. Although statistical errors are still very large, the mean ^{60}Fe flux of the sample of intermediate age is significantly higher than the younger one. Additionally, the measured ^{60}Fe/^{53}Mn ratios are too high to be explained by solar system sources.

The only reasonable explanation of our findings is that the deep ocean sediments analyzed by us contain live ^{60}Fe from one or more recent supernova explosions near to the solar system, and several arguments strongly support this conclusion.

Supernova explosions of massive stars, $M \geq 15\,M_\odot$, eject typically about $0.1M_\odot$ ($M_\odot$ denotes the mass of the Sun) of iron, with about 10^{-3} of it in form of ^{60}Fe. They are the only producers of significant amounts of ^{60}Fe we know of. Supernova explosions of massive stars eject radioactive ^{53}Mn together with ^{60}Fe. Although there is a considerable spallation background of ^{53}Mn one would still expect a correlation between the abundances of these two isotopes if our interpretation is correct and, indeed, we find such a correlation.

In fact, we know that mixing in of radioactive isotopes did occur in the past at the time when the solar system formed. Evidence for *extinct* ^{60}Fe (i.e., excess ^{60}Ni interpreted as being due to the decay of ^{60}Fe) as well as for other extinct radioactive isotopes such as ^{26}Al have been found in meteorites, indicating that fresh products of stellar nucleosynthesis were added to the proto-solar nebula. How this happened is not yet clear, but it is obvious that mixing is easier if these isotopes are carried into the early solar system in form of dust grains. This interpretation is not unreasonable because there is strong evidence from Supernova 1987A that dust formed very soon after the star exploded. About 500 days after the explosion newly condensed dust grains were observed which, very likely, are *iron-rich*. (Other core-collapse supernovae, e.g. SN1993J and SN1994I, did not show evidence for dust formation even two years after the explosion, but the data for these is not as good as for SN1987A.)

The explosion of a massive star less than 30 pc from the solar system would leave a signal on Earth of the kind we have found, provided it happened around 6 to 8 Myr ago. The ejecta from a supernova at this distance (or closer) can penetrate as far as the Earth, because the pressure of the blast wave is comparable to that of the solar wind. Dust grains, in particular, could be accreted easily by the Earth. The amount of ^{60}Fe found in our probe is in fair agreement with earlier predictions. Additional evidence may come from the hot X-ray emitting gas which surrounds the solar system, the so-called local hot bubble, extending to a radius of about 100 pc. This hot gas may have been produced (and may have been re-heated) by one or several supernovae exploding during the past 20 Myr. The presence of ^{60}Fe on earth strongly supports this idea.

Finally, one would like to know whether there are independent clues. Galactic cosmic rays could contain ^{60}Fe but until now there is no evidence for its presence. However, ^{53}Mn has clearly been identified. This is not in contradiction with our results because only about 6000 Fe events have been identified by *Ulysses/HET* which leads to an expectation of at most a few ^{60}Fe events by *HET*. Also, if the galactic distribution of ^{60}Fe follows ^{26}Al, as one expects, the γ-ray line flux from its decay would be just below the detection limit of the COMPTEL detector. INTEGRAL, on the other hand side, may have a fair chance to detect an ^{60}Fe signal.

In summary, based on these arguments we conclude that the high sedimentation rate of ^{60}Fe together with a high count rate of ^{53}Mn found in the older layers of our probe is clear evidence for at least one supernova that exploded at a distance of at most 30 pc from the solar system about 6 to 8 Myr ago. The approximately 10 times lower sedimentation rate of the younger layer may indicate that there is a background of radioactive Fe in the solar neighbourhood which could come either from supernova dust in the local hot bubble or from local galactic cosmic rays. In the latter case one might hope that with better statistics such a component could be detected directly since it would contribute to the iron abundance in cosmic-rays at the level of 10^{-3}. (Klaus Knie (TUM), Wolfgang Hillebrandt)

2.3 Cygnus X-2 and the formation of millisecond pulsar binaries

Pulsars are rapidly rotating, strongly magnetized neutron stars which emit electromagnetic radiation over a very broad wavelength range. Because the emission is strongly anisotropic the radiation seen by an observer (predominantly as radio emission) is pulsed at the rotation period of the neutron star like the light seen from a light house, hence the name 'pulsar'. Millisecond pulsars form a subgroup of pulsars which is characterized by extremely short rotation periods in the range of a few to a few tens of milliseconds and a comparatively weak magnetic field. The fact that most millisecond pulsars are members of binary systems supports theoretical ideas according to which millisecond pulsars are neutron stars that have been spun up by accretion during an earlier phase of mass transfer from the companion star.

Cygnus X–2, on the other hand, belongs to the class of low–mass X–ray binaries. These are binary systems in which a very compact star (either a neutron star or a black hole) accretes from a companion star of comparatively low mass, typically less than about 1.5 solar masses (in the following $M_\odot$). The X–ray emission, in turn, is a direct consequence of the accretion process.

What is so special about Cygnus X–2 and what is its relation to the millisecond pulsars? It is the observation that the donor star is much too hot to be consistent with the hitherto accepted model for Cygnus X–2 and that our attempts to resolve that contradiction have led to the discovery of an entirely new channel through which a particular subclass of millisecond pulsar binaries must have formed.

It has long been known that Cygnus X–2 has an orbital period of 9.84 days and that its donor star is of spectral type F9, i.e. that its surface temperature is about 7300K. Furthermore, it is known that the compact star is a neutron star. This is because Cygnus X–2 shows occasionally X–ray bursts which are associated with a thermonuclear explosion of accreted helium on the surface of a neutron star.

Given the comparatively long orbital period of Cygnus X–2 one would have expected the donor star to be a cool giant, i.e. a low–mass star of low surface temperature, typically 3000K to 4000K. But as we have seen, observations tell us otherwise. In order to save the canonical model for Cygnus X–2 it has thus been argued that what we see as the donor star is in fact only part of it, namely the X–ray heated hemisphere facing the neutron star. In this picture the cool back side of the donor is so faint that it leaves no trace in the optical spectrum. Postulating a donor star with an uneven brightness distribution leads, however, immediately to the prediction that the observable brightness of the binary should be strongly modulated at the orbital period, unless our line of sight is almost perpendicular to the orbital plane. Since no such variations have been observed, it was concluded that the orbital inclination, that is the angle between the orbital plane and the plane of the sky, of Cygnus X–2 is small.

Yet recent detailed spectroscopic observations of Cygnus X–2 have overthrown this picture. Not only did these observations confirm the spectral type F9, they also showed that the donor star is evenly hot, thus ruling out the X–ray illumination picture. Furthermore the masses of the components and with them constraints on the orbital inclination could be derived. Accordingly the mass of the neutron star is about $1.4M_\odot$ to $1.8M_\odot$, that of the donor star between about $0.5M_\odot$ and $0.7M_\odot$, and the orbital inclination larger than about 40°.

These masses combined with the orbital period immediately tell us that the radius of the donor star has to be about 7.5 solar radii and its luminosity about 150 solar luminosities. And here is the problem for the theorist: what kind of star has these properties and, in addition, is in a phase of expansion? Why expansion? Because the donor star is transferring mass to the neutron star. However, that can only happen if either the donor star swells, or if the binary is losing orbital angular momentum. Although the latter is not impossible, we do not have a plausible mechanism which would work in a binary like Cygnus X–2. Therefore, we presume that the donor star is swelling, and, in order to account for the observed mass transfer rate, that it grows on a timescale of about 10^8yr.

Among the many theoretical possibilities which might account for the donor's properties, in the end only one remained which was not immediately in conflict with the basic observed properties: The donor star is now near the end of a phase of mass transfer which began when that star, which originally had a mass of about $3.5M_\odot$, had evolved beyond central hydrogen burning but had not yet reached ignition of central helium burning. Although one can readily account for all of the donor's properties in this picture, the explanation comes at a price: Consider the present total mass of Cygnus X–2 which is close to $2M_\odot$ and compare it with the total mass before the onset of the present phase of mass transfer. Clearly that mass must have been larger than the original mass of the donor, i.e. about $3.5M_\odot$. So where has the remaining mass gone? Because the neutron star now has a mass of about $1.4M_\odot$, a value which is typical for neutron stars, it cannot have accreted much during the preceeding phase of mass transfer. Rather, almost all of the mass transferred from the donor (about $3M_\odot$) must have been ejected.

What about the future evolution of Cygnus X–2? As we have seen, the donor star is currently near the end of a phase of mass transfer. After about 10^6yr, mass transfer will stop and the donor star will have become a helium star. This subsequently will evolve into a carbon oxygen white dwarf with a mass of about $0.6M_\odot$. What about the neutron star? From the fact that it undergoes X–ray bursts one knows that its magnetic field is rather low, typically less than about 10^8 Gauss. Under these conditions the accretion of a few $10^{-2}M_\odot$ during the mass transfer phase will spin up the neutron star to a rotation period of about 10 milliseconds. Once mass transfer stops the neutron star will very probably become a millisecond pulsar in a binary with an orbital period of about 10 days and a carbon oxygen white dwarf companion of about $0.6M_\odot$.

According to the standard model of the formation of millisecond pulsar binaries, systems with an orbital period longer than about 1 day are the descendants of binaries in which a cool giant transfers mass to a neutron star. For such systems theory predicts a tight relation between the mass of the remnant helium white dwarf and the orbital period. Whereas a large fraction of the observed long–period millisecond pulsar binaries conforms to this theoretical prediction there are a few noteable outliers for which there has hitherto been no theoretical explanation. Because the properties of these systems are so similar to those predicted for Cygnus X–2 at the end of mass transfer, we think that they must have been formed in a similar way. Thus, we have found a new channel for the formation of some millisecond pulsar binaries. And all that only because the spectral type of the donor star of Cygnus X–2 did not fit ... (Hans Ritter).

2.4 Gamma-ray bursts from X-ray binaries: cosmic flywheels

Gamma-ray bursts (GRB) are short lived sources of energetic radiation (photons of energy around 1 MeV), observed at random positions in the sky at a rate of about 2 per day. Several of them have recently been identified with distant galaxies, roughly halfway between us and the end of the observable universe. This large distance requires them to be extremely energetic phenomena, corresponding to the conversion into energy of the mass of a giant planet in a few seconds. The extreme properties of these sources make them one of the most hotly debated mysteries in astrophysics. Though many suggestions have been made for the 'central engine' of these bursters, most stumble over the combination of a short time scale and the large amount of energy required. It is generally accepted, however, that whatever the physical nature of the central engine, it must deposit an amount of energy of the order 10^{52} erg into an amount of matter that does not exceed about 10^{-5} solar masses, within a few seconds. If the energy is put into this small amount of mass, the result is a relativistically expanding ($\gamma > 100$) 'fireball', initially consisting mostly of a dense electron-positron pair plasma. The relativistic expansion guarantees that the observed duration of the burst remains short, even though the fireball must expand to a very large size (many astronomical units) before it becomes transparent enough to allow photons to escape.

The 'baryon constraint' that not more than 10^{-5} $M_\odot$ can be involved is a significant hurdle for most models of the central engine. A new model developed at MPA overcomes this hurdle in an elegant way by using low-mass X-ray binaries as the progenitors of GRB. The primaries in these systems are neutron stars rotating with periods of a few milliseconds; the secondaries are

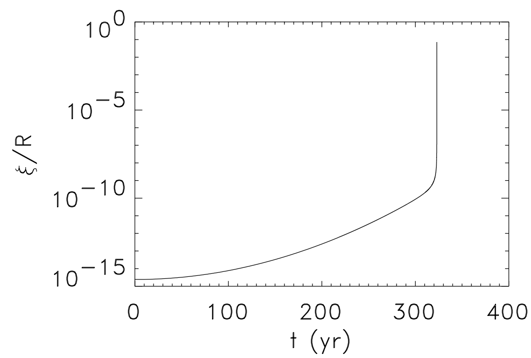


Figure 2.4: Growth in amplitude of an r-mode oscillation in a neutron star rotating with a period of 2 msec. Heating by viscous dissipation reduces the viscosity, leading to a runaway in a finite time.

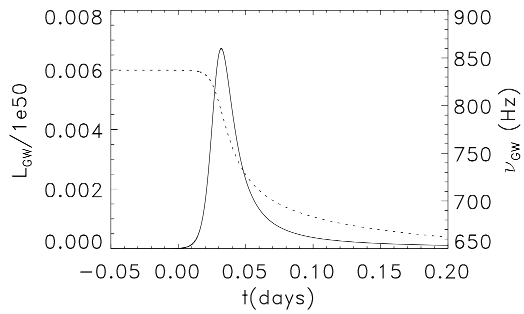


Figure 2.5: Solid: gravity wave luminosity emitted at the peak of the runaway instability. The decline at the end is due to the spindown of the wave-emitting parts of the star by the angular momentum carried by the wave. Dotted: frequency of the emitted wave.

normal low-mass stars. There are a few hundred such binaries in our galaxy. By mass transfer from the secondary, the neutron stars spin up like flywheels. At these short periods, they contain the right amount of energy in rotation to power a GRB.

In order to make a gamma-ray burst out of such an accreting neutron star, one has to find a sufficiently powerful 'brake' to extract the rotational energy of the star within a few seconds. This is not a priori a very likely process, since the forces acting on the star in the binary system are feeble, changing the rotation rate of the neutron star only on a time scale of a hundred million years.

It is known, however, that a magnetic field at the surface of a neutron star can spin it down and radiate its rotation energy in the form of an electromagnetic wave. This process can be observed in detail in the pulsar in the Crab nebula. But to brake the star within a few seconds, a magnetic field strength of 10^{16} G is needed. A neutron star rotating at millisecond periods with such a field strength would indeed produce the required GRB fireball, since the primary energy release in this case is electromagnetic, involving only a very small amount of mass. The required field strengths, however, are several orders of magnitude larger than those known for neutron stars, and it is not obvious why a neutron star would suddenly get magnetized to such a fantastic field strength.

A relativistic object like a neutron star can start to oscillate spontaneously if it rotates fast enough, and in the process radiate gravitational waves. This oscillation is excited in much the same way as the squeaking of a car brake. The brake in this analogy represents the neutron star and the brake lining the gravitational wave. Any nonaxisymmetric mode of oscillation of the star which travels *backward* as seen in the frame rotating with the star, but *forward* in an inertial frame, is excited in principle by interaction with the gravitational wave which it generates.

The existence of this gravitational wave instability makes a sudden magnetization in a rapidly rotating neutron star possible. The process has two steps. The first involves that fact that the viscosity of neutron star matter decreases with increasing temperature (just as for water or engine oil). It turns out that this negative temperature dependence makes the gravitational wave instability a runaway process. After a slow initial phase lasting a few hundred years, the amplitude of the oscillation grows explosively in hours or minutes (Fig. 2.4). As the star oscillates at large amplitude (limited by the saturation or 'wave breaking' of the oscillation) it loses angular momentum rapidly by emitting gravitational waves. The rotation of different parts of the star is braked to a different extent by this gravitational radiation. This leads to the second step in the process: the development of a strong difference in rotation between the interior and outer parts. Such differential rotation rapidly strengthens the weak initial magnetic field of the star by the simple process of 'winding up' of the field lines. This happens on a time scale of days or weeks, depending on the initial field strength. When the field has become strong enough to float from the interior to the surface, the energy of differential rotation turns quickly (on a time scale of milliseconds) into magnetic energy. The star now has a surface field strength of about 10^{17} G. This field strength is sufficient to spin down the star by the electromagnetic pulsar emission mechanism mentioned above. In the process, the entire remaining rotation energy of the star is radiated electromagnetically in a few seconds.

The properties of this model are so far in good agreement with the characteristics of GRB. Its main strengths are the low intrinsic baryon loading and the short time scale (milliseconds) on which the source is likely to vary. It predicts that a strong gravitational wave signal is emitted some days or weeks *before* the gamma ray burst itself (Fig. 2.5). With the physics described, a GRB would be a natural end product of the evolution of low-mass X-ray binaries. The model is not the only one, however, that follows in a natural way from the evolution of a binary. The spiral-in and disruption of neutron stars in neutron star-neutron star or neutron star-black hole binaries is another favorite scenario for GRB's and is also under vigorous study at MPA. (Henk Spruit).

2.5 Gamma-ray burst afterglows

The first evidence of the existence of prolonged X–ray and γ–ray emission lasting for tens to hundreds of seconds after a gamma-ray burst (GRB) was found in the late 80s and early 90s. However the "afterglow era" in GRB studies began in 1997 when fast and accurate localizations of GRBs by the BeppoSAX observatory helped to establish the connection of GRBs with sources of decaying X-ray, optical, and radio emission. Identification of GRB counterparts at other wavelengths and, finally, the discovery of host galaxies was a breakthrough in determining the distance to GRB sources and marked the first step in unraveling their mystery. Optical observations of the GRB host galaxies led to the determination of their redshifts and proved that GRB sources are located at cosmological distances. The most distant presently known GRB source is at a redshift of z=3.4, that is at a distance of about 12 billion light years. The cosmological distances to the GRB sources imply that they are associated with phenomena as energetic as $\sim 10^{53}$ erg in electromagnetic radiation, if isotropic emission is assumed. Such energies exceed by orders of magnitude those emitted in photons during supernova explosions and

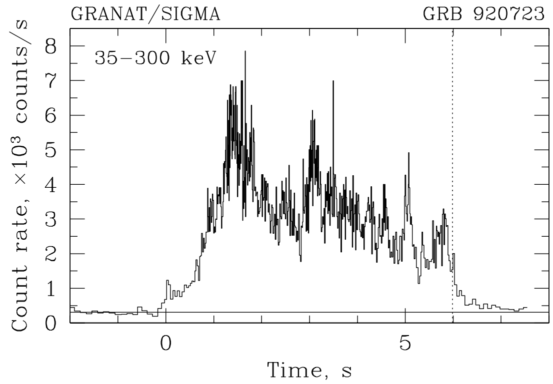


Figure 2.6: GRB 920723 light curve in the 35–300 keV energy band. The reference time is at the burst trigger. The vertical dashed line at t=6 sec indicates the moment of an abrupt change of the spectral index (Fig. 2.8).

mean that GRBs are the most luminous among the presently known objects in the Universe.

Independent of the nature of the progenitor, a quick release of $10^{51} - 10^{53}$ erg in a compact volume could be enough to power a relativistic fireball – a plasma cloud expanding into the surrounding interstellar medium with an ultrarelativistic velocity. Collisions between fireball shells caused by intrinsic variability of the energy source will produce internal shocks at which electrons can be accelerated to ultrarelativistic energies. In the standard fireball scenario inverse Compton and synchrotron radiation from these non-thermal electrons is responsible for the GRB emission which often has a complex, "spiky" light curve (Fig. 2.6). On the other hand, external shocks caused by the interaction of the fireball with the interstellar medium will result in smoother and much longer lasting afterglow emission (Fig. 2.7). Multiwavelength observations of GRB afterglows on time scales ranging from tens of hours to months after a GRB proved general consistency of the generic fireball model and its ability to explain most of the observed features.

Fireball observations immediately after a burst, when the Lorentz factor of the relativistic expansion is at the maximum, are of great interest for the fireball theory. Archival search of the data of the GRANAT X–ray/γ–ray observatory performed in collaboration with MPA researchers resulted in the discovery of such early afterglows for several bright GRBs. The most interesting results were obtained for the gamma–ray burst detected on July 23, 1992 (GRB920723, Fig. 2.6) which was the bright-

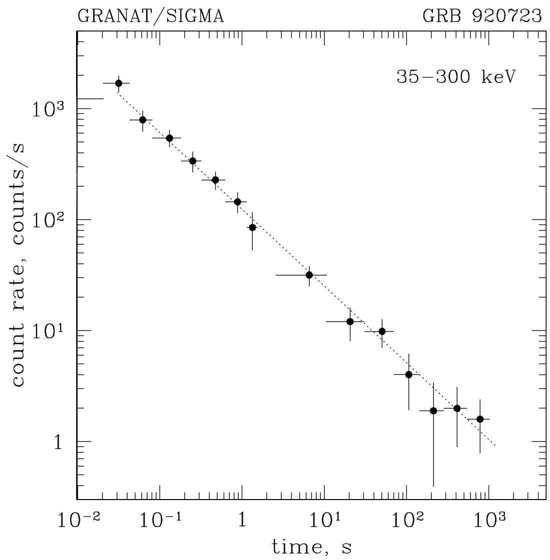


Figure 2.7: The background-subtracted afterglow light curve in the 35–300 keV energy range. Zero time is at the moment of an abrupt change of the spectral index (shown by dashed vertical lines in Figs. 2.6 and 2.8). The main burst is not shown here because it is at $t < 0$ for the choice of time zero.

est event observed by the instruments of the GRANAT observatory. Joint analysis of the data from the WATCH, SIGMA and PHEBUS instruments revealed an abrupt change of the spectral index that occurred near the end of the main burst (Fig. 2.8). This change might indicate the onset of the afterglow emission which in the framework of the fireball theory corresponds to the moment when the synchrotron emission from the external shock exceeds the emission generated by the internal shocks. Remarkably, the afterglow light curve follows a nearly perfect power law with an index of 0.7 over five

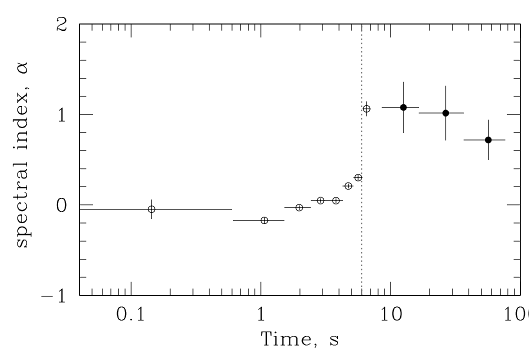


Figure 2.8: Time history of the spectral index in the 8–200 keV energy band. Zero time is the same as in Fig. 2.6.

decades in time (Fig. 2.7). If the observed afterglow emission was indeed due to the interaction of the fireball with the interstellar medium, the early maximum of the afterglow emission implies that the initial relativistic Lorentz factor of the fireball in GRB920723 exceeded $\sim 200-300$. (Marat Gilfanov and Rodion Burenin)

2.6 Hyperaccreting black holes

Our best evidence for the existence of black holes comes from observing the light produced as the black hole swallows gas. This process, known as accretion, releases a huge amount of energy, much of it in the form of X-rays. The gas generally comes from a normal star which is a binary companion to the black hole. When the two are close enough, gas from the outer layers of the star is pulled toward the black hole, and forms a disk around the hole. We observe the bright radiation produced by this disk as the gas spirals slowly into the black hole. These systems are known as black hole X-ray binaries.

This process occurs rather slowly. The gas falls into the hole slowly enough that it would take at least 100 million years for an entire star the size of the Sun to be accreted. Nonetheless, these systems are very bright, because the accretion process releases so much energy, at least 9 times as much as nuclear fusion from hydrogen to helium. As a result, accreting black hole systems such as A0620-00, V404 Cygni, and others can radiate 10,000 or more times as much energy as our Sun.

Recent research suggests that there may be rare catastrophic events during which black holes accrete gas much faster than in the usual situation described above. During such events, a mass on the order of that of our Sun (a solar mass) may be accreted in seconds or minutes, rather than 100 million years.

This may occur if the binary companion of the black hole is not a normal star but instead a compact stellar remnant, such as a white dwarf or neutron star. Because of their small size, these remnants can spiral much closer to the black hole than a normal star. But when they get too close, rather than gradually stealing away gas, the gravity of the black hole can disrupt them completely. The mass of the remnant can then be accreted very quickly.

Another possibility is that the collapse of some massive stars fails to produce a normal supernova, but instead forms a black hole which rapidly accretes much of the gas from the collapsing star. This situation is seen frequently in sophisticated computer models of stellar collapse, but since these models were constructed with the purpose of simulating supernova explosions, those which did not produce supernovae were seen as failures. But it may be that the rapidly accreting black holes produced in the models occur in nature.

What would such a hyperaccreting black hole look like? If the energy released over the 100 million year lifetime of a normal accreting black hole were instead released in a few seconds, the resulting flash of light would be comparable in brightness to a supernova, bright enough to be seen across a large fraction of the universe.

Recent work at MPA has addressed this question. In general, as in the case of normal accretion from a binary companion, the disruption and collapse scenarios result in a disk of matter around the black hole. But the amount of matter involved is so large that this disk is effectively opaque to normal radiation. Thus, as the matter spirals toward the black hole at the center of the disk, it cannot cool, and the energy relased by accretion heats it up to very high temperatures. As it approaches the black hole, the density of the matter also becomes extremely high.

Under these conditions, it becomes possible for the matter to cool by emitting neutrinos. Unlike the photons that make up normal radiation, neutrinos can pass through huge amounts of matter without being absorbed. The emission of neutrinos is very sensitive to the temperature and density of the gas. Our model allows us to see whether the disk around a hyperaccreting black hole is hot and dense enough that neutrinos can carry away the accretion energy. If so, the hyperaccreting black hole may be very bright; if not, it will be dim and the matter will carry the energy into the black hole.

