Max-Planck-Institut
für
Astrophysik

Annual Report 2000

Front cover: Snapshot from a numerical simulation of a powerful relativistic extragalactic jet showing the rest mass density after about 6 million years (darker color indicates higher density). The relativistic jet drives a bow shock through the intergalactic medium. The beam is surrounded by a turbulent cocoon where ambient gas and jet matter (in this case electrons and positrons) are mixing. (L. Scheck, E. Müller)

back cover: False–color image of the dark matter distribution in a simulated galaxy cluster similar in mass to the Coma cluster. This simulation has a spatial resolution better than 0.5 kpc and a mass resolution better than 10^8 solar masses. Dark haloes of many individual galaxies are visible within the cluster (see the highlight article by G. Kauffmann).

Contents

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 devoted primarily 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 reorganization, the MPA (then under its second director, Rudolf Kippenhahn) moved to a new site in Garching, just north of the Munich city limits. The new building lies in a research park just 50 metres from ESO headquarters and is connected to the buildings which house the MPI für Extraterrestrische Physik (the “MPE”). The research 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. The third director, Simon White, was replaced by a board of directors. Its current members are Wolfgang Hillebrandt, Rashid Sunyaev and Simon White. In 2000, Wolfgang Hillebrandt took over as Managing Director.

Research at MPA covers a broad range of topics in theoretical astrophysics. Major areas of interest include stellar evolution, nuclear and neutrino astrophysics, supernovae, astrophysical fluid dynamics, high energy astrophysics, radiative processes, galaxy 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 into a new area – high energy astrophysics.

The European microwave background satellite Planck, scheduled for launch in early 2007, is designed and operated by a large European consortium of institutes. The MPA represents Germany in this consortium and is respondible for developing part of the software system required for Planck data processing and information exchange. The MPA will also coordinate the development of a data simulation pipeline for Planck and will prepare, document and finally release the the final data products to the astronomical community. MPA is also involved in managing and coordinating the data-reduction software required for the mission, and in investigating the scientific applications of this software.

Work related to the Planck mission began in 1998 at the MPA. A team of programmers and scientists was set up to disugn a prototype of the data analysis software. This team was supported by the General Administration of the Max-Planck Society until late 1999, when Germany’s space agency (DLR) took over a large portion of the funding. The team will expand in size as the project progresses, and will consist of 14 members just after the launch of the satellite. The team is currently working in three areas: the data-simulation pipeline, the software infrastructure for data analysis, and an archive system for the data products.

In 2000, the MPA became an Associate Partner in the “Sloan Digital Sky Survey” (SDSS) project. The SDSS will image one quarter of the sky in five photometric bands, determining the positions and luminosities of more than 100 million celestial objects. It will also measure the distances to more than a million galaxies and quasars. SDSS is a joint project of the University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Princeton University, the United States Naval Observatory, and the University of Washington. Apache Point Observatory, site of the SDSS telescopes, is operated by the Astrophysical Research Consortium (ARC). After more than a decade of planning, building, and testing, the Sloan Digital Sky Survey officially started in 2000.

Although most MPA research addresses theoretical issues, the neighboring institutes provide complementary observational and instrumental expertise, and there are many projects that involve collaborations among the different institutes. Major research programmes at MPE are concerned with instrumental, observational and theoretical aspects of infrared, X-ray and gamma-ray astronomy. ESO carries out a broad range of instrumental and observational projects in the optical and infra-red. ESO is also responsible for the design and operation of 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 postdoctoral level and above, as well as 20 graduate students. The MPA has a vigorous visitor's programme, with up to 10 foreign guests present at any one time on visits of varying length. 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 these universities. Ties with the the universities are also established via joint research projects, such as the special research program ("Sonderforschungsbereich") on particle astrophysics, which also includes the MPI für Physik.

The MPA has also been part of EARA (a European Association for Research in Astronomy) since 1996. This association links the MPA 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. Three such networks are coordinated from the MPA. They deal with galaxy formation, gravitational lensing, and accretion onto compact objects. In 1999, a Max-Planck Cosmology Group was established at the Shanghai observatory. The group consists of 8 to 10 researchers, mainly young postdocs and graduate students. A very active exchange between that group and MPA began in 2000.

1.2 Current MPA facilities

The MPA building is a major asset and it contributes a lot to the success of its research activities. It was designed by the same architect responsible for the layout of ESO headquarters. The two buildings are generally considered as important and highly original examples of the architecture of their period. Although the unconventional geometry of the MPA can easily confuse first-time visitors, its open and centrally focused plan is very effective at encouraging interaction between scientists and makes for a pleasant and stimulating research environment. Until late fall of 2000, part of the ground floor and most of the basement of the building was occupied by the infrared group of the MPE. The group has now moved into a new building. The MPA still houses the joint administration of the two institutes.