The conditions which are most important in determining whether neutrinos can carry away the accretion energy turn out to be the rate at which mass is falling into the black hole and the rate at which the black hole is spinning. The disruptions or collapse scenarios produce mass accretion rates in the range from 1/100th up to 10 solar masses per second. As shown in Fig. 2.9, we find that accretion rates of about 1/10th of a solar mass per second are necessary to achieve significant neutrino cooling. The neutrino cooling can be greatly enhanced if the black hole is spinning rapidly.

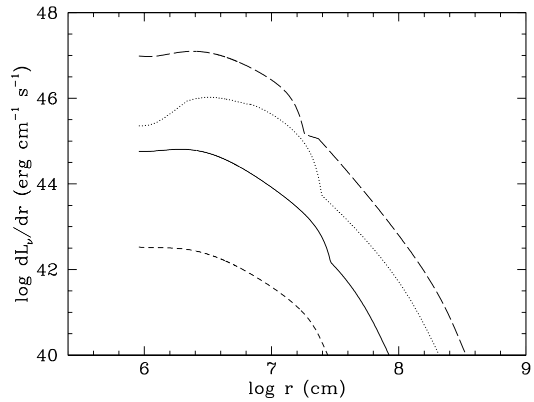


Figure 2.9: The energy emitted in neutrinos per second and per cm of disk radius, as a function of the disk radius. Most of the neutrino emission comes from quite close to the black hole. The four curves are for accretion rates of 0.01, 0.1, 1, and 10 solar masses per second, from top to bottom. Note that neutrino emission is much lower for the 0.01 solar masses per second case.

These results may be applicable to one of the major mysteries in astronomy today, gamma-ray bursts. For many years these bright flashes of gamma-radiation were believed to come from within our Galaxy, but it has recently become clear that the vast majority of them come from other very distant galaxies. In several cases the redshifts of these host galaxies have been determined to be quite large, proving that the gamma-ray bursts must involve very large amounts of energy. Many models have been suggested to explain the origin of these bursts. Our model has shown that the disruption and collapse scenarios can lead to huge amounts of energy being emitted in the form of neutrinos. These neutrinos would interact with each other and produce gamma-rays, which could produce the gamma-ray bursts we see. Our model makes it possible to estimate the amounts of gamma-ray emission that different types of events would produce, and to compare those to the bursts we observe. The host galaxies identified for the bursts appear to have large numbers of forming stars. This favors the collapse scenario discussed earlier, since these events should occur in massive stars which have formed only recently. (Robert Popham)

2.7 Disk accretion onto rapidly rotating neutron stars

The brightest X-ray sources in our Galaxy radiate as a result of the accretion of matter from normal stars onto black holes or neutron stars. In such binary systems the normal star swells until matter is lost either through its stellar wind or through direct flow across the inner Lagrangian point. Part of this outflow is captured by the gravitational field of the companion black hole or neutron star and settles into an accretion disk, slowly spiralling onto the relativistic object.

When observing X-ray sources it is very difficult to tell if we are dealing with a neutron star or a black hole. In the case of accretion onto a black hole, the disk can exist only at radii which exceed the radius of the marginally stable orbit. At smaller radii matter falls in with practically no friction or energy release. The radius of the marginally stable orbit depends on the angular momentum of the black hole and decreases from 3 gravitational radii for the Schwarzschild metrics to one half of the gravitational radius in the case of an extreme Kerr black hole. Correspondingly, the energy release due to accretion increases from 5.7% up to 42% of $\dot{M}c^2$. If a neutron star has a low ($H < 3\times10^8 gauss$) magnetic field, this accretion disk extends practically to the stellar surface, which lies at only 2-4 times the gravitational radius of the star.

It is very interesting that rapidly rotating neutron stars might be as effective an energy source as black holes. In the Newtonian problem half of the energy of accretion is released in the extended Keplerian accretion disk and the second half must be liberated in a geometrically thin boundary layer close to the surface of the neutron star. In this boundary layer, the velocity of the accreting matter drops from its Keplerian value in the accretion disk to the velocity of rotation at the surface of the star; this is usually much smaller than the Keplerian velocity at the same distance from the center of the star. The problem becomes much more interesting if neutron star rotation and all the effects of general relativity are taken into account. From Fig. 2.10 we see that the energy release in the accretion disk is three times smaller than the energy release in the vicinity of the stellar surface for the case of nonrotating neutron star with a radius equal to 2.3 R_g. The most interesting situation arises in the case of counterrotation when matter in the disk and star are rotating in opposite directions. In this case up to 60% of $\dot{M}c^2$ can be radiated, much more than the $\sim$ 22%$\dot{M}c^2$ permitted for a nonrotating neutron star, and much more than in the case of accretion onto a black hole (see Fig. 2.10). Obviously, most of the energy released in this case is taken from the rotational energy of the neutron star which slows down rapidly as a result of the accretion.

This problem was investigated by Sibgatullin and Sunyaev by approximating the metric of the external field of a rapidly rotating neutron star by an exact solution of the Einstein equations in a vacuum, which is entirely specified by the stellar mass M, its angular momentum J, and the quadrupole moment of the mass distribution b. For $b = 0$, this solution transforms to the Kerr solution.

Let us consider the details of the physics of the boundary layer between an accretion disk and the surface of a neutron star (Fig. 2.11). For a hard equation of state, the radius of a neutron star usually exceeds that of the marginally stable orbit. It was usually assumed that matter in the boundary layer forms an atmosphere around a neutron star where the dimension along the meridian is smaller than the radial thickness of the boundary layer (Fig. 2.12). The problem resembles the situation of a spacecraft spiraling into the dense layers of the Earth's atmosphere due to friction with surrounding gas. The rapidly and differentially rotating layers of the atmosphere between disk and star surface rapidly decelerate due to the presence of turbulent viscosity and release their kinetic energy. This energy release heats the boundary layer. It was usually assumed that the surface area of the boundary layer is much smaller than the surface area of the accretion disk, therefore the energy flux from the unit of surface of the boundary layer must be much higher and the radiation spectrum much harder than that of the accretion disk.

Inogamov and Sunyaev came with a new approach to the problem of the boundary layer. They considered the deceleration of matter in the boundary layer due to friction between the dense, slowly rotating underlying layer on the surface of the star and the highly supersonic (half the velocity of light) matter coming from accretion disk. The problem is similar to the deceleration of the supersonic flow in the vicin-

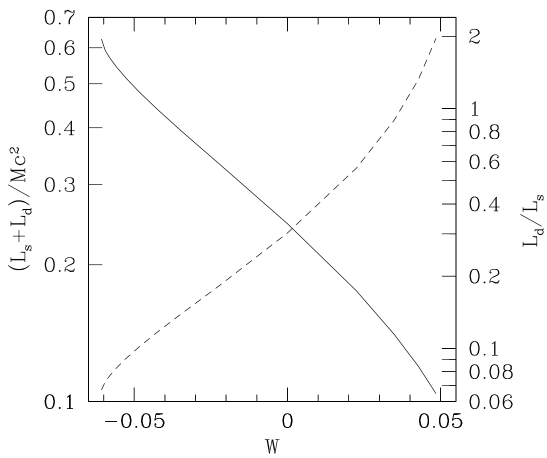


Figure 2.10: The luminosity of the disk and boundary layer as a function of the nondimensional angular velocity of the neutron star $W = GM\Omega/c^3$. Positive and negative W correspond to the cases of corotation and counterrotation of the star and disk. The solid line gives the dependence of the disk and surface luminosities on W (left vertical axis). The dashed line gives the ratio of the disk and surface luminosities (right vertical axis).

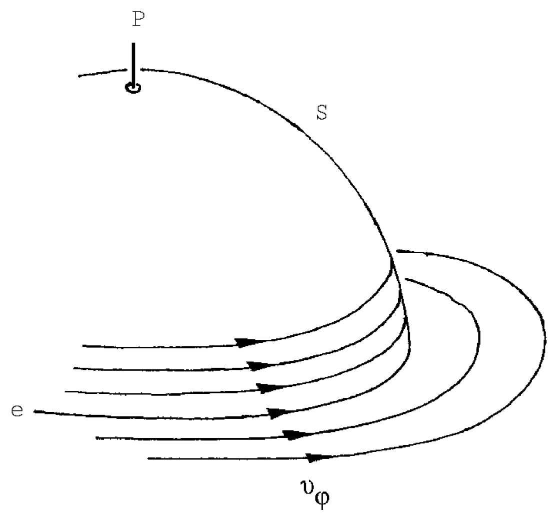


Figure 2.11: A sketch of the disk accretion onto a neutron star with a weak magnetic field. Far from the star, accreting matter is rotating in the equatorial plane. Near the surface of the star the flow begins to spread over the surface. The friction between the dense underlying layer and the rapidly rotating accreting matter decelerates the motion of the latter.

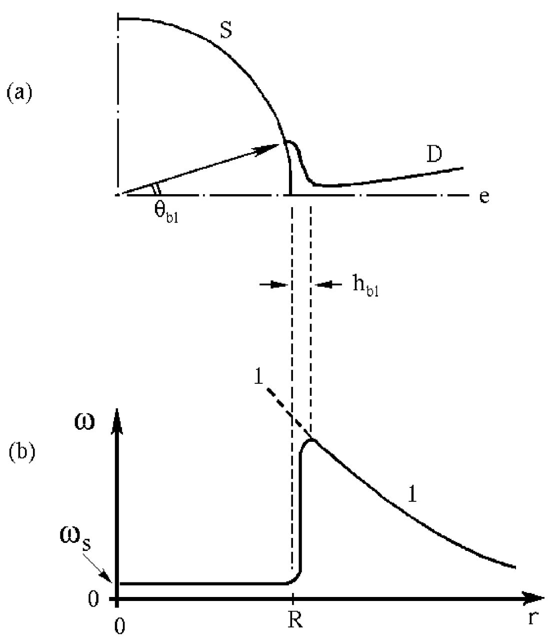


Figure 2.12: (**a**) Shape of the boundary layer in the standard approach. The notation is a follows: e is the equatorial plane, D is the accretion disk, S is the stellar surface, h_{bl} gives the thickness of the boundary layer; (**b**) Angular velocity $\omega = v_\phi/r$ versus radius, where v_ϕ is the rotation velocity; 1 – the Keplerian dependence: $\omega \sim r^{-3/2}$; the angular velocity ω_n in the neck is at a maxium and approximately equal to the Keplerian velocity, angle Θ_{bl} corresponds to the height of the boundary layer along the meridian; inside the star from the center up to its surface $r \leq R$, the rotation is rigid: $\omega \equiv \omega_S$.

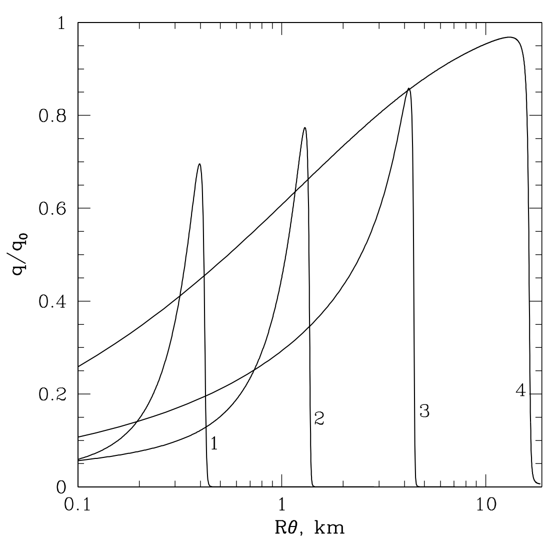


Figure 2.13: The distribution of the radiation flux as a function of the distance $R\Theta$ along the meridian from the equatorial plane. Numbers 1, 2, 3, 4 correspond to different luminosities of the accreting neutron star, 0.01; 0.04; 0.2 and 0.8 of the Eddington Luminosity for the whole neutron star surface, respectively. q_0 corresponds to local critical Eddington flux at which the radiation pressure force on the electron is equal to the gravitational attraction of the proton to the neutron star. It is easy to see how narrow the bright rings on the neutron star surface are.

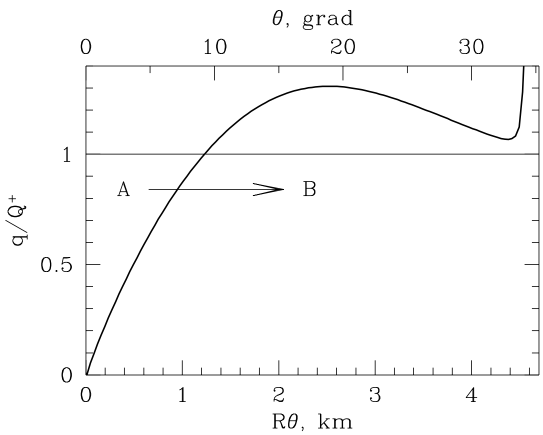


Figure 2.14: The ratio of the radiation flux from the surface unit q to the viscous energy release in the column under this surface unit Q^+, given as the function of the distance from the equatorial plane along the meridian. At small distances the flux is much smaller than the energy release in the column below. At larger distances the flux exceeds the viscous energy release. The thermal energy is transferred by advection, i.e. by the hydrodynamic transfer of radiation energy.

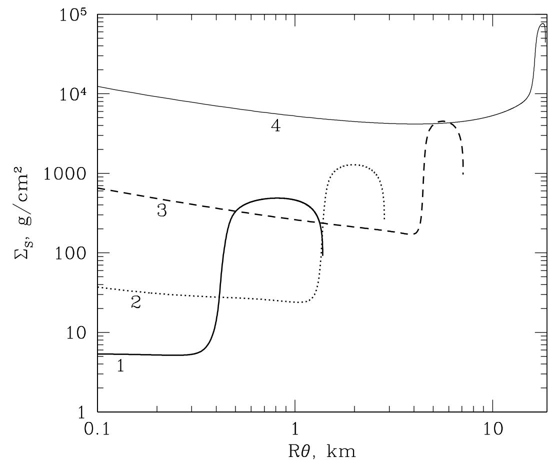


Figure 2.15: The surface density of the matter in the spreading layer as a function of the distance from the equatorial plane along the meridian for four luminosities of the neutron star: 1 – 0.01; 2 – 0.04; 3 – 0.2; 4 – 0.8 of the Eddington Luminosity.

ity of a solid wall, or (in the subsonic case) to the friction of the Gulf Stream on the underlying water in the ocean. The supersonic flow is floating because centrifugal force and radiation pressure force counteract gravity. Under such circumstances, rapidly rotating matter slowly spreads out of the equatorial and disk plane in the direction of the poles of the neutron star. Weak friction slowly decelerates the motion and gravity begins to exceed the centrifugal and radiation pressure forces. As a result, two bright rings appear on the surface of the neutron star parallel to its equatorial plane (Fig. 2.13). In these rings the deceleration is strong. In addition advection brings thermal energy from the regions closer to the equator (Fig. 2.14). These two rings have the hardest X-ray spectrum. At higher latitudes the flow is very slow (subsonic) the matter is rather cold and the energy release is very low.

This theory has several consequences. In the case of small accretion rate, and correspondingly low luminosity, the optical depth of the spreading layer to Thomson scattering is rather small. The surface density Σ of the layer is closer to 7.5 g/cm^2 (Fig. 2.15). This corresponds to a Thomson optical depth of 3. Under these circumstances only the process of comptonisation is able to help the plasma radiate the energy released. A spreading layer has a rather high temperature, on the order of tens of KeVs, and the radiated spectrum has a distinct power law form. For high accretion rate, and so high luminosity, the bright rings move to higher latitudes and the surface density of the matter in them increases up to several kg/cm^2. Under these circumstances matter is able to thermalize the radiation and the spectrum becomes softer than in the previous case. It seems that current observations of low mass X-ray binaries agree well with this theoretical prediction.

Neutron stars with a soft equation of state have radii which are smaller than the radii of the marginally stable orbits around them. In this case accretion disks extend only to the marginally stable orbit and matter then falls onto the neutron star surface in just a few orbits. The width of the gap between the neutron star and the accretion disk depends on the angular velocity of rotation of the neutron star. Centrifugal forces in this case are unable to support floating matter in the spreading layer. As a result the kinetic energy corresponding to the radial component of velocity of infalling matter is transferred into the thermal energy already in the equatorial belt. Rotational velocity slowly decreases due to friction on the underlying layer and in the process of spreading along the merid-

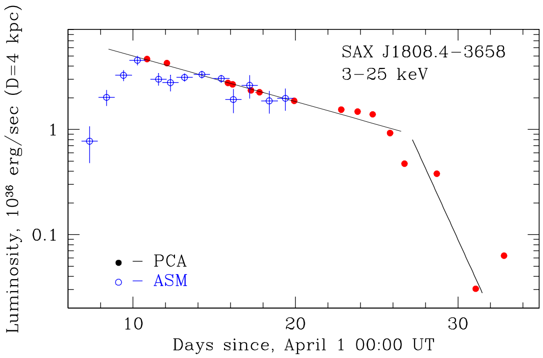


Figure 2.16: The 3–25 keV light curve of SAX J1808.4–3658 obtained by Rossi X–ray Timing Explorer. The solid lines are $L_X \propto e^{-t/10^d}$ and $L_X \propto e^{-t/1.3^d}$.

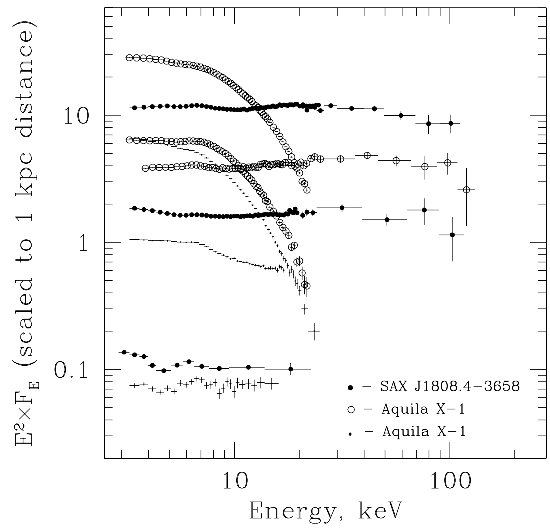


Figure 2.17: The spectra of SAX J1808.4–3658 obtained on April 11–13, 26–29 and May 2-3, 1998 in comparison with the spectra of other X–ray bursters of different luminosity: 4U1608–522 (Spring 1996 outburst) and Aquila X–1 (Spring 1997). All spectra were obtained using RXTE public data.

ian. The spreading layer in this case is much denser and colder.

In the case of accretion onto a neutron star with a weak but non-negligible magnetic field, a rapidly rotating neutron star would manifest itself not only as an X–ray pulsar but also as an X–ray burster. The X–ray bursts would be due to nuclear flashes in the freshly accreted matter on the surface of the neutron star. The very first such object, the transient binary X–ray pulsar/burster SAX J1808.4-3658, was discovered recently by the SAX and RXTE orbital X–ray observatories; it has a pulsation period of 2.5 millisecond.

M. Gilfanov et al. analyzed data from the Rossi X–ray Timing Explorer (RXTE) observations of the recent outburst of SAX J1808.4-3658 and studied the spectral evolution of the source while its luminosity, and so its mass accretion rate, decreased by a factor of ~ 300 (Fig. 2.16). They found that despite this dramatic change in luminosity, the spectrum was remarkably stable (Fig. 2.17). From a theoretical point of view it was particularly surprising that the spectrum did not cut off below 100 keV and had a roughly power law shape with a photon index of ~ 2. For the majority of other X-ray bursters exponential cut-offs in their spectra set in at energies below 10 keV.

Over the past several years millisecond phenomena in low mass X–ray binaries (LMXB) – kilohertz quasi periodic oscillations – have provided strong evidence that the neutron stars in many LMXBs may be spinning with millisecond periods. However, the lack of coherent pulsations has for many years disturbed the theorists. The discovery of the first millisecond accreting X–ray pulsar may provide a missing link between millisecond radio pulsars and low mass X–ray binaries, confirming that neutron stars can be spun up to millisecond periods in the course of disk accretion in a binary system. The reason why the majority of rapidly rotating neutron stars in LMXBs do not show millisecond pulsations may be that their magnetic fields are much weaker than in SAX J1808.4-3658. (Rashid Sunyaev)

2.8 The distance to the LMC after *Hipparcos*

The determination of the distance to any object outside the Solar System is extremely difficult, yet, the knowledge of distances is of fundamental importance in astronomy.

A direct method which works marvelously on Earth and in the Solar System is using a laser, to measure the time it takes for a signal to go to, and reflect back from, a target. If one used this method to determine the distance to the nearest star, however, one would have to wait for more than 8 years before the signal returned to Earth. This is obviously impractical even discounting the technical fact that no telescope is big enough to pick-up the reflected signal because it would be too weak.

The only other direct method to determine the distance to the most nearby stars is to measure their so-called parallax. The principle is very simple: look at an object which is about a meter from you, and close alternatingly your left and right eye. You will notice that you see the object under a slightly different angle. The same principle can be used in astronomy, with a telescope replacing your eye, and the width of the Earth's orbit replacing the distance between the eyes. This method has been applied extensively using ground-based telescopes but its accuracy is limited by the turbulence of the Earth's atmosphere. In 1989 the European Space Agency launched the *Hipparcos* satellite into space to measure the parallax of about 100 000 stars. This was not done in the simple way described above by measuring the difference in angle 6 months apart, but by actually measuring the position of these stars on average a 100 times over a period of 4 years. From that one derives the position (Right Ascension and Declination) at some reference moment (the year 1991.25), the velocity (or proper motion) of the stars in these two coordinates, and the parallax. So, one had to deduce 500 000 unknowns from a set of about 10 million observations. The situation was in fact even a bit more complicated because many stars are not single, but are in binary or even triple systems, and their motion on the sky cannot be described by 5 parameters only. However, this was all taken into account. In fact, the data reduction was done by two independent consortia to avoid errors in this very complicated analysis. The end product is a catalog which contains parallaxes with a typical precision of 1 milli-arcsecond (an angle of 1 milli-arcsecond corresponds to seeing from Earth an astronaut on the Moon). The closest extra-solar star to Earth has a parallax of 772 mas. This at the same time implies that reasonably accurate distances can be obtained for stars up to about 200 pc, or 5 mas (the definition of a parsec is in fact related to the parallax in such a way that the distance in parsec is 1 divided by the parallax in arcseconds).

This is an order of magnitude improvement over what can be achieved from ground-based parallax measurements, but on the other hand, it is is still insufficient to measure directly the distance to the nearest companion galaxy of the Milky Way, the Large Magellanic Cloud, at a distance of approximately 50 000 pc.

To measure such large distances, astronomy has traditionally relied on relative indicators: if one measures a very specific type of star in two galaxies, but receives 4-times less light from one as from the other, then one galaxy is twice as far away as the other. This is very simple, but it implies (1) that one can identify such "standard candles", and (2) one knows the actual distance to at least one star of this type.

Astronomers have come up with many of these standard candles. A few (the Cepheids, and RR Lyrae stars) are variable stars where it turns out that the intrinsic brightness (or absolute magnitude) is a function of the pulsation period. Others, are stars which are in very specific evolutionary phases of their lives, and stand out in one way or the other (stars at the tip of the Red Giant Branch, "red clump" stars). As the LMC contains all of the above standard candles it is the most important calibrator in the extra-galactic distance scale.

Traditional methods of distance determination, applied over the last decades, seemed to indicate a distance of about 50 kpc to the LMC with an uncertainty of about 2.4 kpc. The distance to the LMC itself is calibrated distance to the nearest standard candles in our own Galaxy. Because of its significant improvement in accuracy the *Hipparcos* mission was expected to change the situation dramatically, by determining the first parallaxes for a significant number of Cepheids, and by allowing a significant redetermination of the absolute brightness of RR Lyrae stars in globular clusters and in the field.

However, what we have witnessed since the release of *Hipparcos* results, is a renewed debate about the LMC distance, with different methods providing either very "long" or "short" values. At the extreme end of the new determinations there are (1) the re-calibration of the Cepheids period–luminosity relation by Feast & Catchpole (hereafter FC) using the 26 Cepheids in *Hipparcos* with the highest weight (that is smallest error on the parallax), implying a distance of 55.0 ± 2.4 kpc and (2) the results from the "red clump method" developed by Paczyński, Stanek

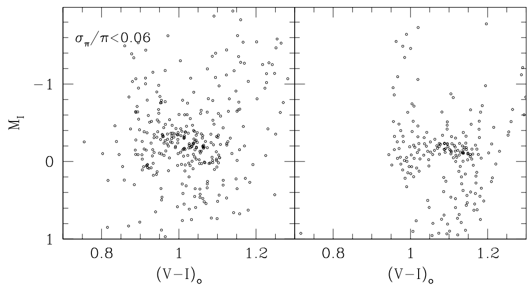


Figure 2.18: The red clump in the colour-magnitude diagram of nearby stars as derived from the *Hipparcos* catalog (left), compared to a synthetic diagram corresponding to a simple galaxy model (right).

and Udalski, which indicate a distance of 41.7 ± 2.6 kpc. Clearly, these two determinations provide inconsistent results. Other methods, based either on the RR Lyrae or on the light echo from the ring around the supernova 1987A, all provide values between these two extremes, usually between 45.7 and 52.4 kpc.

How can the methods based on Cepheids and red clump stars, both objects with trigonometric parallaxes directly measured by *Hipparcos*, provide such different results? Obviously, systematic errors affect either one or both methods of distance determination. Members of the stellar evolution group at MPA have started to study these errors as soon as the first discrepant results appeared.

The "red clump method" makes use of the *Hipparcos* absolute brightness of several hundred red clump stars located within about 100 parsec of the Sun. More than 600 such stars have measured parallaxes with errors less than 10 %. This implies that the mean absolute brightness of the local clump can be determined with an accuracy of *hundredths* of magnitude. Therefore, if we assume that all clump stars have the same absolute brightness, their observation in other galaxies would provide a single-step determination of the distance.

The potential problem with this distance determination turns out to be exactly in this assumption. Examining the behaviour of detailed evolutionary models for these stars, it appears that the clump should be systematically brighter at lower metallicities. The effect is such that the LMC distance modulus as obtained from the "red clump method" should be revised to 45.3 ± 3.0 kpc.

Interestingly, the synthetic colour-magnitude diagrams created to investigate this question, presented some newly seen fine structures, for example, a bright plume of clump stars, and a faint secondary clump. Similar features seem to be present in the colour-magnitude diagram derived from *Hipparcos* (see Fig. 2.18) and in some LMC fields observed to date. This will be studied in more detail in the future.

A problem that potentially lurks in *any* distance measure is bias: one has to be careful that the way one selects a sample of stars does not influence the result. The best-known example is the Malmquist bias, which causes a magnitude-limited sample to be brighter than a volume-complete sample. A less-known effect is the so-called Lutz-Kelker bias (hereafter LK). As there are far more stars farther away (smaller parallax), the probability that a star with true parallax π "scatters" to the observed parallax π_0 is asymmetrical with respect to π_0. In a statistical sense π is smaller than π_0. Lutz & Kelker argue that this applies for individual stars and samples alike, and derive a correction to be applied to the absolute magnitude derived from π_0, and showed this to be a function of the relative error on the observed parallax only.

The prediction by Lutz & Kelker was empirically tested by comparing less accurate ground-based parallaxes for those stars that have a *Hipparcos* parallax determination better than 5 %. It turns out that the magnitude difference is correlated with the relative error in the ground-based parallaxes in the predicted way.

FC in their analyses do not take LK or Malmquist bias into account. However, their best estimate of the distance to the LMC is based on 26 stars with the highest weight. Although formally different, this in practice is equivalent to (some) selection on parallax (error) and hence should be subject to LK-bias. It is therefore necessary to apply an LK correction to the 26 Cepheids with the highest weight. This was done by the MPA group who obtained a distance of 51.5 ± 1.9 kpc, a result based on the 20 Cepheids that pulsate in the fundamental mode.

Thus, present work at MPA indicates that systematic errors in both the Cepheid and red clump methods are probably responsible for the discrepant distances derived from them. However, the different distance determinations to the LMC are not yet fully reconciled and should still be considered as uncertain by as much as 4 kpc. This uncertainty is particularly frustrating if we consider the fundamental role played by the LMC in the extragalactic distance scale. (Martin Groenewegen and Léo Girardi)

2.9 Can tidal tails constrain current cosmological models?

Observed galaxies exhibit a wide range of morphologies, traditionally arranged in a sequence from almost featureless elliptical galaxies through disk-like objects to magnificent grand design spiral galaxies, which are among the most beautiful objects in the sky. However, there exists also a number of "peculiar" galaxies, which do not fit well into this scheme. Many of these galaxies show long and extended tails of stars, which can extend from their main body to distances reaching several hundred kiloparsec. Among the most famous systems of this type are the "Antennae" galaxies (NGC4038/39), the "Mice" (NGC4676), and Arp295, and many more of them may be found in Arp's *Atlas of Peculiar Galaxies*.

Already in 1972, Toomre & Toomre showed with simple numerical experiments that such tails can be ejected by tidal forces in close encounters between dynamically cold disk galaxies. It is now generally accepted that the stellar tails seen in many peculiar galaxies are indeed generated when two galaxies collide with each other. Usually, such encounters lead to a final coalescence of the galaxies, where they form a single pile of stars and lose their original identity.

Mergers of galaxies are a common and inevitable process according to current theories for the growth of structure in the universe, and for the formation of the luminous galaxies within it. In such theories, galaxy formation is assumed to proceed hierarchically; small galaxies form first, and merging and collapse processes lead to the build-up of ever more massive systems.

A crucial assumption of these theoretical models is that the bulk of the mass in the universe consists of "dark matter" in some unknown form, perhaps a yet to be identified elementary particle. While the dark matter has not been directly detected on earth so far, there is a lot of indirect evidence for its existence. This indirect evidence stems from the dark matter's gravitational effects on its surroundings, seen for example in the orbital motions of galaxies within clusters, or in the gravitational lensing of background galaxies by massive foreground objects.

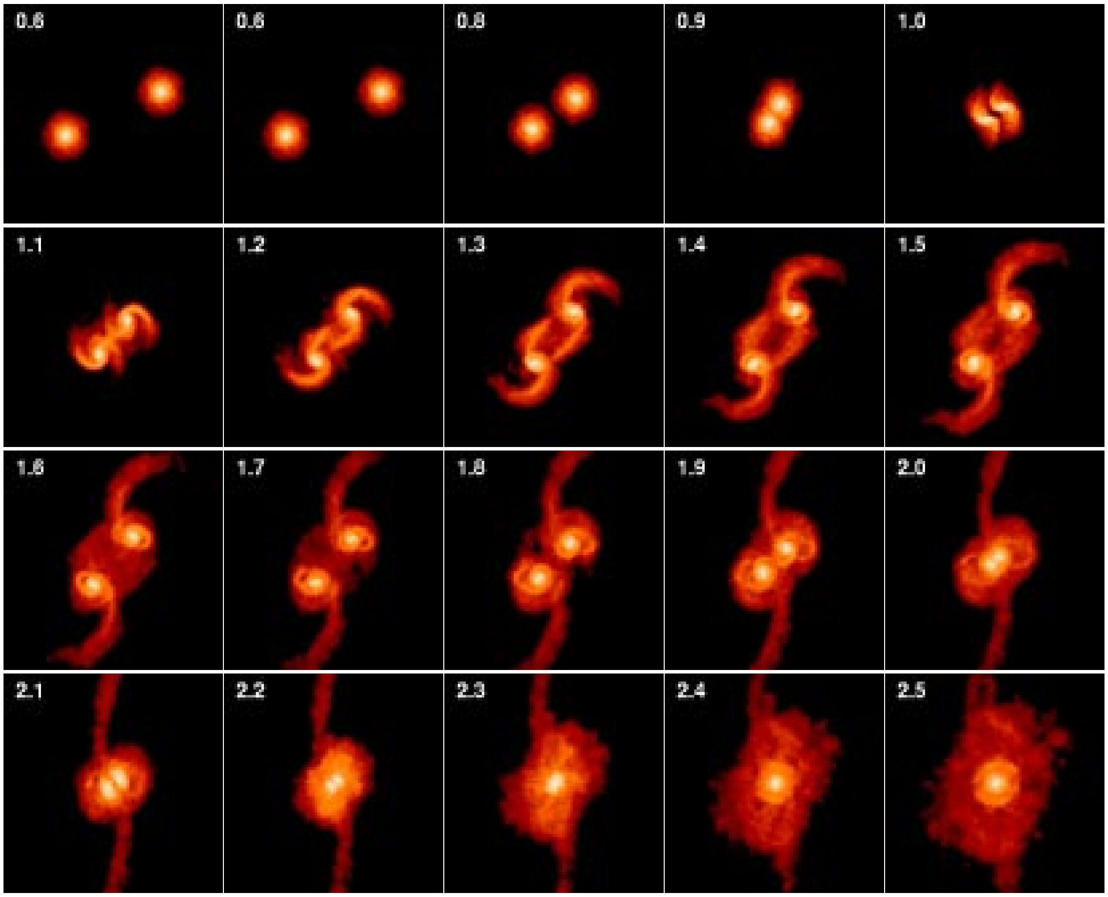
The dark matter is believed to interact with other matter *only* by gravity. This idea brings a great simplification, because the dynamics of the dark matter can then be studied using the laws of gravity alone, without having to worry about the much more complicated physical processes related to the gas that ultimately forms the stars in the visible parts of galaxies.

In recent years, the growth of structure in the dark matter component of the universe has been extensively studied numerically using supercomputers, and the MPA has been at the forefront of this research. As a result, the structure and abundance of galaxy-sized dark matter haloes is now well understood. It is believed that at the center of each of these dark matter haloes a luminous galaxy forms. In particular, the gas, which was initially distributed just like the dark matter, loses energy through radiative processes. As a consequence of this cooling, it falls towards the center of the dark halo, where it becomes dense enough to switch on the formation of stars. However, the detailed processes that lead to the formation of the stellar component are currently not nearly as well understood as the dynamics of the dark matter.

Recently, interest in tidal tails has been stimulated by numerical work that showed that disk galaxies embedded in massive and extended dark haloes may have difficulty in forming tidal tails. This is because such galaxies experience higher encounter velocities, leading to a smaller overall strength of the perturbation of the disk. In addition, the perturbed material has difficulty climbing out of the deeper potential well.

In all viable models of cold dark matter (CDM) cosmologies, the mass of the dark matter haloes of field galaxies is expected to be much larger than the total baryonic mass of the disk itself. Furthermore, the dark haloes are also much more extended than the disks. Taking recent numerical results on tail formation at face values suggests a serious conflict of CDM models with observed tails.

In order to elucidate this point further, we have carried out a large set of collisionless N-body simulations of colliding disk galaxies. One important aspect of our approach has been that we tried to improve upon the initial conditions used in these simulations, i.e. we wanted to set up the structural properties of the disk galaxies and their haloes according to the theoreti-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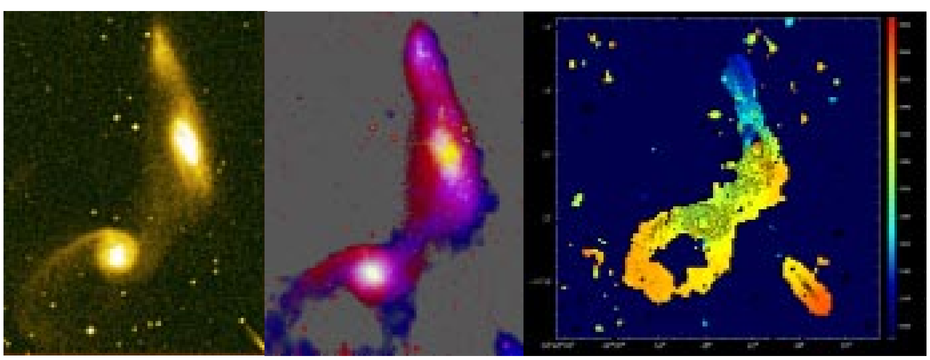

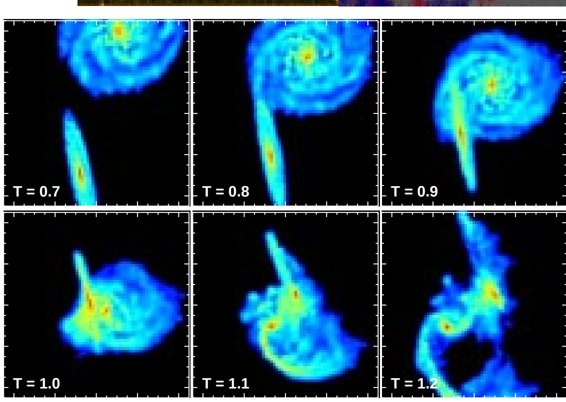
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T = 0.8
T = 0.9
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T = 1.2

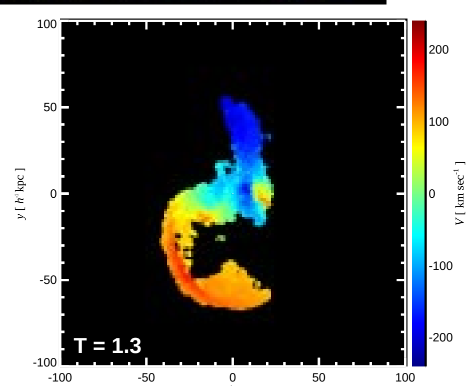
T = 1.3
y [h⁻¹kpc]
x [h⁻¹kpc]
V [km sec⁻¹]
100
50
0
-50
-100
200
-200

Figure 2.19: The time evolution of one of our collision simulations. In this example, two equal galaxies collide on a parabolic orbit with each other, with their disks rotating counter-clockwise parallel to the orbital plane. Only the stellar material is shown. As time progresses from the top left to the bottom right, the disk galaxies collide for a first time at $t \sim 1.0$, where the tidal tails are ejected, and the disks are transformed into a pair of open bisymmetric spirals. Later, the disks come together for a second time, and the galaxies eventually coalesce to form a single spheroidal remnant.

Figure 2.20: Tidal tails in the system NGC 2992/3. The top left panel shows an optical image of this system, taken from the *Digital Sky Survey*. The top middle panel shows a color composite of the stellar population and the neutral/ionized gas, and the HI velocity field is displayed on the top right. These two figures have been kindly provided by Pierre-Alain Duc of the University of Cambridge. In the second row, we show images of a preliminary simulation that tries to model this system. The six small frames visualize part of the time evolution of the projected gas density in the collision, and the figure on the lower right gives the velocity field "observed" in the simulation.

cal framework developed recently by a group of scientists at MPA. According to this work the structure of the disk is intimately linked to that of its halo. The structure of the halo is in turn taken as that found in detailed simulations of the CDM theory.

On the basis of this theory, we generated self-consistent N-body representations of disk galaxies, and let them collide on the computer. Each galaxy was made up of a collisionless dark matter halo, a stellar disk, and a stellar bulge.

In Figure 2.19, we show a typical example of the time evolution of one of our simulations. Here, two equal disk galaxies fall towards each other under their mutual gravitational attraction. When the galaxies reach orbital pericenter for the first time, tidal forces quickly transform the disks into a pair of open bisymmetric spirals. Simultaneously, stars on the outside of the encounter are ejected into arcing trajectories which later form the tidal arms. Material from the near side is drawn towards the companion, giving rise to bridges between the galaxies as they temporarily separate again. The bridges are destroyed when the galaxies come back together for a second encounter, but the tails survive and grow for a longer time in the quiet outer regions. The disks are destroyed as the centres of the galaxies coalesce to form a spheroidal merger remnant.

Study of many such collisions led to the following results. Disk galaxies of differing structure can differ strongly in their susceptibility to tail formation. Models with small disks have difficulty ejecting long tails, while larger disks much more easily produce massive and extended tails.

It appears that in the context of current CDM theories a relatively large number of galaxies should be capable of tail formation. The abundance of observed systems with tidal tails can be explained relatively easily. This conclusion is practically independent of the cosmological parameters of the CDM models. It thus seems unlikely that tidal tails are useful to constrain cosmological parameters.

However, tidal tails remain a very powerful tool to probe the structural properties of galaxies. Here, tidal tails can potentially provide very powerful constraints, especially if detailed dynamical modeling of observed interacting systems is combined with observations of their velocity field. In collaboration with Pierre-Alain Duc (University of Cambridge), we have started such a detailed study. In Figure 2.20 we show encouraging first results from a preliminary simulation that tries to model the interacting pair of galaxies NGC 2992/3. (Volker Springel, Simon White)

2.10 The large-scale distribution of galaxies

In past years, galaxy redshift surveys have played an important role in mapping out the structure of the Universe. Three coordinates are needed to specify the position of a galaxy: two angular coordinates giving the galaxy's position on the sky and a third giving its distance away from the observer. By taking a spectrum of a galaxy, one can derive its redshift and thus its line-of-sight velocity. If it is assumed that this velocity is due to cosmic expansion, Hubble's law can be used to assign a radial distance to the galaxy.

The Center for Astrophysics (CfA) redshift survey was the first data set to contain many thousands of galaxy redshifts and it revealed for the first time the frothy, bubble-like tex-

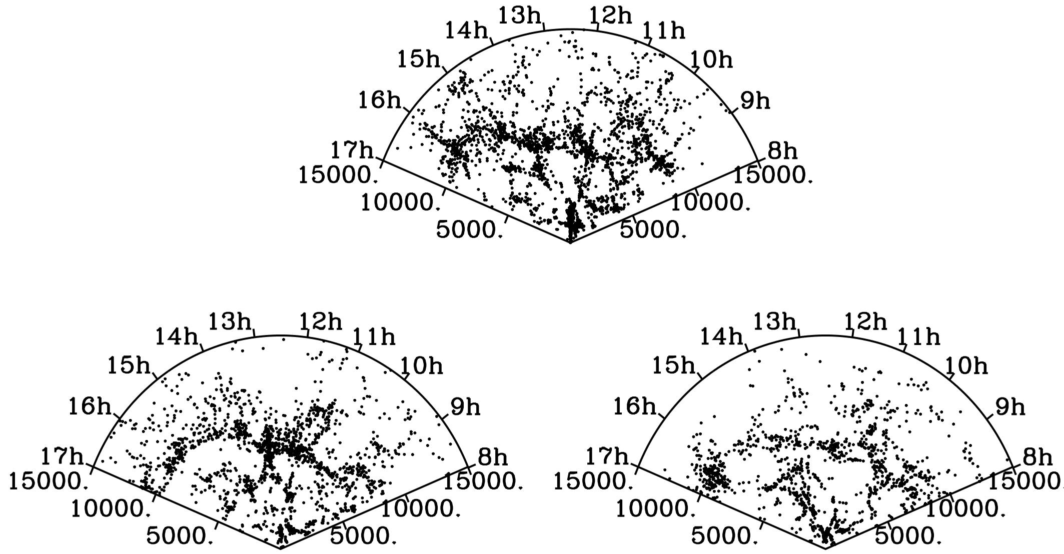

Figure 2.21: Galaxy distribution in the northern celestial hemisphere in the CfA redshift survey. Each dot represents a galaxy plotted in right ascension vs. radial velocity (measured in $\mathrm{km\,s^{-1}}$) coordinates. The declination coordinates have been collapsed into three distinct slices.

ture of the galaxy distribution (see Fig. 2.21). Galaxies are concentrated on filamentary and sheet-like structures surrounding nearly empty voids of size 20-50 megaparsecs (or roughly 10^{21} km). The most striking feature in the CfA survey is the so-called Great Wall, a coherent sheet of galaxies that extends over an area of at least 60×240 megaparsecs and that is only a few megaparsecs in thickness. The Great Wall is situated at a distance of 100 megaparsecs away from the Earth and lies perpendicular to the line-of-sight. In the three slices shown in Fig. 2.21 one can see the Great Wall as a "filament" at a radial velocity in the range from 5000 to 10000 km s^{-1}, extending from one side of the slice to the other.

The inhomogeneities observed in the distribution of galaxies are believed to reflect the inhomogeneities present at very early epochs in the Universe. According to the standard theoretical paradigm, these were generated shortly after the Big Bang by quantum fluctuations during a period of accelerated expansion, usually termed inflation. These early inhomogeneities were then gravitationally amplified as the Universe expanded. Eventually, material contained in initially overdense regions of the Universe stopped expanding and began to collapse. The smallest objects formed first in this way, and these later merged together to form larger and larger structures. Note that the collapsing structures consist of both dark matter and gas. Galaxies form when the gas reaches high enough densities to cool, sink to the centre of their surrounding dark matter *halos* and form stars.

The growth of structure in the dark matter component of the Universe has been studied for more than 15 years using computer simulations. In these simulations, a finite volume of the universe is divided into a system of N particles that only interact with each other gravitationally. At the start of the simulation, all the particles are placed on a uniform grid and are given a tiny displacement as specified by the initial conditions of the theory. The computer then follows the growth of structure in the volume by integrating the equations of motion for the N-particle system.

Figure 2.22 shows four snapshots from a state-of-the-art simulation carried out on the Cray parallel supercomputer at the Garching Computer Centre. This simulation was designed to study the galaxy distribution in a volume of the universe comparable to that covered by the CfA redshift survey: it tracked the positions and velocities of 17 million particles of 10^{10} solar masses each in a volume of $\sim 10^7$ cubic megaparsec. At first glance, the $z = 0$ snapshot has an appearance that is certainly reminiscent of the observational data – there are striking filamentary structures that surround large underdense regions. The largest collapsed structure

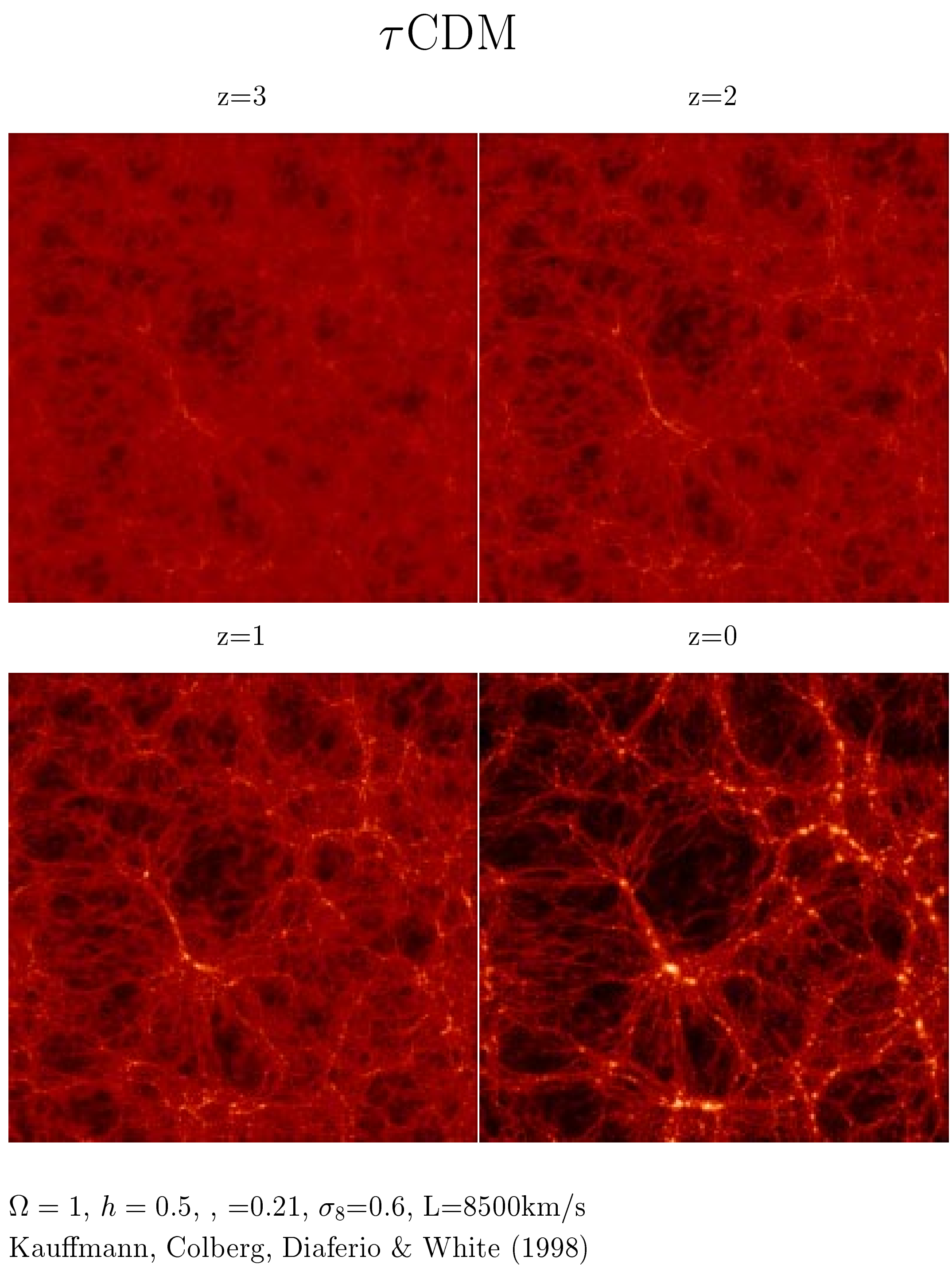

Figure 2.22: Evolution of the matter density perturbations in a Cold Dark Matter cosmological model. Time runs from left to right and from top to bottom. Each panel is a slice 170 megaparsec on a side and 16 megaparsec thick. Bright spots indicate regions where the matter density is several orders of magnitude larger than the mean value within the entire volume. These high-density regions are the dark matter halos where gas can cool and form stars and galaxies.

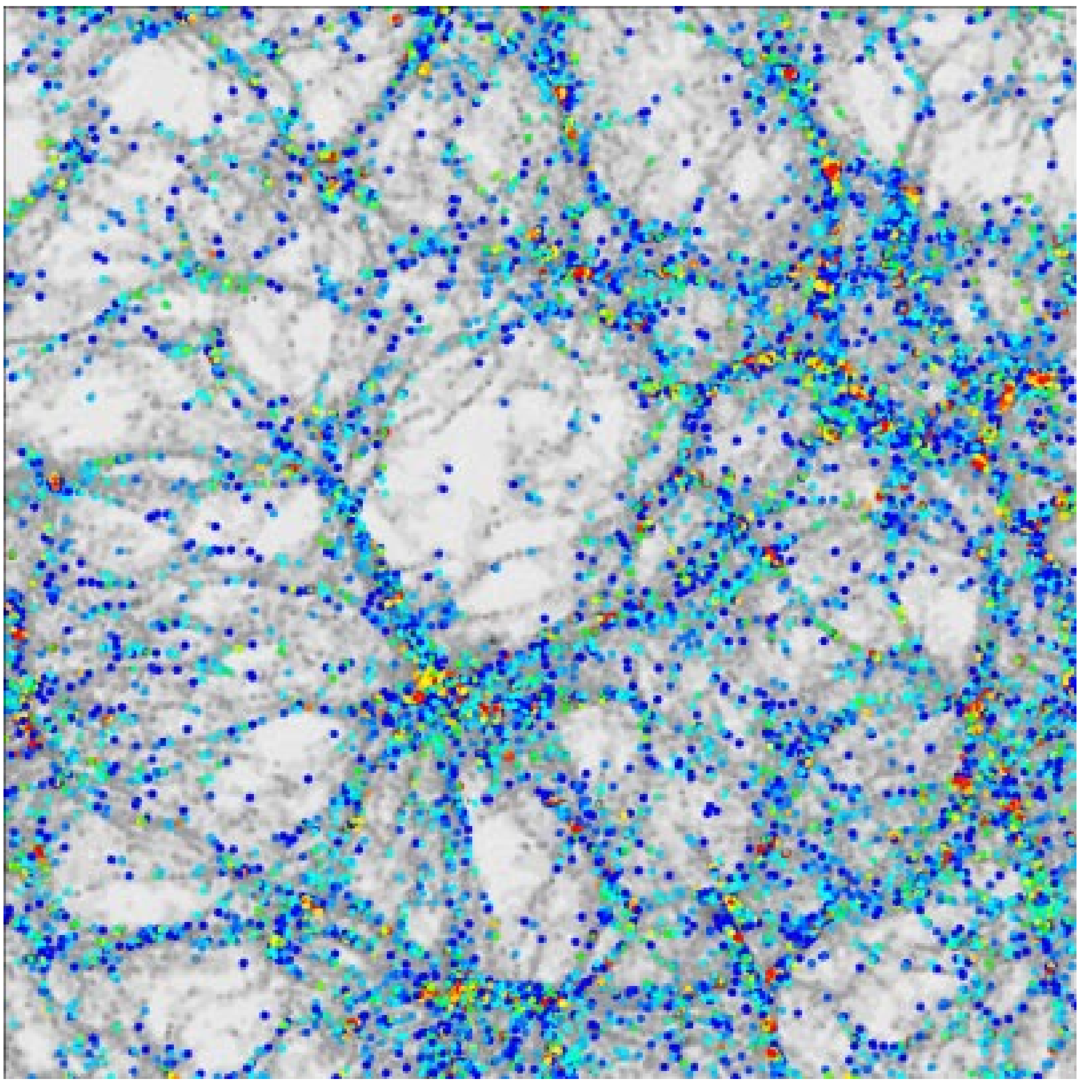

Figure 2.23: The dark matter density distribution from the bottom right panel of Fig. 2.22 is now shown on grey scale. Galaxies have been superimposed as coloured circles. Colour ranges from red to yellow, green and blue. This sequence represents an increasing rate of star formation.

in the volume has a mass of about 10^{15} solar masses, which is quite comparable to the mass of Coma, the largest cluster in the CfA survey.

Is it possible to make quantitative comparisons between the simulations and the observations? One major obstacle has been that simulations of this kind do not follow the evolution of the gas and the formation of stars and galaxies. Up to now in most analyses, *ad hoc* assumptions have been made about how the distribution of galaxies tracks that of the underlying dark matter. The simplest possibility is that galaxies provide a statistically fair sample of the dark matter. However, the formation efficiency of galaxies is likely to depend on the environment in which they are situated. One concrete example of this kind of environmental *bias* is the fact that in high density regions of the Universe such as clusters, most galaxies contain very little cold gas and have no ongoing star formation, whereas in low-density regions, galaxies are observed to form stars much more vigorously.

In order to understand the relationship between galaxies and dark matter on large scales, MPA researchers have included a set of phenomenological prescriptions for where and how galaxies form and evolve in these dark matter-only simulations. These are essentially physically-motivated "recipes" that describe the cooling and condensation of gas at the centres of dark matter halos, the transformation of this gas into stars, the effect of energy input from supernova explosions on the intergalactic medium, and the merging of galaxies orbiting within a common dark matter halo. Many of these phenomena are governed by physical processes that operate on scales that are many orders of magnitude smaller than the resolution limit of the simulation. Because of the complexity of the physics involved, the adopted recipes are subject to considerable uncertainty. The methodology developed by the MPA group has enabled them to vary some of the prescriptions and to identify those properties of the galaxy distribution that are insensitive to different assumptions about star formation and energy injection by supernovae. These properties can thus be regarded as robust tests of the theory. On the other hand, those properties of the galaxy distribution which *are* very sensitive to the prescriptions may provide important insight into the physical processes governing the formation of galaxies.

Figure 2.23 shows the present-day distribution of galaxies (large circles) superimposed on the dark matter for an N-body simulation in which phenomenological modelling of galaxy formation and evolution has been included. Galaxies have been colour-coded according to the rate at which they form stars: blue galaxies are actively forming stars, whereas red galaxies have little or no star formation. Note that red galaxies occur predominantly in clusters and blue galaxies in lower-density regions, in good agreement with what is observed.

So far the MPA group has concentrated its efforts in two main areas. First, a detailed comparison of the simulation with the CfA redshift survey has been carried out. To do this, mock galaxy redshift samples were extracted from the simulation with the same geometry and selection effects as in the real data. The simulation catalogues and the observational catalogues were then analyzed using the same software. Although the smaller-scale clustering properties of galaxies in the simulation agree remarkably well with the data, no sheet-like structure as large as the Great Wall is found in the entire simulation volume. Because there is only one such structure in the CfA survey, we will have to wait for the next generation of million-galaxy redshift surveys before it is known whether Great Walls are rare objects in the Universe, or whether there is indeed a problem with the theory. Second, the MPA group has studied the evolution of galaxy clustering to higher redshift. Although galaxies are a reasonably unbiased tracer of the dark matter at the present day, this is no longer true at early times – galaxies at high redshift occur only in the very densest regions of the universe. The precise epoch at which galaxies evolve from biased to unbiased tracers of the dark matter depends on a number of factors, including the cosmological initial conditions, as well as the luminosities and morphologies of the galaxies in the sample. Future work will focus on the redshift evolution of galaxies in clusters and groups for comparison with imaging data from the Hubble Space Telescope and ground-based spectroscopy. (Guinevere Kauffmann and Antonaldo Diaferio)

2.11 The Planck Surveyor Mission

The most widely accepted picture of the origin of the Universe asserts that it began in a very hot and dense early phase, and cooled down as it expanded subsequently. In the course of the expansion, electrons, protons, neutrons and the other elementary particles were created. Electrons and protons formed a plasma, through which photons could not travel freely. About 300,000 years after the beginning, the Universe was cool enough for atoms to form. Electrons and protons combined within relatively short time, and the Universe became transparent. From then on, photons propagated undisturbed, but lost energy because of the overall expansion of the Universe. By now, this sea of photons filling the entire Universe has cooled down to a temperature of only 2.73 degrees above absolute zero. At this temperature, the wavelength of the photons is of the order of millimetres, in the regime of microwaves.

The presence of an all-pervading cosmic microwave background is one of the key predictions of the Big-Bang model for the origin of the Universe. Its discovery in 1965 by Penzias and Wilson erected one of the main pillars on which Big-Bang cosmology rests.

The intensity of the cosmic microwave background (CMB) is almost uniform across the sky, but not entirely. We are surrounded by structures like galaxies, clusters of galaxies, or even larger assemblies of matter. They should have formed out of tiny fluctuations seeded in the Universe at very early times, and these fluctuations should also have left their imprint on the CMB.

The search for these CMB fluctuations went on for a long time without any positive detections, until the Cosmic Microwave Background Explorer satellite (COBE) in 1992 discovered highly significant fluctuations in the temperature of the CMB at a level of approximately a thousandth of a per cent. Translated to a more familiar picture, this corresponds to centimetre-high waves on the surface of an ocean 1000 meters deep.

COBE was thus able to support one of the key expectations of physical cosmology, namely that structure originated from tiny seed fluctuations in the early Universe, and the amplitude of the discovered fluctuations fits in nicely with the amount of structure seen in our local cosmic neighbourhood. However, dictated by scientific, technical, and financial considerations, COBE had fairly poor vision. The smallest structures it could resolve were 7° wide on the sky. No comprehensive analysis of the detailed structures in the CMB was therefore possible with the COBE data alone.

A wealth of information should be hidden in the CMB at angular scales of about one degree down to a few arcminutes. In particular, the detailed physics of the tiny matter fluctuations during the phase when electrons and protons combined to form atoms should have left characteristic signatures in the structure of the CMB. The exact size and structure of these signatures depends critically on a number of parameters characterising the global structure and average properties of the Universe today. Among them are the density of matter in the Universe, its expansion rate, the so-called cosmological constant, and many more. Poor knowledge of these parameters hampers cosmology to this date, and detailed predictions in many branches of cosmology require detailed knowledge of exactly what values these parameters have.

Considerations like these nourished the demand for a new and more powerful COBE-like experiment that would measure the CMB fluctuations on the whole sky at much improved angular resolution and higher sensitivity. Two such satellite experiments are currently being planned and set up, NASA's Microwave Anisotropy Probe (MAP), and the European Space Agency's Planck Surveyor mission.

Of those, Planck is the more ambitious. Its angular resolution will reach down to five arcminutes, and it will be able to detect temperature fluctuations at the level of two parts in a million. Planck will therefore be able to produce sky maps about 50 times more detailed and about ten times more sensitive than COBE (see Fig. 2.24).

These maps will contain a sufficient level of detail for constraining cosmological parameters to better than one per cent relative uncertainty. Given that most cosmological parameters are currently not known to better than within 50%, constraints with such an accuracy will clearly revolutionise cosmology, and finally allow detailed predictions in many sub-areas of cosmology and astrophysics that can so far only be vague.

However, this is by far not the end of the story. Of the microwave sky, the CMB is only one component of many. Bodies in the solar system like the Sun, the Earth, the Moon and the planets, emit microwaves and contribute to the signal Planck will measure. Our Galaxy adds diffuse microwave emission due to various phys-

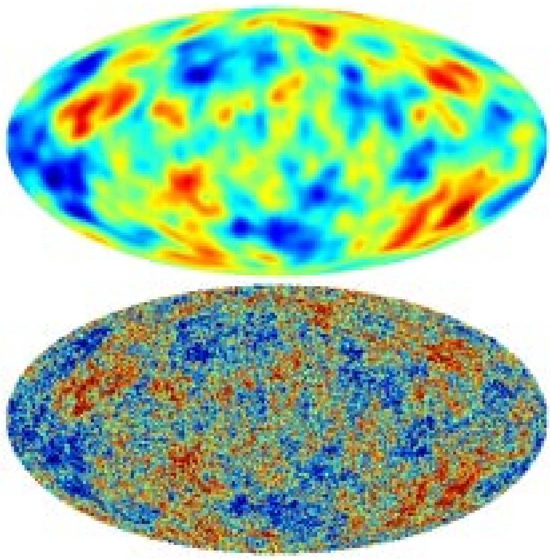

Figure 2.24: Two simulated full-sky maps of the CMB temperature, viewed with the angular resolution of COBE (top) and Planck (bottom). The colours run from $-0.13\,\mathrm{mK}$ (blue) to $0.13\,\mathrm{mK}$ (red) on both maps.

ical processes. Distant galaxy clusters cast shadows on the microwave sky, and there are other classes of cosmic sources of microwave emission. The CMB will therefore only constitute one, however important, part of Planck's measurements. In addition, Planck will detect of order 10,000 distant radio sources, and about as many galaxy clusters far beyond reach of current techniques to survey the sky for such objects.

As a European mission, Planck is being planned by the European Space Agency and its instruments will be built and their data analysed by two consortia of groups and institutions across Europe. The Max-Planck Institute for Astrophysics in Garching represents Germany in these consortia. Specifically, part of the software system required for Planck data processing and information exchange within the consortia will be developed at MPA, and MPA will be the place where the final data products of the Planck mission will be prepared and documented for release 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 scientific aspects of it.

Work at MPA related to the Planck mission commenced in 1998. A small team of programmers and scientists was set up, and the design of a data-analysis software prototype was started in due course. This team has so far been supported entirely by the Max-Planck Society, but it is envisaged that a major support will be provided by Germany's space agency (DLR) starting in 2000. This will then allow appropriate expansion of the team as the project progresses. According to current plans, the team will have 14 members at peak time just after launch.

The scheduled launch date for Planck is in early 2007. Planck will then survey the microwave sky twice during two years. After that, data will be processed for about one year, after which the processed data will be released to the Planck consortium for scientific exploitation. After one more year, all Planck data will be released to the general community.

It can be expected that the Planck Surveyor mission will be one of the most important cosmological experiments for several decades to come. The data are of great importance not only for cosmologists alone, but also for a broad community from various fields of astrophysics. Planck will either definitively answer some of the outstanding cosmological questions, or it will shatter the foundations of our picture of the Universe, should the results not fit within the range of theoretical expectations. Either way, Planck will be a source of scientific excitement for many years to come – and MPA will be near the core of the action. (Matthias Bartelmann)

2.12 Gravitational lensing on the Cosmic Microwave Background

The standard paradigm of modern cosmology is the expanding universe model, where the universe started with a hot big bang and has been expanding ever since. The universe is predicted to be homogeneous and isotropic on large scales with initially small density fluctuations superimposed on that background. These fluctuations have been amplified by gravity to become the present day galaxies, groups of galaxies and even larger conglomerations. This paradigm, while successful in explaining all the observations, still leaves many questions unanswered. Among these are the value of cosmological parameters, such as the rate of expansion of the universe, the nature and density of dark matter, the density of ordinary matter, the existence of gravity waves in the early universe and the

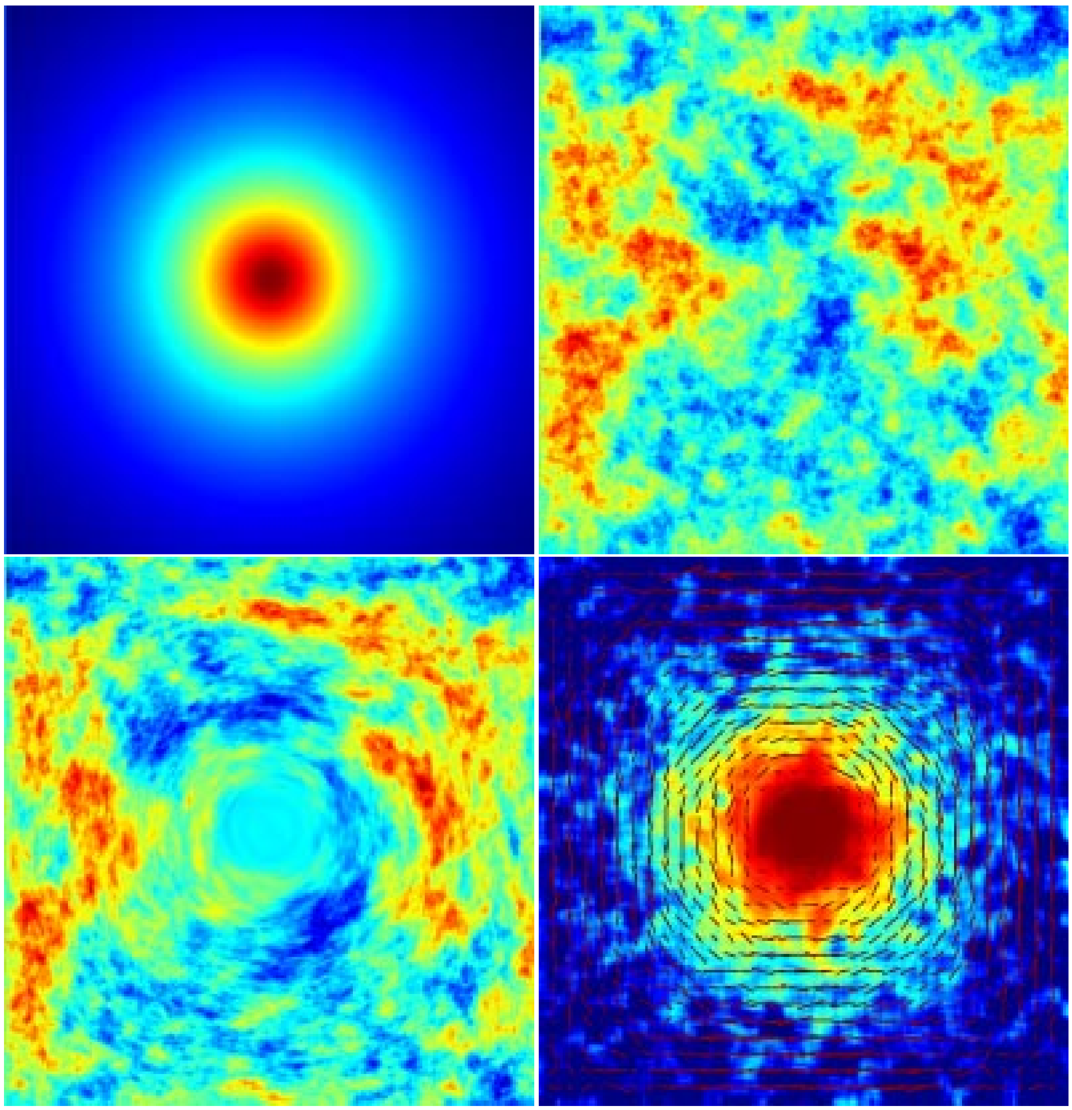

Figure 2.25: A toy example simulation of the gravitational lensing effect on the CMB. In the upper left corner an example of a mass concentration is shown, while in the upper right corner a random section of the CMB field in the absence of gravitational lensing effects can be seen. If the mass concentration is placed in front of the CMB one obtains the lower left figure. The mass distorts CMB by magnifying it in the center and elongating it in the direction perpendicular to the center of the mass. The developed method allows one to reconstruct the original mass distribution, as shown in the lower right figure. Also shown is the reconstructed distortion map (rods).

mechanism that generates the initial perturbations.

Observational efforts are necessary to provide the answers to the above questions. One of the most promising methods is to use fluctuations in the temperature of the cosmic microwave background (CMB), which is a relic radiation from the early epochs of evolution, when the universe was about 1000 times hotter than today. The CMB can be observed in all the directions in the sky and has been found to be extremely isotropic, to one part in hundred thousand. Still, small variations in the temperature as a function of position in the sky exist and have been generated by the small fluctuations in the universe at that epoch. Because the conditions at that epoch depended sensitively on the value of various cosmological parameters one can deduce these by studying statistical properties of these fluctuations. The first detection of hot and cold spots in the CMB was achieved by the COBE satellite in 1992. COBE was only able to measure very large spots because of poor angular resolution and sensitivity. Since then there have been a number of new experiments confirming the first measurement and extending it to smaller angular scales. Future experiments, such as MAP in USA and Planck Surveyor in Europe, will be able to accurately measure the fluctuations on all angular scales of interest. This will provide much more information on cosmological parameters and will allow one to determine some of these with an accuracy of a percent or even better.

Even with new satellites there will still be cosmological models that will not be distinguishable using information from the CMB only. Additional important information can be provided from other measurements, among which measuring fluctuations in the matter distribution of the universe is probably the richest source. Because most of the matter appears to be dark such information is not directly accessible to observations. It is possible that galaxies follow dark matter, but there may also be other processes that complicate this relation and so it would be desirable to have a method that is directly sensitive to dark matter. One possible way to measure dark matter directly is using the fact that matter deflects light through gravity, the so-called gravitational lensing effect. In extreme cases this can generate multiple images of a background source, but more often it just distorts its shape. Because the CMB is the most distant light source that can be observed in our universe all the matter between us leads to distortions, allowing one in principle to detect directly dark matter even at very early epochs of our universe.

The (somewhat exaggerated) effect of a mass concentration on the CMB is shown in Figure 2.25. The hot and cold spots in the CMB are both magnified and distorted, which allows one to reconstruct the mass distribution by averaging the distortions over the CMB spots. While this effect is too small to be detected for individual matter concentrations such as galaxy clusters or filaments, statistical averaging allows one to measure the statistical properties of dark matter quite accurately. This will be specially promising with the upcoming CMB satellite Planck Surveyor, which is being developed in Europe and in which MPA is playing a major role. It will allow one to statistically detect dark matter clustering on larger scales and at earlier epochs than any other method proposed so far. As such it will yield important information that will allow one to distinguish many of those models that the CMB alone cannot separate.

Additional information will be provided by comparing the CMB and the gravitational lensing effect on the CMB. Some theories, including most of the currently popular ones, predict that many of the very large hot and cold spots in CMB were generated not when the universe was 1000 times smaller and hotter, but by nearby structures when the universe was just a few times smaller than today. These spots correspond to actual mass concentrations and so the same structures should also bend CMB light through the gravitational lensing effect. By comparing the two maps one should be able to detect the similarity between them if it exists. If no similarity is detected then this would rule out most of the currently popular models which predict low density of matter. This effect will also become testable with the MAP and Planck Surveyor satellites and will provide additional constraints that the correct cosmological model should satisfy.

The simple interpretation of gravitational lensing effects on the CMB and their sensitivity to cosmological models make the proposed method one of the most promising ways to determine cosmological parameters, specially when combined with the primary information from the CMB itself. This should provide further incentive for high sensitivity all-sky CMB experiments such as the Planck satellite. The CMB will be a true data goldmine in the years to come and should revolutionize our understanding of how the universe was created and how it evolved to its present state. (Uros Seljak)

2.13 Antimatter in the Universe

A tiny fraction of a second after the Big Bang, the very early universe consisted of a plasma of particles and antiparticles, which were constantly annihilated into and created from light. In thermodynamic equilibrium the creation of particles and antiparticles has equal probability, therefore the early universe, which was very close to thermodynamic equilibrium, should have been filled with equal numbers of particles and antiparticles. When the temperature dropped due to the expansion of the universe, the creation of particle-antiparticle pairs from light was no longer possible, and particles and antiparticles annihilated into light. This light is what we see today as the cosmic microwave background radiation (CMBR)—cooled down to a temperature of 3 Kelvin in course of the evolution of the universe over the past 15, or so, billion years.

But why is the universe filled with the matter we and everything else in the universe—from dust grains to clusters of galaxies—is made of? If the universe was filled with exactly equal amounts of matter and antimatter, nothing but light should have been left after the annihilation was complete. There must have been a tiny bit more matter than antimatter, about one extra particle for every billion thermal particle-antiparticle pairs. How was this excess of matter over antimatter created? This process, called baryogenesis, is one of the big puzzles of cosmology remaining to be solved.

There are two fundamentally different possibilities to end up with the world we see. One possibility is that matter and antimatter were actually created in equal amounts, but some still unknown mechanism has separated them on very large scales. Observational searches for antimatter indicate that this scale should today be nearly as large as the observable part of the universe. In this case we would live in a so-called baryo-symmetric universe, meaning there are exactly equal amounts of matter and antimatter in the universe, but we are only able to see a part of the universe which contains matter only. We can only observe regions of the universe where light had enough time during the existence of the universe to travel from its origin to us. This distance—the lifetime of the universe multiplied by the speed of light—is called the current horizon. Since the universe is about 15 billion years old, the current horizon should be as large as 15 billion light years.

The alternative explanation for baryogenesis is that there were temporary deviations from thermodynamic equilibrium in the early universe, e.g. phase transitions, in which an excess of matter over antimatter was created. After annihilation of all the thermally created antimatter, some matter was left over. Much later during the evolution of the universe stars and everything else was formed out of this matter. This baryo-asymmetric solution is currently favored by cosmologists, even though the first scenario is not excluded on observational grounds.

Recently, baryo-asymmetric models for baryogenesis were proposed predicting the creation of small-scale matter-antimatter regions, which would disappear very early in the course of the evolution of the universe. Would such regions leave any observable trace?

Many observational searches for antimatter in the universe have been undertaken in the past. These searches started in our closest neighborhood, the solar system. A very direct proof that the nearest astrophysical object, the moon, is not made out of antimatter was the fact that the Apollo astronauts were able to make a second small step. Other ways to search for antimatter on distances beyond our own "backyard" include observations of the CMBR and the gamma-ray background. But regions which are so small that they annihilate earlier than a few hours after the Big Bang would escape unobserved. Is this baryogenesis model then the "perfect crime", in the sense that no one will be able to tell on ground of observations if that may have happened or not? Fortunately that is not the case, as we will see.

The best-understood physical process in the early universe is the synthesis of the light elements, namely Big Bang Nucleosynthesis (BBN). All the deuterium and most of the helium was created very early in the history of the universe, a few minutes after the Big Bang. The light elements are constantly built up from neutrons and protons and destroyed again by high energy photons in the early universe. At some point during the evolution of the universe, about a minute after the Big Bang, the photons are not energetic enough any more to break up the light nuclei. Essentially all neutrons available at this time are bound into helium nuclei. Thus the final amount of helium synthesized is very sensitive to the number of neutrons present at this moment. This number may be affected dramatically by the presence of antimatter domains.

In an MPA project, we use BBN as a tool to investigate the possibility that antimatter regions were present in the early universe. By means of simulations, we calculate the amount of helium synthesized in scenarios with antimatter regions and can therefore constrain certain parameters of the baryogenesis scenarios which would create such small-scale antimatter regions.

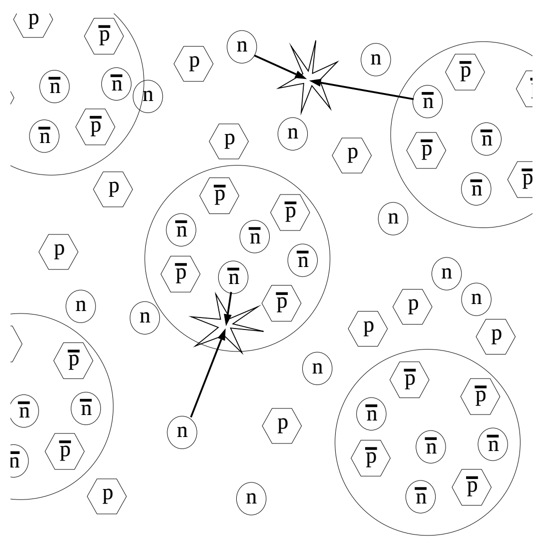

Figure 2.26: Regions of antimatter embedded in the matter-filled universe. Neutrons (n) and antineutrons ($\bar{n}$) are able to diffuse, whereas protons (p) and antiprotons ($\bar{p}$) are confined to their respective regions. Annihilations into light may take place whenever particles and antiparticles meet.

Matter and antimatter may diffuse from their respective region into the other and may annihilate there (Fig. 2.26). However, the diffusion is different for neutrons and protons. The charged protons scatter frequently on electrons, whereas the electrically neutral neutrons interact much more weakly with the electrons. This leads to a more efficient, or faster, diffusion of the neutrons compared to the protons. The neutrons diffuse into the antimatter regions and are annihilated there, and vice versa. The protons, on the other hand, are confined to the matter region due to their much slower diffusion. This results in a depletion of neutrons and therefore to a smaller amount of finally synthesized helium.

In extreme cases, all neutrons might diffuse into the antimatter regions and be annihilated there, so that only protons would be left over. Since it is not possible in the early universe to build up helium from protons only, no helium at all would be produced. That is clearly not what we observe.

If the antimatter regions were somewhat larger, so that even neutrons cannot diffuse in large numbers and smear out the antimatter regions before BBN, we are confronted with a slightly different scenario. In this case BBN would take part in the matter and antimatter regions independently. In the matter regions the usual BBN takes place, whereas in the antimatter regions the corresponding anti-elements would be created. Some time after BBN diffusion of the nuclei allows for mixing between the matter and antimatter regions and annihilation would take place. Annihilation of the nuclei produces mainly photons of relatively high energy. These energetic photons may then destroy other nuclei and so alter the cosmic element abundances even further.

Since both scenarios should be consistent with the observed light elements abundances, very stringent constraints on the antimatter regions can be derived.

In our work, we showed that not more than a few percent of antimatter could have been present just before the epoch of BBN, depending to some extent on the exact length scales of the antimatter regions. The existence of substantial amounts of antimatter on much larger scales, which would survive until epochs later than BBN seems to be excluded as well.

Big Bang nucleosynthesis considerations may well be the only tool to constrain the existence of small-scale antimatter regions in the early universe. Through analyzing BBN with matter and antimatter regions by simulations, a small step towards understanding the mystery of baryogenesis may be made. (Jan Rehm)

3 Research Activities

3.1 Sun and interplanetary matter

U. Anzer and P. Heinzel (Astronomical Institute, Ondrejov) continued their work on solar prominences. They developed a magnetic equilibrium model for vertical thread-like fine structures. In addition they studied equilibria of horizontal threads. Presently they are developing a two-dimensional radiative transfer code which can be applied to these structures. They also derived a simple relation between magnetic dips and the value of the plasma beta in prominences.

Images of water ions in comets have been analyzed and interpreted by R. Wegmann in joint work with K.Jockers, and T. Bonev (both MPI für Aeronomie, Katlenburg/Lindau). A method, based on the scaling law for cometary magnetohydrodynamics, for the determination of the gas production rate has been developed and refined. Results were compared with the results of other observers.

Heavy solar wind ions in high ionization state acquire electrons by charge exchange with neutral molecules in the cometary coma and so radiate X-rays. R. Wegmann and H.U.Schmidt in collaboration with K. Dennerl and J. Englhauser (both MPE) developed a method to determine the gas production rate from X-ray images of a comet. The method is based on large scale model calculations and makes use of a similarity law. The heavy solar wind ions run through a cascade of ionization states as they acquire successively more and more electrons. This process manifests itself in variations of the spectrum which is softer in the near nucleus region.

O. Terekhov studied the process of deuterium synthesis in highly energetic solar flares. The results were used for the estimation of the amount of deuterium produced during the observation period of the GRANAT(1990-1995) and SMM (1981-1989) experiments.

3.2 Stellar structure and evolution

Work on the Garching Solar Model (GARSOM) has been completed in the thesis of H. Schlattl (supervised by A. Weiss). The model is as accurate as the best contemporary one in the literature. Applications included the question of how accurately one can determine the age of a star (here, for the Sun, to 10%) by a comparison of all available observational data with the best models. Helioseismic bounds on axion emission from the Sun were also determined (with G. Raffelt, MPI Physics, München).

A. Weiss and M. Salaris (MPA and John Moores University, Liverpool) continued their determinations of globular cluster ages and extended it to disk clusters, which were found to be 9 ± 1 Gyr old, in nice agreement with the age of the oldest disk white dwarfs, and about 2 Gyr younger than generic halo clusters. The question of reliable colour transformations for isochrones was addressed separately and a new relation derived for $(V - I)$. With L. Pulone (ESO) and R. Buonanno (Univ. of Rome) a semi-empirical relative-age relation was developed, and with colleagues from Pisa and Teramo (S. Cassisi, S. Degl'Innocenti and V. Castellani) general results about recent developments in the fields were published. – The ages of the oldest open clusters were the subject of a collaboration among L. Girardi, G. Carraro, A. Vallenari and C. Chiosi (the three latter from the University of Padua, Italy). They examined the colour-magnitude diagrams of 5 such objects, finding that the oldest one, Berkeley 17, has a maximum age of 10 Gyr. Unless other open clusters older than this limit are found, it seems to confirm the presence of a gap of at least 2 Gyr between the formation of the Galactic halo and the disc.

P. Denissenkov (MPA and St. Petersburg University) investigated possible theoretical models to explain observed abundance anomalies in globular cluster giants with A. Weiss and G. Da Costa and J. Norris (both Mount Stromlo Observatory, Australia), as well as in main sequence stars (with A. Weiss and N. Ivanova, St. Petersburg).

H. Spruit studied the internal rotation of giants and found that their cores are likely to corotate approximately with their envelopes due to magnetic coupling. As a result, the rotation of white dwarfs is not a remnant of the initial main sequence angular momentum. Instead, slight asymmetries in the AGB mass loss are a likely explanation of observed angular momentum of WD.

The evolution of rotating massive single stars (with main sequence masses $8\,M_{\odot} < M < 25\,M_{\odot}$) of solar composition was studied by A. Heger together with N. Langer (Univ. Potsdam) and S.E. Woosley (UCSC/Lick Observatory, Santa Cruz and MPA). The late evolutionary stages of rotating massive stars were investigated and pre-core collapse models for type IIa and type Ib/c supernovae were obtained. These models predict that rotation might become dynamically important in the supernova explosion. The stellar evolution was followed from the main-sequence until the onset of core-collapse and, for the first time, the nucleosynthesis in rotating massive stars was traced with a large nuclear reaction network. – A. MacFadyen and S.E. Woosley (Univ. of California, Santa Cruz) continued their study of convective oxygen burning in massive stars by means of direct numerical simulations, based on SPH and finite volume codes.

The clump of stars on the red giant branch of colour-magnitude-diagrams was studied by L. Girardi, in collaboration with M.A.T. Groenewegen, A. Weiss and M. Salaris (MPA and Liverpool John Moores University, England). They simulated synthetic colour-magnitude-diagrams of galaxy fields, derived from improved grids of evolutionary tracks for core helium burning stars. It turns out that the clump should have fine structure, with features such as a faint secondary clump and a bright plume of stars. The former feature was identified in the colour-magnitude diagram of nearby stars obtained from the HIPPARCOS data. Moreover, they find that the mean luminosity of clump stars depends on the history of star formation and chemical enrichment of the parent galaxy. Therefore, the mean magnitude of the red clump cannot be considered as a standard candle for measuring the distances to Local Group galaxies. L. Girardi also studied the characteristics of the faint secondary clump in the colour-magnitude-diagram of different galaxies, and discussed the constraints to the star formation history of the Magellanic Clouds which could be provided by this fine structure of the red clump.

M. Groenewegen's work concentrated mostly on analyses of molecular data. With T. de Jong (SRON, Utrecht) he took molecular CO data of a sample of S-stars. From all previously published molecular data on S-stars the mass loss rate was determined and plotted – along with other quantities – as a function of pulsation period. The S-Miras do not stand out in any way from the O-rich and C-rich Miras. However, the S-star SR-variables seem to pulsate in a higher order pulsation mode compared to the Miras. – With W.E.C.J. van der Veen (Columbia University) and H.E. Matthews (JCMT, Hawaii) the molecular radiative transfer code of M. Groenewegen was used to analyse all existing molecular CO data of the well-known carbon star IRC +10 216. Combining this with the results of previous analyses of the circumstellar dust shell, they derived values for the star's distance and mass loss rate. With H.-G. Ludwig (Copenhagen) M. Groenewegen mapped the circumstellar CO shell around the same star at high velocity resolution. This has revealed for the first time the presence of a non-spherically symmetric component in the molecular shell. – Finally, he analysed, with R.D. Oudmaijer (Imperial College) and H. Schrijver (SRON, Utrecht) the absolute magnitude of K0V stars from HIPPARCOS parallaxes. The results are: (a) the presence of Malmquist bias, (b) about 20% of the stars classified as K0V in the 'Michigan Spectral Survey' actually have the absolute magnitude expected for K0IV stars, and likely have been misclassified, (c) an absolute magnitude for K0V stars of 5.7, which is 0.2 mag brighter than adopted in the pre-Hipparcos era.

Nuclear burning of hydrogen at the base of the convective envelope of the most massive Aymptotic Giant Branch (AGB) stars causes a deviation from the core-mass luminosity relation. P. Marigo included this effect in synthetic AGB calculations, and compared the results with those found in complete evolutionary models. The agreement turned out to be remarkably good. Synthetic models for AGB stars of different masses were then computed. Making use of her improved synthetic evolutionary models of AGB stars, P. Marigo studied the carbon star luminosity functions in the Magellanic Clouds, in collaboration with L. Girardi and A. Bressan (Padua Observatory, Italy). A new scheme for predicting the onset and switch-off of the third dredge-up episodes was proposed. The factors which give origin to the shape of the observed luminosity functions were investigated. It could be shown that these functions in both the Large and Small Magellanic Cloud could be fitted well by models with an almost constant star formation rate, and with only small changes in the parameters which describe the dredge-up. The large differences in the luminosity functions between the two galaxies can be understood as resulting mainly from their different mean metallicities. As a final aspect of synthetic AGB evolution, P. Marigo, L. Girardi, A. Weiss and M. Groenewegen critically investigated the recently published claim that the core mass-luminosity-relation is invalidated by deep dredge-up on the AGB. They clarified in particular that the relations used in synthetic calculations already include several effects (first pulses, hot bottom burning, composition changes), which lead to a deviation from the classical linear relation. The luminosity evolution observed in the deep dredge-up calculations can perhaps be understood in terms of a combination of these already known effects.

In collaboration with T. Faestermann (TUM, Garching), P. Kienle (TUM, Garching) and N. Langer (Univ. Potsdam), K. Takahashi continued to update Re/Os nucleo-cosmochronometry in the framework of a model of chemical evolution in the solar neighborhood. With the use of most recent observational constraints, experimental data on nuclear β-decays of fully-ionized ^{187}Re, meteoritic abundances of the concerned isotopes and stellar evolution models in the $(1 \sim 60)$ $M_\odot$ mass range, the chronometry set a lower limit of the age of the Galactic disk to be $(12 \sim 17) \times 10^9$ years.

3.3 Supernovae and nucleosynthesis

H. Spruit (with E.S. Phinney, Caltech) studied the internal rotation of giant stars and found that their cores are likely to corotate approximately with their envelopes. As a result, there is too little angular momentum in a pre-supernova core to explain the rotation of pulsars. Instead, the kick process that gives pulsars their space motion is a plausible cause of their rotation.

Explosive oxygen burning and Rayleigh-Taylor instabilities in the stellar envelope triggered by the aspherical shock wave resulting from neutrino driven non-spherical core collapse supernovae have been studied in a Ph.D. thesis by K. Kifonidis, supervised by E. Müller, and in collaboration with T. Plewa (Nicolaus Copernicus Center, Warsaw) and H.-T. Janka (MPA). The two dimensional simulations require locally fine resolution in a large spatial domain, which is obtained by using the adaptive mesh refinement (AMR) technique. Because of nuclear burning and mixing the spatial distributions of various isotopic species have to be followed in detail. For this purpose the consistent multi-fluid advection (CMA) method was implemented into the PROMETHEUS hydrodynamic code used for the 2D simulations. The computational grid covers the whole supernova progenitor (a 20 solar mass blue giant with a radius of $3\,10^{12}$ cm) except for the innermost 1000 km, which are not treated in the simulations. A simplified description for the neutrino wind from the proto-neutron star was implemented, which provides the time-dependent boundary condition at the inner grid boundary.

W. Keil and H.-Th. Janka continued their 2D simulations of convection in nascent neutron stars. Together with S. Yamada (Univ. of Tokyo) they studied the effects of a reduction of the neutrino opacities due to many-body correlations and multiple-scatterings between nucleons in the dense nuclear medium.

H. Dimmelmeier has begun a Ph.D. project supervised by E. Müller to investigate general relativistic, axisymmetric, rotational core collapse. The aim of the thesis is to simulate the collapse of polytropes in two spatial dimensions within the framework of the Wilson approximation to GR, i.e. integrating the GR hydrodynamic equations together with the Einstein field equations within the (3+1) ADM formalism and describing the curvature of the three-geometry by a position-dependent conformal factor times a flat-space Kronecker delta (conformally flat gauge condition).

The formation of the inner ring of SN 1987A remained a controversial subject. F. Meyer showed that early breakthrough of ionization and heating in the lower density polar regions of the originally cool red supergiant wind that is irradiated from the inside by the ionizing flux of the subsequent blue supergiant stage of the SN 1987A progenitor leads to compression of still unionized higher density equatorial regions into a thin equatorial inner ring and naturally explains the location, speed, extent, density and mass of the inner ring, well inside the outer ring system.

S. Hardy examined the consequences of the increased effective mass of electrons in the center of a core-collapse supernova. An electron in the core of a supernova behaves as if its mass is much larger than it is in a vacuum. In the densest parts of the collapsing star this increase may be more than a factor of twenty. This leads to important consequences, such as a reduction in the opacity of the dense core material to the transport of antineutrinos.

H.-Th. Janka and G. Raffelt (MPI Physik, Freimann) investigated the effects of strong magnetic fields on possible neutrino oscillations in the atmospheres of newly formed neutron stars. They could show analytically that the observed fast motions of pulsars cannot be explained by models which postulate anisotropies of the neutrino emission as a consequence of neutrinospheric deformations caused by the field dependence of the neutrino oscillations.

A nuclear reaction network for studies of nucleosynthesis in supernova explosions was developed by I.V. Panov (ITEP, Moscow), enabling the computation of the nucleosynthesis of heavy elements by neutron captures and β-decays (the r-process) along with that of lighter elements via charged-particle induced reactions. Still existing uncertainties of various nuclear reactions were also considered.

K. Knie, G. Korschinek (TU München), T. Faestermann (TU München), C. Wallner (TU München), J. Scholten (Univ. Kiel) and W. Hillebrandt have searched for radioactive ^{60}Fe in deep ocean sediments and have found traces in sediments from the South Pacific which are approximately 4 to 6 million years old. This discovery indicates that at about this time a supernova exploded near to the solar system within a distance of less than 20 pc. Consequences of this interpretation of the data are under investigation.

Y. Mochizuki (RIKEN, Japan), K. Takahashi, H.-Th. Janka, W. Hillebrandt and R. Diehl (MPE, Garching) investigated whether the delayed decay of ionized ^{44}Ti can have an observable effect on the ^{44}Ti radioactivity of young supernova remnants. They found that the COMPTEL measurement of the 1.16 MeV line activity in Cas-A and the supernova model predictions of the ^{44}Ti abundance are in better agreement if ^{44}Ti was present in dense clumps where it could be ionized by the reverse shock during an early phase of the remnant evolution.

M. Lisewski uses the so-called "one dimensional turbulence" model of A. Kerstein to investigate statistical properties of nuclear flames in the distributed regime. This work, a thesis supervised by W. Hillebrandt, is carried out in collaboration with S.E. Woosley (Univ. of California, Santa Cruz) and J.C. Niemeyer (MPA and Univ. of Chicago). First results show that the model is indeed capable of reproducing observed properties of highly turbulent flames. They also indicate that the transition from a deflagration to a detonation in type Ia supernovae is not likely to happen.

S.I. Blinnikov and V.P. Utrobin (ITEP, Moscow) have continued their work on supernova light curves and spectra, using a novel radiation hydrodynamic code. N. Dunina-Barkovskaya (ITEP, Moscow), S.I. Blinnikov and V.S. Imshennik (ITEP, Moscow) investigated the URCA-process during the ignition of carbon-burning in degenerate C+O white dwarfs. They could calculate the initial conditions for the thermonuclear runaway by means of a non-adiabatic one-dimensional model of convection.

M. Reinecke, in a diploma-thesis supervised by W. Hillebrandt, has used a novel front-tracking scheme in type Ia supernova simulations. This method, a level-set scheme which allows the reconstruction of thermodynamic quantities ahead and behind the burning front, was developed in collaboration with R. Klein (Humboldt-Univ., Berlin) and J.C. Niemeyer (MPA and U. Chicago) and could, for the first time, resolve structures in the front down to the grid scale. However, the acceleration of the front due to its increased surface area was still insufficient for a fast deflagration and the models do not resemble typical type Ia supernovae. Possible solutions of this problem include the still unknown turbulence spectrum, additional sources of turbulent kinetic energy, such as rotation, and/or active turbulence. These questions are investigated by M. Reinecke in his doctoral thesis.

Bolometric light curves of Type Ia supernovae have been constructed in a Ph.D. thesis by G. Contardo, supervised by E. Müller and B. Leibundgut (ESO), in collaboration with W.D. Vacca (Univ. of Hawaii). The bolometric light curves have been fitted with a descriptive model using observational data from the *UBVIR* filter bands for a set of (up to now) nine well observed type Ia supernovae. Fitting light curves with a descriptive model has the advantage over template methods that it is ideally suited to explore the variety among type Ia supernovae and that it provides a way to look for correlations. The results show that the shapes of the bolometric light curve of individual type Ia supernovae vary significantly and that the secondary maximum observed in the R and I light curves shows up with varying strength in the bolometric light curves, too. The variety of the light curve shapes indicates subtle variations in the energy release of these explosions.

3.4 Close binaries and accretion

U. Anzer, G. Börner, T. Matsuda (Kobe University), E. Shima (Kawasaki Heavy Industries) and H.M.J. Boffin (Royal Observatory of Belgium) completed their numerical study of 2 dimensional isothermal wind accretion flows.

F. Meyer and E. Meyer-Hofmeister investigated the evolution of accretion disks in close binaries in connection with evaporation of matter into a hot corona above the innermost disk. Implications for X-ray novae were studied in collaboration with S. Mineshige (Kyoto Univ.), while F. Meyer examined the applicability of this process to black hole sources. E. Meyer-hofmeister computed the evolution of the disk in the black hole transient system A0620-00 in connection with the feeding of an advection dominated accretion flow (ADAF) near the hole. A study of WZ Sge showed that the viscosity is extremely low in the late stages of evolution of cataclysmic variables (CV). Consequences for the CV population and X-rays expected are investigated together with H. Ritter and U. Kolb (Univ. of Leicester). The low viscosity can be understood as related to the transition of the secondary star from a magnetic low-mass star to a cool brown dwarf without magnetic activity (F. Meyer, E. Meyer-Hofmeister). F. Meyer and E. Meyer-Hofmeister continued the collaboration with V. Suleimanov (Kazan State Univ.) on the reprocessing of soft X-rays in supersoft X-ray sources.

H. Ritter and R. Stehle (Univ. of Leicester) studied the long–term chemical evolution of the donor stars of cataclysmic binaries which are repeatedly polluted by intercepting a fraction of the heavy element–enriched nova ejecta. The effects of pollution are of minor importance for donor stars with a Pop. I initial chemical composition. In contrast, the metal abundances of donor stars with an initial Pop. II composition are significantly changed by the nova ejecta, even if the effective cross section for interception of the ejecta by the donor is much smaller than the geometrical one. In addition, the initial large change of the metallicity in Pop. II donors leads to a significant thermal readjustment of the star, which in turn gives rise to a phase of increased mass transfer.

H. Ritter and A.R. King (Univ. of Leicester) examined possible evolutionary states for the donor star in the low–mass X–ray binary Cygnus X–2. The donor star must be in the final phases of mass transfer following an early massive Case B binary evolution. The current parameters of Cygnus X–2 require that the neutron star ejected essentially all the matter transferred to it at super–Eddington rates. Cygnus X–2 is the prototype of an evolution which ends with the formation of binary millisecond pulsar systems with short orbital periods and a relatively massive white dwarf companion.

H. Ritter examined which properties mass transfer cycles in cataclysmic binaries must have in order to be compatible with observational facts, and found that the product $A\ d$ of amplitude A and duty cycle d must be smaller than unity. Irradiation–driven mass transfer cycles, however, are characterized by $A\ d \gg 1$, hence cannot account for the long–term mass transfer variations suspected to occur among cataclysmic variables.

Based on power–law approximations for the core–mass luminosity and the core–mass radius relation for stars on the first giant branch, H. Ritter derived complete analytical solutions for the evolution of a close binary with nuclear time–scale–driven mass transfer from a giant donor star.

I. Barraffe (Centre de Recherche Astrophysique, Lyon) and U. Kolb computed the long–term evolution of cataclysmic binaries with a nuclear evolved donor star as a function of mass transfer rate, in an attempt to account for the discrepancy between the observed spectral type and that expected from the donor's mass. A consistent picture as to why the observed spectral types are on average too late did not yet emerge.

H. Spruit showed how gamma-ray bursts (GRB) can be produced in X-ray binaries. The rapidly spinning neutron loses angular momentum by r-mode gravitational wave instability and winds up the weak initial magnetic field to an azimuthal field of 10^{17}G. This strong field breaks through the surface by buoyancy instability and powers a GRB as in the model by Kluzniak and Ruderman.

H. Spruit and V. Joergens analysed high resolution WHT spectra of the cataclysmic variable EX Dra in outburst. The Doppler maps show the pattern characteristic of spiral shocks previously seen by Steeghs and Horne in an outburst of IP Peg. Spiral shocks may be a common feature in the disks of CV's in outburst.

B. Deufel started research for a PhD degree under supervision of H. Spruit on theoretical models for X-ray spectra and time variability in X-ray binaries.

G. Ogilvie started as postdoc in the TMR network 'Accretion onto black holes...' . He considered the fluid dynamics of differentially rotating, quasi-spherical accretion flows in which the heat generated by viscous dissipation is retained in the fluid. The time-dependent problem was studied within a simplified one-dimensional model. A similarity solution of finite size was obtained, which is expected to describe the asymptotic evolution of the system. Even in the important but singular limit of an adiabatic exponent of 5/3, the flow is differentially rotating and does not reduce to Bondi's solution for spherical accretion.

Investigations of newly discovered Polars were continued by H.-C. Thomas in collaboration with K. Beuermann and K. Reinsch (Univ. Göttingen), V. Burwitz (MPE), and A.S. Schwope (AIP, Potsdam). They mainly focused on two long-period systems (RX J020348.7+295921, period 275 min, RX J131317.1-325909, period 251 min) and one system in the period gap (RX J050146.2-035927, period 171 min).

R. Popham, in collaboration with S. Woosley (UC Santa Cruz) and C. Fryer (UC Santa Cruz), studied black holes accreting at rates of 0.01 to 10 solar masses per second, which may serve as the central engines for gamma-ray bursts. For rapidly spinning black holes, the resulting accretion disk is cooled by neutrino emission from the hot, dense inner region, producing neutrino luminosities of $10^{51} - 10^{53}$ ergs/s. Neutrino-antineutrino annihilation in the low-density region near the rotation axis can then produce the pair fireball which is believed to result in a gamma-ray burst.

The relativistic outflow occurring in the collapsar model for gamma-ray bursts has been studied by means of two-dimensional special relativistic hydrodynamic simulations by M.A. Aloy, J.Mª. Martí, José Mª. Ibáñez (all Univ. Valencia, Spain) and E. Müller in collaboration with A. MacFadyen and S.E. Woosley (both UC Santa Cruz, USA). In the collapsar model the core of a massive rapidly rotating star collapses to a Kerr black hole. The stellar envelope forms a thick accretion torus before being accreted by the central black hole. A large fraction of the energy liberated during the accretion of the envelope via viscous heating near the inner edge of the accretion torus is converted into neutrino anti-neutrino pairs which then are thought to annihilate predominantly in a narrow region near the rotation axis. Previous Newtonian simulations indicated that the localized enormous energy deposition might drive a relativistic collimated outflow. This was confirmed by axisymmetric simulations with the relativistic hydrodynamic code GENESIS. The simulations show the formation of highly collimated outflows with Lorentz factors of up to 20 at the time when the jet reaches the stellar surface.

R. Popham proposed that the dwarf nova oscillations observed in cataclysmic variables and the kilohertz quasi-periodic oscillations in low-mass X-ray binaries are fundamentally the same, based on their periods (similar to the Keplerian rotation period at the stellar surface) and similar amplitudes, coherences, and variations in period. He also proposed that the oscillations are produced by a rotating bulge or hot spot located at the interface between the optically thick disk and the optically thin boundary layer.

R. Sunyaev, E. Churazov, M. Gilfanov, S. Kuznetsov, M. Revnivtsev, S. Trudolyubov (IKI) and the GRANAT/SIGMA team (IKI; CESR, Toulouse; CEA, Saclay) studied hard X-ray data of a number of black hole candidates. Long term monitoring of GRS1758-258 and 1E1740.7-2942 shows that their light curves are remarkably different from most of the other galactic black hole candidates (known to be transient sources). They may represent a special class of accreting black hole binaries. From timing and spectral analysis of RXTE data on the galactic superluminal source GRS1915+105 a clear correlation of the quasi periodic oscillation frequency with the parameters of the soft emission component was established.

M. Gilfanov, in collaboration with R. Burenin (IKI), A. Vikhlinin (CfA), E. Churazov and R. Sunyaev studied a soft gamma–ray afterglow observed by GRANAT/SIGMA immediately ($\sim 10^3$ sec) after GRB920723. A simple fireball model encounters certain difficulties in explaining the early stages of gamma–ray burst afterglows.

M. Gilfanov, in collaboration with M. Revnivtsev (IKI), E. Churazov and R. Sunyaev studied ASCA observations of X-ray bursters. In their low spectral states, the optically thick part of the accretion disk does not approach the compact object closer than $R_{disk} \sim 10 - 30 R_g$. The characteristic temperature in the inner part ($R < 20 R_g$) of the accretion flow, including the boundary layer exceeds ~ 2 keV, independent of the assumed density of the matter. Electron scattering is the dominant contribution to the opacity. Studying the millisecond X–ray pulsar/burster SAX J1808.4-3658 (RXTE data) they found that the spectrum of the source was remarkably stable as the luminosity changed by a factor of ~ 100. They suggest Comptonization on the bulk motion in radiation dominated shocks as the formation mechanism of the spectrum. An upper limit on the magnetic field $B \lesssim$ few $\times 10^7$ Gauss has been obtained from the shape of the X–ray light curve. Broad band spectral and temporal properties of several black hole binaries (GRS1915+105, XTE1755–324 etc.) have been studied using RXTE, ASCA and GRANAT/SIGMA data.

A. Emelyanov (Moscow Institute of Physics and Technology, Dolgoprudny) studied the properties of the newly discovered soft X-ray transient XTE J1806-246 using results from the Rossi X-ray Timing Explorer (RXTE) (under the supervision of R. Sunyaev).

N. Inogamov (Landau Institute of Theoretical Physics, Chernogolovka) and R. Sunyaev studied the process of spreading of matter from an accretion disk over the surface of the neutron star.

S. Molkov and S. Grebenev (IKI) investigated the behavior of the LMXB system GX3+1 using spectroscopic observations with the telescope ART-P on GRANAT in the Fall of 1990. They have started an analysis of RXTE observations as part of an ongoing study of the Z-source GX340+0.

N. Sibgatullin (Moscow State University) and R. Sunyaev analyzed the effect of the quadrupole component in the mass distribution of a rapidly rotating neutron star on the energy release in the boundary layer on the surface of the accreting star and in the accretion disk. They calculated the velocities and trajectories of the particles that fall on the stellar surface from the marginally stable orbit for a low-luminosity accreting source. The corresponding external gravitational field of the star is modeled by a new exact solution of the Einstein equations in vacuum. The parameters of this solution are adjusted by reconciling the numerical data for the radius of the marginally stable orbit with the gravitational redshift measurements of Cook et al. (1994).

A. Kercek, in a thesis supervised by W. Hillebrandt and in collaboration with J.W. Truran (Univ. of Chicago), has performed 2- and 3-dimensional numerical simulations of thermonuclear burning of hydrogen-rich matter accreted onto a white dwarf. One of the aims of the study was to explain the mixing of carbon and oxygen into the hydrogen layer which is observed in classical nova outbursts. However, in none of the simulations, including one in which C and O were enriched relative to their solar abundances by a factor of five prior to the outburst, a fast nova was obtained, possibly because the accreted envelope of the white dwarf did not have enough mass. Alternative initial conditions are under investigation.

The interaction of (one of) the precessing, mildly relativistic twin jets of the binary system SS433 located within the supernova remnant W50 with the supernova remnant has been investigated by O. Stranner in a diploma thesis, supervised by E. Müller, and in collaboration with W. Brinkmann (MPE). The supernova remnant has been modeled as a geometrically thin, dense spherical gas shell. The interaction has been simulated with a three dimensional version of the PPM based hydrodynamic code PROMETHEUS parallelized for shared memory machines. The outcome of the interaction depends sensitively on the surface density of the supernova remnant. While the jet drills a hole through a remnant with a small surface density, jet matter accumulates in front of a remnant with a higher surface density. In the latter case a large part of the supernova remnant is eventually accelerated. The simulations predict a strongly enhanced X-ray luminosity during the interaction, and an X-ray spectrum exhibiting dominant iron Lyman lines, as observed in SS433/W50.

M. Ruffert (Univ. of Edinburgh) and H.-Th. Janka modeled the accretion phase of the black hole that forms after the merging of two neutron stars and studied the possibility to explain gamma-ray bursts by the annihilation of neutrinos and antineutrinos emitted from the accretion disk. In his Diploma thesis, supervised by H.-Th. Janka and M. Ruffert in collaboration with C. Fryer (UC Santa Cruz), T. Eberl extended these investigations by simulating the merging of neutron star black hole binaries. The results suggest that mergers of binary neutron stars might be the source of short, weak gamma-ray bursts, whereas neutron star black hole binaries might account for longer and more energetic events.

The variability of GRB sources on time scales $\sim$ 100–1000 s was studied by R. Burenin (Space Research Institute, Moscow), M. Gilfanov, R. Sunyaev and O. Terekhov (Space Research Institute, Moscow). A power-law soft gamma-ray afterglow of the bright GRB 920723 was found in GRANAT/SIGMA data. It is the first convincing observation of an afterglow immediately after a GRB. The power law slope of the afterglow light curve appears to be too flat to be consistent with the last stage of the evolution of a relativistic fireball. The investigation of the long-term variability of fainter GRB's observed by GRANAT/SIGMA is in progress.

A. Tkachenko and O. Terekhov analyzed observations of the soft gamma-ray ($100-500$ keV) afterglows of the two brightest GRBs detected by the PHEBUS instrument aboard GRANAT: 910402 and 920723. The light curves of the main events make a smooth transition into the afterglows with fading fluxes. The best-fit power law indices are -0.74 ± 0.07 for the first $\sim$700 s after GRB 920723 and -1.07 ± 0.17 for the first $\sim$500 s after GRB 910402. In the case of GRB 920723, the data strongly favor a power-law flux decay against an exponential one.

3.5 The Galaxy, external galaxies, and Active Galactic Nuclei

A. Helmi (Leiden) and S.D.M. White made models for the formation of the stellar bulge of the Milky Way through the disruption of smaller units, 'satellite galaxies'. They showed how the debris from a single disrupted system spreads out in position and velocity within the stellar halo. At the present time, most disrupted satellites will no longer be visible as well defined streams of stars in configuration space. In velocity space, however, stars from each satellite will be confined to a relatively small number of kinematically cold streams. A rough estimate suggests that the stellar halo in the solar neighborhood could be made up entirely of a few hundred such streams each with an internal velocity dispersion of a few km/s.

V. Springel and S.D.M. White studied how the ability of colliding disk galaxies to make extended tidal tails is influenced by the structure of the dark matter halos in which they are embedded. In particular, they studied whether halos with the 'universal' structure predicted in CDM-type cosmogonies would allow the formation of tidal tails, and, if so, for which cosmological parameters. They concluded that tail formation should be possible for most disk galaxies in models of this type, and furthermore that different cosmologies differ very little in their tail-making ability. Observed tidal tails cannot therefore be used to place useful constraints on cosmological parameters (for example, Ω_0) within the CDM family of models.

C.R. Kaiser in collaboration with A.P. Schoenmakers (Utrecht University) and H.J.A. Röttgering (Sterrewacht Leiden) investigated the evolution of so-called Double-Double Radio Galaxies (DDRGs). These objects consist of two unequally sized but aligned pairs of radio lobes which have a common radio core and host galaxy. It was shown that the peculiar radio structure of DDRGs must be caused by a disruption of the jet flow. The subsequent restart of the jet and the development of the inner source structure indicates that cold, dense clouds embedded in the surrounding IGM must have passed into the outer cocoon. This has important implications for the extended optical emission observed in powerful radio galaxies.

In collaboration with X.-Y. Xia (Tianjin Normal Univ.), H. Wu, Z.-G. Deng, Z.-L. Zou (Beijing Astronomical Obs.) and Th. Boller (MPE), S. Mao studied the optical and X-ray properties of the ultra-luminous IRAS galaxy 10026+4347, and found that this post-merger galaxy is a unique narrow-line QSO with very strong FeII emission. The object has a very high X-ray luminosity ($L_X \approx 10^{45}$erg s^{-1}) with a soft X-ray spectrum (photon index ≈ 3.2). The X-ray luminosity exhibits variabilities of a factor of eight over four years and a factor of two within two days. All the optical and X-ray properties resemble those of narrow-line Seyfert 1 galaxies, except that the full width at half maximum of Hβ (~ 2500km s^{-1}) is larger than that for most narrow-line Seyfert 1 galaxies.

A complete count-rate limited sample of 397 soft high-galactic latitude X-ray sources from the ROSAT All-Sky Survey has been spectroscopically identified by H.-C. Thomas in collaboration with K. Beuermann and K. Reinsch (Univ. Göttingen), A.S. Schwope (AIP, Potsdam), J. Trümper and W. Voges (MPE). Further identifications for 75 fainter sources were collected by the same collaboration. The special properties of the AGN in this sample were studied by D. Grupe (MPE), K. Beuermann and K. Mannheim (Univ. Göttingen) together with H.-C. Thomas.

3.6 Gravitational lensing

S. Mao, in collaboration with J. Reetz and D. Lennon (Universitäts-Sternwarte, Munich) proposed a new method to detect luminous gravitational lenses in the ongoing microlensing experiments using medium and high resolution spectroscopy ($\lambda/\Delta\lambda > 6000$). This method is based on the fact that the radial velocity of the lens and lensed source typically differs by ~ 100 km s^{-1} and so the spectral lines from the lens and source will be shifted relative to each other by $(1-2)$Å in the optical. Using a differential correlation technique, they found that it is possible to detect the presence of the lens at a brightness of $\sim 3\%$ of the source, with high-resolution spectrographs available on a 8-10m class telescope such as VLT.

S. Mao and H. Witt (AIP, Potsdam) studied extended source size effects in astrometric microlensing, where the centroid motions of microlensed images are monitored. They obtained analytical expressions for the centroid motion for a source with limb-darkening profile. They found that when the impact parameter is comparable to the source radius, the centroid motion is significantly modified by the finite source size. In particular, when the impact parameter is smaller than the source radius, the trajectories become clover-leaf like. Such astrometric motions can be detected using space interferometers such as the Space Interferometry Mission. This offers exciting possibilities of determining stellar radii to a few percent accuracy.

M. Bartelmann and P. Schneider continued their work on an extended review on weak gravitational lensing, which nears completion; it will provide a thorough and timely overview of the present status of this quickly developing field.

Together with Y. Mellier (IAP), L. van Waerbeke (CITA) and S. Seitz (USM), P. Schneider and T. Erben have investigated the weak gravitational lens effect in the cluster Abell 1942. Using three different data sets, all very deep and with superb seeing, they have reconstructed the surface mass density of this cluster, using different methods of image analysis, reconstruction algorithms, and the various data sets, to test the stability of the results. The surprisingly good agreement of all reconstructed mass maps demonstrates the reliability of weak lensing mass reconstructions. It was found that the cluster core consists of two massive clumps, only one of which is associated with bright cluster galaxies, so that these two clumps must have a vastly different mass-to-light ratio. In addition, these wide-field images were used to search for (dark) mass concentrations, using the aperture mass method. At least one mass concentration, in addition to the cluster, was found, with a significance larger than 99.99%, and without any obvious galaxy concentration.

To detect the weak lensing effect, and to measure the statistical mass properties of cluster galaxies, B. Geiger and P. Schneider have developed a method to simultaneously account for the shear effect of the cluster as a whole, and the individual cluster galaxies. This method is a combination of an entropy-regularized maximum-likelihood cluster reconstruction algorithm with galaxy-galaxy lensing techniques. After thorough testing on synthetic data, this method was applied to HST data of the cluster Cl0939+4713. The mass profile of this cluster was obtained, as well as an estimate for the characteristic velocity dispersion and size of the dark halo of elliptical cluster galaxies. The combination of several such cluster data sets will allow one to test whether the halos of cluster galaxies have been reduced by stripping, relative to those of field galaxies.

In preparation for the future mission of the Next Generation Space Telescope, P. Schneider and J.-P. Kneib (OMP) have obtained predictions for weak lensing studies with extremely deep images. They pointed out that NGST will be able to measure with high precision the mass properties of high-redshift galaxies, detect and quantitatively analyze the mass profiles of clusters at high redshift $z \sim 3$, and that of low-mass groups at medium redshifts. Together with the huge number of arcs that can be detected in every massive medium-redshift cluster, the mass profile of these clusters will be determined with extreme precisions, as demonstrated by simulations.

Several projects related to cosmic shear, the distortion effect due to light propagation through an inhomogeneous Universe, have been performed. Using very large N-body simulations, B. Jain (JHU), U. Seljak and S.D.M. White have studied the light propagation through the resulting three-dimensional mass distribution. They verified the previously assumed smallness of non-scalar components of the shear. The results for the rms shear are in good agreement with analytical results, but higher-order moments of the shear distribution can deviate significantly from perturbation theory predictions. Several techniques for estimating Ω_0 were investigated on the simulation data, suggesting that Ω_0 can be determined to within 0.1 - 0.2 from a deep survey of several square degrees. With P. Schneider, M. Bartelmann showed that one particular measure for cosmic shear, the so-called aperture mass, provides a direct measure for the power spectrum of projected matter. The matter power spectrum therefore becomes an observable quantity.

Longer-term projects for the measurement of the gravitational lens action of the large-scale matter distribution in the Universe (cosmic shear) were continued. On the one hand, observations in the frame of an ESO Key Program were carried out; basically none of the observations scheduled for service observing have been delivered, and half of the run in Oct./Nov. 1998 failed because of unfavourable weather conditions. The three nights of useful data are being analyzed. This project is a collaboration between Y. Mellier (IAP), F. Bernardeau (IAP), B. Fort (IAP), W. Freudling (ESO), B. Jain, F. Moali (IAP), P. Schneider, S. Seitz (USM), L. van Waerbeke (CITA), and S.D.M. White. On the other hand, in a collaboration between L. Collodel (ST-ECF), S. Seitz (USM), N. Pirzkal (ST-ECF), T. Erben, W. Freudling (ST-ECF), P. Schneider, R. Fosbury (ST-ECF) and S.D.M. White, HST-STIS parallel data were analyzed with respect to cosmic shear. Careful co-addition of images, and detailed investigations of the point spread function of the parallel images have been performed, and new methods for the determination of the PSF been developed. A first set of 17 images have been analyzed, and a very marginal detection of cosmic shear was obtained; although this result is not significant yet, large values of an rms cosmic shear can already be excluded: from comparison with theoretical models, a COBE-normalized standard CDM universe, for which an rms shear of $\sim 7\%$ would be predicted on the scale of STIS images, can be ruled out.

G. Kruse and P. Schneider have estimated the number of mass concentrations which one expects to find using the aperture mass method. For this, they have combined the number density of halos as obtained from the Press-Schechter formalism with the 'universal' density profile found by Navarro, Frenk and White, to calculate the number density of halos with an aperture mass greater than a given threshold. For deep ground based images, used for measuring the shear via the galaxy ellipticities, they found that one expects at least 10 halos per square degree with a signal-to-noise ratio of larger than 5, whereby this number is strongly dependent on cosmology: for cluster-normalized models, a standard Cold Dark Matter universe yields less than half the number of mass-selected halos of low density models. These analytical predictions were verified by K. Reblinsky, G. Kruse, B. Jain (JHU) and P. Schneider, by applying the aperture mass method to the results of the aforementioned ray-tracing simulations through a cosmological matter distribution. Whereas there are small differences between the analytical results and those obtained numerically, the overall agreement is better than one could have hoped for, and verifies the strong dependence on cosmological parameters of the expected abundance of halos to be seen by the aperture mass method.

As part of her Ph.D. thesis with M. Bartelmann, K. Reblinsky investigated projection effects in mass-selected galaxy-cluster samples. Selection of clusters by mass is possible through the weak lensing effect. Mass-selected cluster samples are significantly more reliable in terms of completeness and lack of spurious detections than optically selected ones, and their masses are determined with a relative accuracy of $\approx$ 30%.

Gravitational lensing of the cosmic microwave background (CMB) has been studied by U. Seljak in collaboration with M. Zaldarriaga (IAS, Princeton). It was shown that lensing induces distortions in the CMB that can be used to study the dark matter distribution on very large scales. Combinations of products of derivatives of the CMB can be used as estimators of the projected density field. This method has sufficient signal to noise to be directly observed with the upcoming Planck Surveyor satellite and will provide a measurement of the projected dark matter density power spectrum from 0.1 to 10 degree scales. Cross-correlation of the reconstructed density with the CMB itself should give positive detection whenever there is a time-dependent gravitational potential. This information will further increase the accuracy of the determination of cosmological parameters from CMB measurements.

3.7 Clusters of galaxies and large scale structure

As part of his Ph.D. thesis with M. Bartelmann, K. Dolag performed cosmological magnetohydrodynamical simulations of galaxy clusters to study the evolution of intracluster magnetic fields. The main results were that shear flows in the intracluster gas amplify the magnetic field by about an order of magnitude, that Faraday-rotation measurements in clusters can well be reproduced assuming an initial magnetic field of 10^{-9} G *rms* strength at redshift 15, and that the structure of the initial field is largely irrelevant for the final field structure in clusters.

S. Sazonov (Space Research Institute, Russian Academy of Sciences, Moscow) and R. Sunyaev implemented a relativistic treatment of the spectral effects that arise during the passage of the cosmic microwave background radiation through intracluster gas due to chaotic motion of electrons (thermal effect) and due to the proper motion of a galaxy cluster (kinematic effect). Using Monte Carlo simulations they (i) confirmed the existence of the previously proposed relativistic corrections to the thermal effect of the $(kT_e/m_ec^2)^n$ form, and (ii) provided evidence for the presence of additional corrections related to the cluster peculiar motion. The most important correction is proportional to the radial component of the cluster velocity and the temperature of the gas ($V_r/c \times kT_e/m_ec^2$). An exact analytical expression that describes this correction was derived. The newly found effect is important for future spectral measurements of the cosmic microwave background with experiments like PLANCK.

E.Churazov, M.Gilfanov, Forman (CFA), C.Jones (CFA), H.Donnelly (CFA) studied the gas temperature distribution in several clusters of galaxies using ROSAT and ASCA data. In the case of the Coma cluster moderate temperature variations were interpreted as an evidence for an ongoing merger. Analysis of the central part (few arcminutes) of the Perseus cluster revealed significant asymmetric structures suggesting complex interactions between the dominant galaxy NGC 1275 and ambient cluster gas.

M. Pavlinskii developed an improved method for the analysis of extended sources with a coated mask imaging X-ray telescopes, which has allowed him to construct a map of the Virgo Cluster diffuse X-ray emission in the $3-30$ keV energy range using the data of the ART-P instrument.

Together with a large group of scientists from ESO, T. Erben participated in the ESO Imaging Survey (EIS), which consists of two parts: EIS-Wide, carried out with the EMMI instrument on the ESO-NTT, mapped 4 patches of the sky (a total of $\sim$ 18 sq. degrees) in the I-band, with 1.5 square degrees in two additional bands (B and V). This part of the survey was intended mainly to find high-redshift clusters, and more than 200 cluster candidates have been identified, some of them at redshifts $z \sim 1$; in addition, the multi-color part of the survey allowed for selecting QSO and brown dwarf candidates. EIS-Deep mapped two regions of the sky with the SUSI2 and SOFI instruments on the ESO-NTT, one of them centered on the Hubble Deep Field-South, the other on the AXAF Deep Field; these multi-color data are intended mainly for selecting targets for VLT spectroscopy and for estimating photometric redshifts in these fields. The raw and reduced data of this survey, together with derived products such as objects lists, cluster candidates etc. have been made available to scientists in the ESO community, and the data covering the HDF-S are available worldwide.

W. Salzmann in his Diploma Thesis, supervised by G. Börner and H.J. Mo, investigated the infall regions of galaxy clusters by using Monte-Carlo realizations of the linear density fluctuations around galaxy clusters expected from Gaussian random fields.

Y.P. Jing and G. Börner continued the statistical analysis of the Las Campanas redshift survey. The 3-point correlation function has been measured reliably, and a significant deviation from the hierarchical approximation was found. A best-fit CDM model leads to a 3-point correlation function which is about twice as large as the value obtained from the data.

D. Christlein (TU, Munich) and G. Kauffmann studied the luminosity function of galaxy groups in the Las Campanas Redshift Survey. The main result was that the luminosity function of galaxy groups is not universal; both M_* and α (the parameters in the Schechter function fit) depend on the velocity dispersion of the group.

Methods for the morphological analysis of large–scale structure and CMB maps were developed by J. Schmalzing. Together with M. Kerscher, T. Buchert and H. Wagner (Theoretical Physics, University of Munich), fluctuations in the IRAS 1.2Jy catalogue were discovered and confirmed on scales of $100h^{-1}$Mpc and beyond. In collaboration with S. Shandarin (University of Kansas), V. Sahni (IUCAA, Pune) and S.D.M. White, the geometry of density fields constructed from simulations is being studied with Minkowski functionals and shapefinders. Analogous methods were developed for CMB maps with K.M. Górski (TAC, Copenhagen) and applied to the COBE DMR four–year data.

The Cosmic Density–Velocity Relation was studied by means of analytical methods and numerical simulations by A. Kudlicki in cooperation with M. Chodorowski, E.L. Łokas, M. Różyczka (NCAC Warsaw), F. Bernardeau (Saclay), R. Stompor (Berkeley) and T. Plewa. Formulae for coefficients of the polynomial expansion for the mildly nonlinear DVR have been derived and verified by numerical simulations (both N-body and Eulerian). The polynomial approximation well describes δ as a function of θ, but not the inverse relation. A semiempirical formula for the inverse relation has been proposed and tested.

Cosmic flows from a sample of Tully-Fisher measurements of peculiar velocities were studied by A. Nusser in collaboration with L. Da Costa and W. Freudling (ESO). The flows were shown to match the gravity field from the IRAS 1.2 JY galaxy redshift survey indicating a moderate value for the cosmological density parameter.

J. Colberg, S.D.M. White and T. McFarland (RZG) continued their parallel supercomputer simulations of the formation of galaxies, galaxy clusters and large-scale structure as part of the international Virgo Supercomputing Consortium. A high point of the year was the completion on the T3E at the RZG of two 'Hubble Volume Simulations'. These used 10^9 particles to follow the evolution of the dark matter distribution in very large regions of an Einstein-de Sitter and of a low density flat CDM universe. They are by far the largest N-body simulations ever carried out, and they attracted considerable media attention. Because of the very large length scales involved (cubes of side 2000 and 3000 h^{-1}Mpc in the high and low density cases respectively) data were stored along the past lightcones of several observers as well as in standard 'snapshots'. These lightcones allow the evolution of structure back to redshift 4 to be visualised in a single image (see back cover).

J. Colberg used these simulations to study the abundance of massive clusters at early times and the predicted clustering of rich galaxy clusters on large scales. He was able to show that the high density model, although designed to reproduce the current observed abundance of massive clusters and the observed power spectrum of *galaxy* clustering, produced too few massive clusters at redshifts approaching unity and too little *cluster* clustering at the present day to be consistent with reality. The low density flat model fared better in both respects although it remained marginally deficient.

Within the Virgo Consortium, J. Colberg and S.D.M. White led studies of the formation of galaxy clusters and of their peculiar motion. The first showed how cluster formation is linked intimately to the Cosmic Web of large-scale structure, leading to a correlation between cluster internal structure and cluster environment. The second study demonstrated that linear theory cannot be used to predict accurately the peculiar motions of clusters. In all realistic situations nonlinear effects boost cluster motions to substantially larger values than a linear extrapolation of their velocities at early times.

A. Kudlicki (with A. Evrard of U. Michigan) worked on statistics of X-ray emission expected from clusters found in lightcone data from the Hubble Volume simulations.

A. Diaferio, G. Kauffmann, J. Colberg and S. White extracted mock galaxy redshift surveys from these same models and compared them with the northern region of the Center for Astrophysics Redshift Surveys. The properties of groups and clusters and the redshift space correlation function are reproduced quite well by both high and low density models with no obvious dependence on Ω_0. However, some modest discrepancies remain and can be attributed to the presence of a two-dimensional large scale structure in the real catalogue, the "Great Wall". It remains to be investigated whether the lack of such a coherent two-dimensional structure in the mock catalogues is a significant problem of the models, or reflects cosmic variance and the relatively small size of the simulated regions.

3.8 Galaxy formation and intergalactic medium

The evolution of the K-band luminosity function as a constraint on theories of galaxy formation was studied by G. Kauffmann and S.Charlot (IAP. Paris). It was shown that although both hierarchical models and pure luminosity evolution models could fit the observations at z=0, by redshift 1 the two models differ greatly in the predicted abundance of bright galaxies. The recent K-selected redshift survey of Cowie et al. yields results that agree well with the hierarchical predictions.

R. Sheth developed analytic models for the evolution of clustering from Gaussian initial conditions. These include models of the halo mass functions, merger rates, the merger history tree and the evolution of the nonlinear stochastic bias between the known halo and the dark matter distributions. Sheth developed an efficient algorithm for generating the forest of merger history trees associated with the hierarchical formation of dark matter haloes. He and G. Lemson (Hebrew Univ., Jerusalem) showed that these forests were similar to those which grow in numerical simulations of hierarchical clustering. They also used their merger tree model to study the halo-to-mass bias relation. This bias is nonlinear and stochastic, and the detailed predictions of the model are in good agreement with simulations.

R. Sheth and G. Tormen (Padova) showed that the halo-to-mass bias relation on large scales can be accurately determined if the number density of haloes as a function of halo mass is known. Their model predicts that more/less massive haloes should be less/more strongly clustered than previous models predict. This difference is in good agreement with numerical simulations, and is important for galaxy formation studies, as well as for models of the reionization history of the universe.

R. Sheth also showed that, for certain non-Gaussian initial conditions of current interest, it is possible to develop fully analytical models of hierarchical clustering, just as in the Gaussian case. The predicted evolution of the halo distribution in these non-Gaussian models differs from that in Gaussian ones mainly at early times.

G. Kauffmann, J. Colberg, A. Diaferio and S. White studied the clustering evolution of galaxies in a hierarchical Universe. This was done by combining dissipationless cosmological N-body simulations with semi-analytic models of galaxy formation. The first part of the study focussed on the global properties of the galaxy distribution at z=0, including predictions for luminosity functions, Tully-Fisher relations, two-point correlation functions, pairwise peculiar velocities, colour distributions and star formation rates. The biasing of galaxies of differing luminosity, type and colour was evaluated. In the second part, the evolution of clustering to high redshift was studied and showed to be a possible indicator both of galaxy formation processes and of the density of the universe.

Together with H.J. Mo and S.D.M. White, S. Mao studied the structure and clustering properties of Lyman-break galaxies under the assumption that these galaxies are the central galaxies of the most massive dark halos present at $z \sim 3$. They found that the observed sizes, luminosities, kinematics and star-formation rates of Lyman-break galaxies are also well-reproduced assuming this identification. The model predicts that Lyman-break samples should preferentially contain objects with low angular momentum, and so small size, for their mass. In contrast, samples of damped Lyα systems at similar redshift, should be biased towards objects with large angular momentum; damped Lyα systems should therefore have low star-formation activity and be relatively metal-poor.

S. Mao and H.J. Mo studied the nature of GRB hosts expected in a scenario where the rate of GRBs is proportional to the star formation rate in the universe. The model explicitly incorporates a luminosity function for the GRBs and provides a good match to the observed number counts of GRBs as a function of peak-count rate. The model predicts that the host galaxies have their redshift distribution peaked around $z \sim 1$, and about 15% have $z > 2.5$. They find that the host galaxies of GRBs have magnitudes in the range from 21.5 to 28 in the I band, and about 90% of them have semi-major axis smaller than 1.3 arc-seconds; both predictions are consistent with the observations.

In collaboration with D. Syer and H.J. Mo, S. Mao used observational data to constrain theoretical models of galaxy formation. They found that the angular momenta as inferred from observational data are in excellent agreement with those found in N-body simulations. Assuming only that the radial surface density distribution of disks is exponential, they estimate the maximum-disk mass-to-light ratio in the I-band and obtain a mean value $\Upsilon \lesssim 3.56h$, for a Hubble constant of $100h$ km s^{-1}Mpc^{-1}, consistent with other determinations. They also found that the baryonic fraction in disk galaxies is approximately $0.086\Upsilon/(3.56h)$.

Relationships of galaxies and quasars were studied by H. Arp.

The hydrodynamics and stability of galactic cooling flows was investigated by A. Kritsuk (Univ. of St. Petersburg), H. Böhringer (MPE), Ewald Müller and T. Plewa (Nicolaus Copernicus Center, Warsaw). Using an explicit direct Eulerian implementation of the PPM algorithm they probed the stability of hydrostatic equilibrium recycling models of hot gaseous coronae of giant elliptical galaxies with respect to a variety of perturbations. In the absence of heat conduction the equilibria are unstable due to radiative cooling. If heat conduction is taken into account, the equilibria are stable provided the perturbations are of low ($< 10\%$) amplitude. This group also studied the cooling instability for the first time in two spatial dimensions. Using axisymmetric random velocity perturbations the instability manifests itself by a set of narrow cooling gas streams flowing towards the center of the galaxy against a global subsonic galactic wind. The characteristic averaged X-ray observables of such hybrid gas flows do not deviate significantly from those of the initial equilibrium state, although the equilibrium conditions are considerably violated. It is planned to run simulations at much better numerical resolution and to study cooling flows in three spatial dimensions by using the adaptive mesh refinement code AMRA.

A. Nusser (now Technion, Haifa) and M. Haehnelt developed a method for the recovery of the real space line-of-sight mass density field from Lyman absorption in QSO spectra assuming that the absorption is due to a photoionized intergalactic medium which traces the mass distribution as suggested by recent numerical simulations. The method corrects redshift distortions iteratively from a simultaneous estimate of the peculiar velocity and was tested with mock spectra obtained from N-body simulations. Nusser and Haehnelt demonstrated that accurate estimates of higher order moments of the density probability function can be obtained. Haehnelt, Nusser and M. Rauch (ESO, Garching) applied the method to an AAT spectrum of the QSO in the Hubble Deep Field South and to a Keck spectrum of Q1422+231.

T. Theuns, in a collaboration with J. Schaye (Institute of Astronomy, Cambridge), G. Efstathiou (Institute of Astronomy, Cambridge) and A. Leonard (Oxford University), has been working on a method to determine the temperature of the intergalactic medium, based on the distribution of the line-widths of quasar absorption lines. Very high-resolution simulations of the Lyman-alpha forest are used to calibrate the method. To increase the dynamic range of these simulations, a new parallelized version of the simulation code has been developed.

J. Miralda-Escudé (University of Pennsylvania), M. Haehnelt and M. Rees (University of Cambridge) used a model of the density distribution in the intergalactic medium motivated by numerical simulations to investigate the effect of a clumpy matter distribution and discrete sources on the reionization of the universe.

The formation of the first mass concentrations in the Universe was studied by T. Abel in collaboration with G. Bryan (MIT), Y. Zhang (NCSA), P. Anninos (NCSA), A. Stebbins (Fermilab) and M. Norman (NCSA). Realistically simulated collapse and fragmentation of proto–galactic objects at high redshifts,and the radiative feedback of these first objects on subsequent structure formation has been investigated by Tom Abel in collaboration with B. Ciardi (Arcetri), A. Ferrara (Arcetri), Z. Haiman (Fermilab) and M. Rees (IoA, Cambridge). T. Abel and H.J. Mo gave arguments that such small pre–galactic objects might be the origin for the Lyman Limit absorption systems seen in quasar spectra at high redshifts. T. Abel has developed numerical methods to follow the ionization front created by a quasar at high redshift (in collaboration with M. Norman (NCSA) and P. Madau (IoA, Cambridge)).

3.9 Early universe

K.M. Górski (TAC, Copenhagen), E. Hivon (CalTech, USA), R. Stompor (Berkeley, USA), B. Wandelt (TAC, Copenhagen) and A.J. Banday have studied various schemes for the pixelisation of CMB full-sky observations for next generation very high resolution satellite projects. Simulations of such CMB skies are being studied in order to assess various important issues for the instrumental design and scanning strategy of the ESA-PLANCK satellite mission. Methods of component separation and power spectrum estimation are being implemented.

A.J. Banday, G. Hinshaw (GSFC, USA), A. Kogut (GSFC, USA) and K.M. Górski (TAC, Copenhagen) are generating the COBE-DMR Calibrated, systematic-error corrected Time-Ordered-Data in a simple FITS format for delivery to the astronomical community. The DMR sky maps will be repixelised as part of this project into the HEALPIX scheme devised by K.M. Górski and collaborators.

A. Alefeld, C. Leichtweiss, M.S. Bartelmann and A.J. Banday are developing the 'Pipeline Engine' for the two instrument consortia of the Planck Surveyor mission.

The influence of small-scale, matter-antimatter domains on the predicted light-element abundance yields during Big Bang nucleosynthesis was analyzed numerically by J.B. Rehm (Ph.D. thesis, supervised by K. Jedamzik). Many scenarios of Big Bang nucleosynthesis with matter-antimatter domains were analyzed, and limits were placed on the amount of antimatter present in the early universe.

The formation process of primordial black holes from pre-existing density fluctuations was studied by means of one-dimensional, general-relativistic hydrodynamics simulations by K. Jedamzik in collaboration with J.C. Niemeyer (University of Chicago). It was numerically verified that primordial black hole formation is facilitated for fluctuations entering the cosmic horizon during a strongly first-order phase transition. This result implies that for generic initial density fluctuation spectra primordial black holes form preferentially on the horizon mass scale during epochs when the universe undergoes a phase transition.

The evolution of stochastic, primordial magnetic fields from very early times up to the time of cosmic recombination was investigated by K. Jedamzik, in collaboration with V. Katalinic (University of Chicago) and A. Olinto (University of Chicago). It was found that the magnetic field energy is efficiently dissipated by photon viscosity and heat conductivity.

3.10 Physical processes

E.Churazov, R.Sunyaev, and D. Uskov (Lebedev Inst., Moscow) considered the scattering of X-ray emission lines. They could show that taking into account rotational and vibrational levels of the ground state does not affect strongly the appearance of the scattered spectra. The possibility to use the shape of the "compton profile" of the bright X-ray emission lines for diagnostics of the scattering medium in astrophysical objects was further investigated. Specific predictions for the evolution of the surface brightness, flux and shape of the neutral iron fluorescent line from the molecular clouds in the Galactic Center region were made, assuming that these clouds were illuminated by an outburst of the Sgr A* emission a few hundred years ago.

S. Grebenev (Space Research Institute, Russian Academy of Sciences, Moscow) performed computations of the radio emission from a molecular gas cloud surrounding a transient X-ray source. He could show that UV photons emitted by the outer parts of an accretion disk in a low-mass X-ray binary should ionize hydrogen in the extended region around the source which could be detected by its radio emission (thermal bremsstrahlung and radio recombination lines). The properties of this region should differ in many aspects from a conventional HII region because of the nonstationarity induced by the X-ray variability of the source or its fast motion in the cloud.

S. Sazonov (Space Research Institute, Russian Academy of Sciences, Moscow) and R. Sunyaev studied how Compton scattering affects the shapes of spectral lines. Having accounted for relativistic corrections and the recoil effect, they calculated the single-scattering profile of an initially monochromatic line that would emerge from an optically thin cloud of hot electrons. Such profiles can be realized in various astrophysical situations.

The process of X-ray continuum and line production due to atomic interactions of low energy cosmic rays with the ambient medium was studied in detail by S. Trudolyubov (Moscow Institute of Physics and Technology, Dolgoprudny, Russia) under the supervision of Prof. Sunyaev. The results were applied to the Sgr B2 giant molecular complex.

D. Uskov (P.N.Lebedev Physical Institute, Russian Academy of Sciences, Moscow) and R. Sunyaev have calculated the partial cross sections of the charge exchange in the $Fe(q^+) + H_2 \rightarrow Fe(q^+, n,l) + H_2^+$ reactions for the 1–8 keV energy range. They have also calculated the radiative cascade of He– and Li– like Fe ions after the capture of an electron into one of the highly excited states of the Fe ion. Line intensities were calculated for several models of charge exchange reactions. A number of lines and line ratios were shown to be good indicators of charge exchange reactions in astrophysical objects (molecular clouds, comets, nebulae)

3.11 Numerical methods

In collaboration with M. Norman (NCSA), P. Paschos (NCSA) and P. Madau (IoA, Cambridge), T. Abel has developed numerical methods to accurately include radiative transfer in cosmological hydrodynamic simulations. These methods allow to follow the chemo–thermal structure of cosmological ionization fronts in one and three dimensions.

A numerical code which solves the Boltzmann equation for neutrino transport in type II supernovae by using a discrete-angle method was compared with flux-limited diffusion and Monte Carlo transport methods by S. Yamada (Univ. of Tokyo), H.-Th. Janka and H. Suzuki (KEK, Japan). It was found that the results obtained with the Monte Carlo and Boltzmann solver techniques show good overall agreement, but flux-limited diffusion has severe weaknesses to describe the neutrino transport and neutrino-matter interactions in the semi transparent regime.

M. Reinecke and A. Gröbel, in a diploma thesis under the supervision of W. Hillebrandt, are continuing the work on the level-set front-tracking scheme for turbulent combustion, both in stars and in technical applications. In particular, studies are performed to demonstrate that the method can handle reflecting boundaries, strongly curved fronts, degenerate equations of state, and large decompression ratios as, e.g., found in combustion of hydrogen in air.

T. Plewa (Nicolaus Copernicus Center, Warsaw) and E. Müller have proposed a simple modification of higher-order Godunov schemes to allow for accurate and consistent advection of multi-fluid flows in hydrodynamic simulations. The proposed modification is appropriate for any difference scheme written in conservation form. Unlike other commonly used methods it does not violate the conservative character of the advection method. Numerical experiments have been performed which demonstrate the capability of the Consistent Multi-fluid Advection (CMA) method in case of smooth and discontinuous distributions of fluid phases and under different hydrodynamic conditions. They have also finished a 3D version of the adaptive mesh refinement code AMRA coupled to a revised version of the hydrodynamic code PROMETHEUS. The new code HERAKLES performs very efficiently on both RISC and vector machines by optimizing the usage of the cache memory and the vector registers, respectively. It has been parallelized for shared memory multi-processors.

R. Wegmann developed a quadratically convergent iterative method for the numerical calculation of the conformal mapping from a circular region to a multiply connected region. The method requires in each step the solution of a function theoretic boundary problem on a circular region, which can be solved efficiently by the fast Fourier transform.

3.12 Quantum mechanics of atoms and molecules; astrochemistry

Accurate and reliable theoretical studies are required, among others, to assist in the interpretation of the Rydberg spectra of atoms and molecules, of their complexes with rare gas atoms and with other molecules, as well as of atoms and molecules embedded into small clusters and into the condensed phase. Corresponding investigations are being pursued by G.H.F. Diercksen in close cooperation with experimental spectroscopists (R.J. Donovan, K.P. Lawley; Edinburgh, UK; K. Yamanouchi, Tokyo, Japan). The interpretation of recent experimental observations of the Rydberg spectra of singly charged cations requires, among others, theoretical studies of the structure and stability of the corresponding doubly and higher charged cations. Rigorous quantum chemical studies using the coupled-cluster method are being performed for the doubly and triply charged cation of the ozon molecule and preliminary results confirm the existence of metastable electronic ground and excited states (M. Urban, Bratislava, Slovak Republic). Challenging theoretical studies have been started in order to investigate the proposed formation of cavities around the Rydberg states of atoms like gold and silver and molecules like corbonmonoxid in liquid helium. (J Karwowski, Torun, Poland; PK Mukherjee, Calcutta, India). Further theoretical studies are beeing performed in order to explain the origin of the experimentally observed large changes in the dipole moment of CO and other small molecules like N_2, HF and HCl van der Waals bound to CO_2 (V. Kelloe, Bratislava, Slovak Republic).

The progress in computer hardware and in software engineering has made it possible to apply methods of quantum theory to study chemical and physical phenomena of molecules in complex solute-solvent systems. However, many industrial processes and almost all biomedical important processes are characterized by such high complexity that there is little hope that they will become accessible to quantum chemical studies in foreseeable future 2E. Therefore the development and use of alternative theoretical approaches for describing properties of increasingly complex molecular systems is of high practical relevance. A most interesting and promising direction for the theoretical description of molecular properties and reactivity in condensed media is emerging from the efficient combination of the methods of quantum theory with the search for theoretical quantitative structure-activity/property relationships. It was demonstrated that various molecular descriptors can be highly dependent on the quality of the optimization of the molecular geometry. Thus, the electrostatic descriptors were redefined on the basis of the quantum-chemically calculated charge distribution in the molecule and the molecular shape. These descriptors were also found to be highly sensitive to the accuracy of the basis set used in the quantum-chemical calculations. The reliability of the respective molecular descriptors were validated by the comparison of the calculated dipole and higher moments and the polarizabilities of the test compounds with their experimental values. (M. Karelson, Tartu, Estonia).

In science and technology large amounts of data are generated, mostly in electronic form, by observations, experiments, and computer simulations. In the computational sciences large amounts of data are generated routinely as result of simulating physical and chemical properties. Surprisingly little attention has been paid to discovering and using hidden knowledge in data generated in research and technology. This seems primarily due to the fact that, in general, the data describing a case, like an observation, an experiment or a simulation, are large and of increasing complexity. For discovering new knowledge it is necessary to define objects and to develop classification schemes and similarity measures. In general, in science the object is an arbitrary complete study and is referred to (by us) as a Case. It is important to note that instances of a Case may serve a manifold of different purposes. Most important, they may serve for defining, organizing, performing and documenting observations, experimental studies and computer simulations. Case bases containing the evaluated results of completed studies may serve as basis for machine learning, case-based reasoning, knowledge discovery (data mining) and computer based learning. It is easily recognized that the concept of a Case and its formal definition have been developed originally for use within the framework of case based reasoning with the aim of developing intelligent scientific software in computational chemistry. But it is easily recognized that a Case can be processed by different software tools, possibly residing on remote hosts, each performing a specific task. This provides the possibility to perform a case study by sending the Case in the appropriate order to different software tools, possibly connected to an observation or experiment, for processing. The outlined concept of a Case forms the basis of the OpenMol project developed by an international cooperation involving groups from Estonia (M. Karelson, Tartu), Finland (L. Laaksonen, Espoo), Germany (G.H.F. Diercksen, MPA), Japan (S. amamoto, Toyota), Northern Ireland (W. Dubitzki, P. Kilpatrick, Edinburgh), Poland (W. Duch, J. Karwowski, Torun) and the Slovak Republic (V. Kellö, M. Urban, Bratislava). Research is being persued at present on finding molecular descriptors sensitive to the property to be computed and to the theoretical method employed and in finding mathematical criteria to judge the reliability of theoretical studies. Calculations are being performed to provide sensible cases for verifying the developed descriptors and criteria.

Quantum mechanical state-to-state studies of the radiative association formation process of diatomic ions were now extended to include all possible ions which can be formed under primordial gas conditions: H_2^+, HeH^+, He_2^+, $HeLi^+$, LiH^+ and the corresponding deuterated species (W.P. Kraemer). For most of these ions the accuracy of the *ab initio* calculations can be assessed by a direct comparison with the results of high-resolution spectroscopical measurements of transitions between highly excited rotation-vibration levels close to the dissociation limit. Previous calculations for the "atmospheric" molecular ions O_2^+, N_2^+, CO^+ were also extended to include SiO^+ (W. P. Kraemer). In collaboration with P. Soldán (University of Southampton) partition functions were determined for these diatomics over wide temperature ranges.

For the triatomic weakly bound atom-diatom system HeH_2^+ highly accurate *ab initio* potential energy surfaces for the ground and first excited $^1A_1$ states were calculated including all possible dissociation channels (W.P. Kraemer). Similar calculations were also started for the corresponding neon compound, NeH_2^+ (W.P. Kraemer), which is frequently used as a test system in scattering experiments. The extension of the *ab initio* state-to-state studies of the radiative association formation process to general triatomic molecules is still a major problem due to the high density of highly excited rotation-vibrational levels close to the dissociation limit and due to the resulting strong couplings among these states. In addition to the previously devised new method (V. Špirko, Czech Academy of Sciences), applying the concept of the adiabatic separation of the vibrational motions and using high-order Rayleigh-Schrödinger perturbation theory to evaluate the non-adiabatic coupling effects. another direct iterative approach was also employed to determine the entire number of bound rotation-vibrational energy levels of the HeH_2^+ ground electronic state. Due to the complexity of the problem, it was not possible yet to make an unambiguous assignment of recently measured transition frequencies.

A new project was started studying photodissociation processes of small molecular ions in collaboration with O. Bludsky (Czech Academy of Sciences, Prague). The results of some first test calculations for CH^+ are in good agreement with previous theoretical studies. The present approach will be applied th triatomic ions and corresponding potential energy surface calculations for the lowest electronic states of the HCO^+ ion were started (W.P. Kraemer).

The recently developed method for calculating electronic resonances in low-energy electron-molecule collisions was extended to include also vibronic couplings between Rydberg levels close to the ionization limit (P.-Å. Malmqvist, University of Lund, Sweden).

J. Schaefer calculated the electronic transition probabilities of H_2, from $B^1\Sigma_u^+$ and $C^1\Pi_u$ into the bound and the continuum states of the ground state, $^1\Sigma_g^+$.

3.13 Observational projects

I. Aretxaga (MPA), D. Le Mignant (Grenoble), J. Melnick (ESO), R.J. Terlevich (RGO): 5.–6.10., ESO 3.6m, La Silla, Chile, ADONIS, High resolution NIR imaging of z=2 QSO hosts;

M.A.T. Groenewegen, M. Sevenster (Mt. Stromlo), A. Omont (IAP), H. Habing (Leiden): 10.3.-14.3., ESO, La Silla, Chile, SEST, spectrometers, The dynamical behaviour of infrared carbon stars;

M.A.T. Groenewegen, W.E.C.J. van der Veen (Columbia), H. Habing (Leiden), A. Omont (IAP): 25.3.–28.3., IRAM, Pico Veleta, Spain, 30m telescope, bolometer, The recent mass loss history of highly evolved stars;

M.A.T. Groenewegen, A. Omont (IAP), H. Habing (Leiden), M. Sevenster (Mt. Stromlo): 22.4.–28.4., IRAM, Pico Veleta, Spain, 30m telescope, spectrometers, The dynamical behaviour of infrared carbon star;

M.A.T. Groenewegen, F. Kerber(Innsbruck), M. Bremer (IRAM Grenoble), T. Tauch (Tübingen): 1.6.–4.6., IRAM, Pico Veleta, Spain, 30m telescope, spectrometers, CO observations of Sakurai's object;

M.A.T. Groenewegen: 30.9., ESO, La Silla, Chile, SEST, spectrometers, Do short period Miras lose mass, or how effective is radiation pressure on dust?

F. Kerschbaum (Vienna), M.A.T. Groenewegen, C. Lazaro (IAC), H. Habing (Leiden), J. Hron (Vienna): 27.11.–29.11., IAC, Tenerife, Spain, 1.5m TCS, IR photometer, A search for long-period carbon Mira variables;

X.-W. Liu (Univ. College London), X.-Y. Xia (Tianjin Normal Univ.), S. Mao: 19.6, 26.6, William Herschel Telescope, La Palma, Spain, ISIS, spectroscopy of Mrk 273x;

Y. Mellier (IAP), F. Bernardeau (IAP), B. Fort (IAP), W. Freudling (ESO), B. Jain, F. Moali (IAP), P. Schneider, S. Seitz (USM), L. van Waerbeke (CITA), S.D.M. White: 6 nights in Oct. and Nov., ESO, La Silla, Chile, New Technology Telescope, SUSI2, Probing cosmological scenarios from cosmic shear measurements;

E. Terlevich (RGO), I. Aretxaga (MPA), G.Cotter (RGO), R.J. Terlevich (RGO), A.I. Diaz (UAM): 19.2 - 20.2, William Herschel Telescope, La Palma, Spain, ISIS, Do all AGN have nuclear star formation?

4 Publications and Invited Talks

4.1 Publications in journals

4.1.1 Publications that appeared in 1998:

Abel, T., P. Anninos, Y. Zhang and M. L. Norman: First structure formation: I) Primordial star forming regions in hierarchical models. Astrophys. J. **508**, 518–529 (1998).

Abel, T., and H.J. Mo: A "minihalo" model for the Lyman limit systems at high redshift. Astrophys. J., Lett. **494**, L151–L154 (1998).

Abel, T., A. Stebbins, P. Anninos and M. L. Norman: First structure formation: II) Cosmic tring + HDM models. Astrophys. J. **508**, 530–534 (1998).

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4.3 Popular articles and books

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Arp, H. Seeing Red: Redshifts, Cosmology and Academic Science. Apeiron, Montreal 1998, 306 pages.

4.4 Preprints ("Green Reports")

The following preprints appeared in 1998 as official MPA "Green Reports":

Aloy, M.A., J.M. Ibanez, J.M. Marti and E. Müller: GENESIS: A high-resolution code for 3D relativistic hydrodynamics. MPA1123

Aretxaga, I., D. Le Mignant, J. Melnick, R.J. Terlevich and B.J. Boyle: Adaptive Optics observations of LBQS 0108+0028: K-band detection of the host galaxy of a QSO at $z \approx 2$. MPA1093

Churazov, E., R. Sunyaev, M. Gilfanov, W. Forman and C. Jones: The 6.4 keV fluorescent iron line from cluster cooling flows. MPA1095

Churazov, E., R. Sunyaev and D. Uskov: Scattering of X-ray emission lines by a hydrogen molecule. MPA1114

Colberg, J., S. White, A. Jenkins, T. MacFarland, F. Pearce, C. Frenk, P. Thomas and H. Couchman: Peculiar velocities of galaxy clusters. MPA1096

Contardo, G., M. Steinmetz and U.F.v. Alvensleben: Photometric evolution of galaxies in cosmological scenarios. MPA1076

Denissenkov, P.A., N.S. Ivanova and A. Weiss: Main-sequence stars of 10 and 30 $M_\odot$: approaching the steady-state rotation. MPA1101

Dolag, K., M. Bartelmann and H. Lesch: SPH simulations of magnetic fields in galaxy clusters. MPA1126

Geiger B. and P. Schneider: A simultaneous maximum likelihood approach for galaxy-galaxy lensing and cluster lens reconstruction. MPA1090

Gilfanov, M., M. Revnivtsev and E. Churazov: RXTE broad band observations of X-ray Nova XTE J1755-324. MPA1112

Gilfanov, M., M. Revnivtsev, R. Sunyaev and E. Churazov: The millisecond X-ray pulsar/burster SAX J1808.4-3658: the outburst light curve and the power law spectrum. MPA1110

Girardi, L. and G. Bertelli: The evolution of the V-K colours of single stellar populations. MPA1074

Girardi, L., M.A.T. Groenewegen, A. Weiss and M. Salaris: Fine structure of the red giant clump from Hipparcos data and distance determinations based on its mean magnitude. MPA1097

Groenewegen, M.A.T.: Carbon stars in populations of different metallicity. MPA1121

Heger, A.: The presupernova evolution of rotating massive stars. MPA1120

Heger, A. and N. Langer: The spin-up of contracting red supergiants. MPA1082

Janka, H.-T. and G. Raffelt: No pulsar kicks from deformed neutrinospheres. MPA1107

Jedamzik, K., V. Katalinic and A.V. Olinto: Damping of cosmic magnetic fields. MPA1084

Jedamzik, K. and J. C. Niemeyer: Near-critical gravitational collapse and the initial mass function of primordial black holes. MPA1081

Jedamzik, K. and J. X. Prohaska: Redshift and models of protogalactic disks. MPA1083

Kercek, A., W. Hillebrandt and J. Truran: Two–dimensional simulations of the thermonuclear runaway in an accreted atmosphere of a C+O white dwarf. MPA1073

Kercek, A., W. Hillebrandt and W. Truran: Three dimensional simulations of classical novae. MPA 1119

Kritsuk, A., E. Müller and H. Boehringer: Hydrodynamics and stability of galactic cooling flows. MPA1078

Kruse, G. and P. Schneider: Statistics of dark matter haloes expected from weak lensing surveys. MPA1099

Langer, N., A. Heger and G. Garcia-Segura: Massive stars: the pre-supernova evolution of internal and circumstellar structure. MPA1087

Mao, S., G. Boerner, X.Y. Xia, T. Boller, H.Wu, Y. Gao, Z.G. Deng and Z.L. Zou: An X-ray luminous, dwarf Seyfert companion of Mrk273. MPA1085

Mao, S., H. Mo and S.D.M. White: The evolution of galactic disks. MPA1092

Mao S., J. Reetz and D.J. Lennon: Detecting luminous gravitational microlenses using spectroscopy. MPA1106

Mao, S. and H.J. Witt: Extended source effects in astronometric gravitational microlensing. MPA1105

Marigo, P.: Envelope burning over-luminosity: a challenge to synthetic TP-AGB models. MPA1091

Marigo, M., L. Girardi and A. Bressau: The third dredge-up and the carbon star luminosity functions in the Magellanic Clouds. MPA1116

Meyer-Hofmeister, E., F. Meyer and B.F. Liu: WZ Sagittae - an old dwarf nova. MPA1113

Meyer, F. and E. Meyer-Hofmeister: On the source of viscosity in cool binary accretion disks. MPA1124

Mo, H., S. Mao and S.D.M. White: The structure and clustering of Lyman break galaxies. MPA1125

Popham, R., S. Woosley and C. Fryer: Hyper-accreting black holes and gamma-ray bursts. MPA1100

Reblinsky, K. and M. Bartelmann: Projection effects in mass-selected galaxy-cluster samples. MPA1118

Rehm, J.B. and K. Jedamzik: Big bang nucleosynthesis with matter/antimatter domains. MPA1080

Reinecke, M., W. Hillebrandt and J.C. Niemeyer: Thermonuclear explosions of Chandrasekhar mass C+O white dwarfs. MPA1122b

Reinecke, M., W. Hillebrandt, J.C. Niemeyer and R. Klein: A new model for deflagration fronts in type Ia supernovae. MPA1122a

Reinecke, M., W. Hillebrandt and J.C. Niemeyer: Modeling turbulent nuclear flames in type Ia supernovae. MPA1103

Ruffert, R. and H.–T. Janka: Gamma-ray bursts from accreting black holes in neutron star mergers. MPA1111

Ruffert, M. and H.-Th. Janka : Colliding neutron stars: gravitational waves, neutrino emission and gamma-ray bursts. MPA1088

Salaris, M. and A. Weiss: Metal-rich globular clusters in the galactic disk: new age determinations and the relation to halo clusters. MPA1079

Sazonov, S.Y. and R. A. Sunyaev: Spectral distortions of the cosmic microwave radiation due to interaction with the hot gas in a moving cluster: inclusion of relativistic effects. MPA1109

Sazonov, S.Y. and R. Sunyaev: Cosmic microwave background radiation in the direction of a moving cluster of galaxies with hot gas: relativistic corrections. MPA1102

Seitz, S. and P. Schneider: A new finite-field mass reconstruction algorithm. MPA1077

Seitz, S., P. Schneider and M. Bartelmann: Entropy-regularized maximum-likelihood cluster mass reconstruction. MPA1086

Shima, E., T. Matsuda, U. Anzer, G. Boerner and H.M.J. Boffin: Numerical computation of two dimensional wind, accretion of isothermal gas. MPA1089

Sibgatullin, N. and R. Sunyaev: The disc accretion in the gravitational field of the rapidly rotating neutron star with quadrupole mass distribution. MPA1117

Springel, V. and S. D. M. White: Tidal tails in CDM cosmologies. MPA 1104

Sunyaev, R. and E. Churazov: Equivalent width, shape and proper motion of the iron fluorescent line emission from the molecular clouds as an indicator of the illuminating source X-ray flux history. MPA1094

Sunyaev, R. and E. Churazov: Scattering of X-ray emission lines by a helium atom. MPA1075

Wagenhuber, J. and M.A.T. Groenewegen: New input data for synthetic AGB evolution. MPA1098

Weiss, A. and M. Salaris: Colour transformations for isochrones in the V-I-plane. MPA1115

Yamada, S., H.–T. Janka and H. Suzuki: Neutrino transport in type II supernovae: Boltzmann solver vs. Monte Carlo method. MPA1108

4.5 Invited talks

H. Arp: IAU 194, "Activity in Galaxies and Related Phenomena" (Byarakan, Armenia, Aug. 17–21)

M. Bartelmann: ESO/MPA Conference "Evolution of Large-Scale Structure: From Recombination to Garching" (Garching, Aug. 2 – Aug. 7)

G. Börner : Leopoldina Tagung "Der Zufall" (Halle, April 16 – April 18)

E. Churazov: 3rd INTEGRAL Workshop "The Extreme Universe" (Taormina, Italy, Sept. 14 – Sept. 18)

A. Diaferio: Workshop "From Stars to Galaxies to the Universe" (Castle Ringberg, Rottach-Egern, June 1 – June 4)

M. Gilfanov: Workshop on "Observational Evidence for Black Holes in the Universe" (Calcutta, India, Jan. 11 – Jan. 17)

L. Girardi: Ringberg Workshop "From Stars to Galaxies to the Universe" (Castle Ringberg, Rottach–Egern, June 2 – June 6)

M.A.T. Groenewegen: IAU Symposium 191 "AGB stars" (Montpellier, France, Aug. 27 – Sept. 1)

W. Hillebrandt: Int. Conf. on "Numerical Astrophysics 1998" (Tokyo, Japan, March 10 – March 13)

W. Hillebrandt: Int. Workshop on "Type Ia Supernovae: Theory and Cosmology" (Univ. Chicago, USA, Oct. 29 – Oct. 31)

H.-Th. Janka: Ninth Workshop on "Nuclear Astrophysics" (Castle Ringberg, Rottach–Egern, March 23 – March 27)

H.-Th. Janka: International Symposium on Nuclear Astrophysics "Nuclei in the Cosmos V" (Volos, Greece, July 6 – July 11)

G. Kauffmann: ESO/MPA Conference "Evolution of Large-Scale Structure: From Recombination to Garching" (Garching, Aug. 2 – Aug. 7)

G. Kauffmann: ESO Conference on "Chemical Evolution from Zero to High Redshift" (Garching, Oct. 14 – Oct. 16)

G. Kauffmann: 19th Texas Symposium on "Relativistic Astrophysics" (Paris, France, Dec. 14 – Dec. 18)

S. Mao: The Xth Rencontres de Blois "The Birth of Galaxies" (Blois, France, June 28 – July 4)

F. Meyer: "Disk Instability" Workshop (Kyoto, Japan, Oct. 27 – Oct. 30)

E. Müller: XXVI International Workshop "Gross Properties of Nuclei and Nuclear Excitations" (Hirschegg, Austria, Jan. 11 – Jan. 17)

E. Müller: VII International Conference "Hyperbolic Problems: Theory, Numerics and Applications" (Zürich, Switzerland, Feb. 9 – Feb. 13)

E. Müller: Mini Workshop "Numerical Methods in Astrophysics: Numerics and Applications" (Oslo, Norway, June 3 – June 5)

P. Schneider: "19th Texas Symposium on Relativistic Astrophysics" (Paris, France, Dec. 14 – Dec. 18)

P. Schneider: "The Next Generation Space Telescope: Science Drivers and Technological Challenges" (Liège, Belgium, June 15 – June 18)

P. Schneider: "Wide-Field Surveys in Cosmology", 14th IAP Meeting (Paris, France, May 25 – May 29)

R. Sunyaev: Aquila School on "3K Cosmology from Space" (Aquila, Italy, Sept. 2 – Sept. 11)

R. Sunyaev: International Euroconference on "3K Cosmology" (Rome, Italy, Oct. 5 – Oct. 10)

R. Sunyaev: Symposium "Highlights in X-ray Astronomy" in honor of Joachim Truemper's 65th birthday (Garching, June 17 – June 19)

A. Weiss: "Nuclear Astrophysics" (Hirschegg, Jan. 12 – Jan. 17)

S.D.M. White: Darwin Lecture of the Royal Astronomical Society (London, March 13)

S.D.M. White: Discussion Meeting "Large Scale Structure in the Universe" of the Royal Society (London, March 25 – March 26)

S.D.M. White: "The Next Generation Space Telescope: Science Drivers and Technological Challenges" (Liège, Belgium, June 15 – June 18)

S.D.M. White: Xth Rencontres de Blois "The Birth of Galaxies" (Blois, France, June 28 – July 4)

S.D.M. White: The Third Stromlo Symposium "The Galactic Halo: Bright Stars & Dark Matter" (Canberra, Australia, Aug. 17 – Aug. 21)

S.D.M. White: ESO Workshop on "Chemical Evolution from Zero to High Redshift" (Garching, Oct. 14 – Oct. 16).

5 Personnel

5.1 Scientific staff members

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

Scientific Member: R.-P. Kudritzki

Staff: U. Anzer, A. Banday, M. Bartelmann, G. Börner, M. Brüggen (since Dec. 1), E. Churazov, D. Clowe (since Sept. 1), C. Cress (since 15.9.), G.H.F. Diercksen, I. Forcada (Jan 1 – July 31), M. Gilfanov, A. Groebl (since Nov. 1), M. Groenewegen, M. Haehnelt (since Sept. 1), H.-T. Janka, K. Jedamzik, V. Joergens (since Oct. 15), P. Kafka (till May 30), C. Kaiser (since Oct. 1), G. Kauffmann, W. Keil (till March 31), A. Kercek (since Sept. 1), K.-M. Knie (till Jan. 31), U. Kolb (till April 30) W.P. Kraemer, S. Mao, E. Meyer-Hofmeister (till April 30), H.J. Mo, E. Müller, J.C. Niemeyer (on leave since Oct. 1, 97), A. Nusser (till Sept. 30), R. Popham, H. Ritter, P. Schneider, R.K. Sheth, H.C. Spruit, D. Syer (till Dec. 31), K. Takahashi (since April 1), H.-C. Thomas, A. Ulmer (till Dec. 31), R. Wegmann, A. Weiß, A.G. Weiss (April 1 – June 30), S. Zaroubi (since Oct. 1).

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

Ph.D. students: T. Abel, R. Casas, J.M. Colberg (till Sept. 30), C. Cramphorn, B. Deufel (since May 1), H. Dimmelmeier (since Sept. 1), K. Dolag, M. Ferwagner (since Jan. 1), I. Forcada (till Jan. 31), B. Geiger (till Oct. 31), A. Heger (till Nov. 30), A. Kercek (till Aug. 31), K. Kifonidis, G. Kruse, M. Lisewski, S. Marri (since Nov. 1), H. Mathis (since Sept. 1), N. Przybilla, M. Rampp, K. Reblinsky, J. Rehm, M. Reinecke (since May 15), H. Schlattl, J. Schmalzing, V. Springel, N. Yoshida (since June 1).

Diploma students: T. Eberl (till June 30), R. Fritsch (since Aug. 1), A. Groebl (since July 1), H. Hämmerle (since Aug. 17), M. Reinecke (till May 4), W. Salzmann (till Feb. 28), M. Schirmer (since Sept. 20), O. Stranner (till Oct. 31).

5.2 Staff news

G. Kauffmann was awarded the Annie Jump Cannon Special Commendation of Honour for 1998.

E. Müller held the best university course at the Technical University Munich during the winter semester 97/98.

R. Sunyaev received the Sir Massey Gold Medal of the Royal Society and COSPAR.

5.3 Visiting scientists

Name (home institution) duration of stay at MPA

MPG fellowships:

R. Adamczak (Torun, Poland) Oct. 19 – Dec. 18; I. Baraffe (Lyon, France) Sept. 1 – Dec. 31; C. Benoist (Garching) since Oct. 1; S. Blinnikov (Moscow, Russia) Aug. 1 – Aug. 31; E. Branchini (Durham, England) May 18 – June 12; R.A. Burenin (Moscow, Russia) Nov. 15 – Dec. 20; S. Cassisi (Teramo, Italy) Feb. 25 – March 27; C. Charbonnel (Toulouse, France) Oct. 5 – Oct. 18; C. Chiosi (Padova, Italy) Nov. 4 – Dec. 3; P. Denissenkov (St. Petersburg, Russia) Feb. 1 – Aug. 31; A. Diaferio (Garching) since Sept. 15; N. Dounina–Barkovskaya (Moscow, Russia) Aug. 1 – Aug. 31; W. Duch (Torun, Poland) Aug. 4 – Sept. 4; A.N. Emelyanov (Moscow, Russia) Oct. 18 – Nov. 29; C. Fryer (Santa Cruz, USA) July 17 – Sept. 8; T. Futamase (Sendai, Japan) July 1 – Sept. 5; O. Goussev (St. Petersburg, Russia) since Oct. 15; S.A. Grebenev (Moscow, Russia) Oct. 11 – Dec. 20; Z. Haiman (Batavia, USA) Nov. 30 – Dec. 13; S. Hardy (Sydney, Australia) till May 31; P. Heinzel (Ondrejov, Czech Republic) Feb. 1 – Feb. 28 and May 1 – May 31; A. Helmi (Leiden, Netherlands) March 30 – April 9, Oct. 4 – Oct 11 and Nov. 2 – Nov. 20; M. Ho (Kingston, Canada) Oct. 16 – Dec. 15; J. Hwang (Koegu, Korea) till Feb. 19; A.A. Ibragimov (Kazan, Russia) Nov. 15 – Dec. 20; N.A. Inogamov (Moscow, Russia) Sept. 20 – Dec. 19; B. Jain (Baltimore, USA) July 19 – Aug. 11; J. Karwowski (Torun, Poland) July 28 – Aug. 28; M. Kasai (Hirosaki, Japan) Aug. 1 – Sept. 29; P. Kilpatrick (Belfast, Northern Ireland) Jan. 13 – Jan. 23 and July 6 – Aug. 14; A. King (Leicester, England) April 5 – April 9 and Aug 2 – Aug. 15; A. Kritsuk (St. Petersburg, Russia) July 5 – Sept. 6; N. Langer (Potsdam) July 24 – Aug. 2 and Sept. 6 – Sept. 20; G. Lemson (Jerusalem, Israel) March 16 – May 5; W. Lin (Peking, China) since Aug. 1; A. MacFayden (Santa Cruz, USA) July 24 – Oct. 5; P.-Å. Malmqvist (Lund, Sweden) May 18 – June 17 and Nov. 1 – Nov. 30; P. Marigo (Padua, Italy) April 1 – Dec. 31; Y. Mellier (Paris, France) March 1 – April 30; S.V. Molkov (Moscow, Russia) Oct. 18 – Nov. 29; D. Nadyozhin (Moscow, Russia) March 22 – April 21; J. Navarro (Tucson, USA) Feb. 1 – Feb. 28; J.C. Niemeyer (Chicago, USA) March 15 – April 5; H. Noh (Daejon, Korea) till Feb. 19; I. Panov (Moscow, Russia) Oct. 15 – Dec. 13; M.N. Pavlinskii (Moscow, Russia) Oct. 11 – Nov. 10; U.-L. Pen (Toronto, Canada) Nov. 1 – Nov. 30; T. Plewa (Warsaw, Poland) June 1 – Aug. 31 and Oct. 1 – Nov. 30; A.R. Prasanna (Ahmedabad, India) Nov. 20 – Dec. 13; M.G. Revnivtsev (Moscow, Russia) May 1 – May 31 and June 22 – Aug. 9; M. Ruffert (Cambridge, England) March 28 – April 7 and April 14 – April 17; P. Ruiz-Lapuente (Barcelona, Spain) till Feb. 6 and since Oct. 10; M. Salaris (Liverpool, England) July 17 – Aug. 1; B. Salasnich (Padua, Italy) Nov. 1 – Dec. 4; S.Y. Sazonov (Moscow, Russia) Feb. 15 – March 14, May 22 – Aug. 9 and Oct. 11 – Dec. 20; U. Seljak (Cambridge, USA) since July 24; C. Shu (Shanghai, China) May 1 – Oct. 31; N.R. Sibgatullin (Moscow, Russia) Oct. 15 – Nov. 14; V. Špirko (Prag, Czech Republic) May 18 – July 31; P. Soldán (Southampton, England) May 18 – June 18 and June 29 – July 10; K. Subramanian (Pune, India) till Feb. 16; M Takada (Sendai, Japan) July 1 – July 15; K. Tanaka (Tokyo, Japan) July 27 – Aug. 27; O.V. Terekhov (Moscow, Russia) till Jan. 1 and Nov. 15 – Dec. 14; A. Timokhin (Moscow, Russia) till Feb. 14; A.Y. Tkachenko (Moscow, Russia) Nov. 15 – Dec. 12; G. Tormen (Garching) Jan. 1 – April 30; S.P. Trudolyubov (Moscow, Russia) May 1 – May 31, June 22 – Aug 9 and Oct. 18 – Nov. 29; M. Urban (Bratislava, Slovak Republic) Jan. 7 – Feb. 6 and July 9 – Aug. 9; D.B. Uskov (Moscow, Russia) Nov. 15 – Dec. 14; V. Utrobin (Moscow, Russia) Aug. 1 – Aug. 31; S.E. Woosley (Santa Cruz, USA) Aug. 13 – Oct. 15; B. Wybourne (Torun, Poland) July 28 – Aug. 27; S. Yamada (Tokio, Japan) till Feb. 28; S. Yamamoto (Nagoya, Japan) July 27 – Aug. 27; M. Zaldarriaga (Cambridge, USA) Aug. 1 – Aug. 31.

Alexander von Humboldt–research awards and fellowships:

Alexander von Humboldt awards: M. Norman (Urbana, USA) till July 31; J. Paldus (Waterloo, Canada) June 1 – Aug. 16.

Alexander von Humboldt fellowships: P. Denissenkov (St. Petersburg, Russia) Feb. 1 – July 31; L. Girardi (Porto Alegre, Brazil).

DAAD–fellowships:

A. Kudlicki (Warsaw, Poland) till July 31.

EC–fellowships:

I. Aretxaga (till Sept. 30); A. Diaferio (till Sept. 14); S. Hardy (since June 1); G. Ogilvie (since Oct. 1); M. Salaris (till March 31); T. Theuns (since Oct. 1).

WTZ–fellowships:

M. Karelson (Tartu, Estonia) Oct. 5 – Nov. 2; V. Kelloe (Bratislava, Slovak Republic) Aug. 18 – Oct. 15; S. Sild (Tartu, Estonia) Oct. 5 – Nov. 2; M. Urban (Bratislava, Slovak Republic) July 9 – Aug. 9.

5.4 Diploma, Ph.D. and Habilitation theses

Diploma theses:

T. Eberl: "Numerische Simulationen zur Verschmelzung von Neutronensternen mit Schwarzen Löchern", Technical University Munich;

M. Reinecke: "Ausbreitung turbulenter Flammenfronten in Typ Ia Supernovae", Technical University Munich;

W. Salzmann: "Geschwindigkeitsfelder und Dichteverteilungen in der Umgebung von Galaxienhaufen", Ludwig Maximilians University Munich;

O. Stranner: "Präzedierende Jets und ihre Wechselwirkung mit Supernovaüberresten", Technical University Munich.

Ph.D. theses:

B. Geiger: "Constraining the Mass Distribution of Cluster Galaxies by Weak Lensing", Ludwig Maximilians University Munich.

A. Heger: "The Presupernova Evolution of Rotating Massive Stars", Technical University Munich;

A. Kercek: "Modelle für die thermonukleare Wasserstoffverbrennung auf der Oberfläche Weißer Zwerge", Technical University Munich.

Habilitation thesis:

M. Bartelmann: "Diagnostics of Galaxy Clusters with Light Deflection and X-Ray Emission", Ludwig Maximilians University Munich.