The MPA and the MPE also share a large and fully stocked astronomical library located in the MPA building. It contains more than 16000 books and conference proceedings. All major astronomical books and periodicals are available. Researchers at both institutes have electronic access to a wide variety of on-line archives and to most of the journals to which the library has subscribed. ESO also has a library, which maintains a complete collection of optical sky maps and photographic sky surveys. The MPE acts as a European data centre for the ROSAT and ISO satellites and has extensive data analysis facilities.

The MPA has always placed considerable emphasis on computational astrophysics and has therefore ensured access to forefront computing facilities. The current in-house system consists of a central cluster of about 10 IBM RS6000 workstations, with additional Sun and SGI graphics workstations for data analysis and graphics applications. Users have free access to all workstations and are generally connected via large-screen X-window terminals or desk-top workstations. In 2000, the MPA bought a 16-processor IBM SP3 supercomputer, which was installed at the central computing centre of the Max-Planck-Gesellschaft at Garching (RZG). This supercomputer supplements the existing 18-processor IBM SP2. For still larger computing tasks, MPA scientists can use a 816-processor CRAY T3E and a 4-processor NEC SX-5, and they have access to a large cluster of high-end workstations and tera-byte mass storage systems at RZG. Plans to replace the CRAY T3E by a much faster computer by the end of 2001 have recently been approved by the President of the Max-Planck-Society.

MPA scientists are among the top users of the facilities at the RZG. 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. Finally, MPA scientists have applied successfully for time on the teraflop tera-byte supercomputer Hitachi SR8000 of the Leibnitz-Rechenzentrum in Munich.

1.3 2000 at the MPA

A major event in 2000 was the visit of the Fachbeirat on January 31 and February 1. In addition to its regular members (Roger Blandford, Catherine Cesarsky, Günther Hasinger, Ken'ichi Nomoto, Bohdan Paczynski, and Nigel Weiss) two non-astronomers (Professors Landwehr and Martienssen), together with Vice-President Wegner, joined the committee this year to compare the MPA with other Max-Planck-Institutes specializing in stronomy and astrophysics. They reported to President Markl, who also joined the meeting for a few hours. According to their report, they were apparently quite satisfied by what they had seen and heard.

As in every year since 1997, the MPA invited a world-class theoretical astrophysicist to give three talks over a one month period on a subject of his or her choice. This set of prize lectures, known as the Biermann Lectures, was given this year by Bohdan Paczynski from Princeton University. The subject of his lectures was Astronomy with Massive Variability Searches. All lectures were very well attended and once again the audience spilled out of the lecture theater. In the future, we will use the lecture theater in the MPE's new building which can seat up to 200 people, so we expect that this problem will be solved.

Several workshops and conferences were organized by MPA scientists in 2000, including a MPA/ESO/MPE Conference on “Mining the Sky” which took place in Garching from July 31 through August 4, the traditional (Tenth) Workshop on “Nuclear Astrophysics” at at the Ringberg Castle in March, a workshop at Shanghai Observatory entitled “Cosmology in the new Millennium”, a workshop and research programme at the ITP at Santa Barbara on “Galaxy Formation and Evolution”, and many others.

MPA's national and international cooperations and collaborations also flourished in 2000. An initiative designed in 1999 to further enhance the visibility of astronomy in Garching/Munich and to increase collaboration between the different institutions by means of a newly created International Max-Planck Research School (IMPRs) in Astrophysics at the Ludwig-Maximilians-University was approved by the Max-Planck-Gesellschaft, and the MPA will take an active part in it. Efforts to attract approximately 20 graduate students from all over the world to the School began in 2000, and the first of them are expected to arrive in Garching in spring. As a consequence of the various European TMR-networks coordinated by MPA scientists, there were many visitors from all over Europe at the MPA.

The year 2000 was proclaimed as the “Jahr der Physik” by the German Ministry of Education and Research (BMBF) and the German Physical Society (DPG). Our institute actively participated in the effort to carry our science to the general public and, in particular, to school children and students. The opening ceremony of the “Jahr der Physik” was devoted to astrophysics, and MPA joined the main event in the URANIA exhibition center in Berlin from January 17 till January 21. About 8000 visitors, 3000 of them school pupils, were informed about latest achievements and developments in modern astronomy and astrophysics, and were able to attend public lectures given by leading scientists in the field.

MPA ran the “Cosmic Cinema” at this event, presenting short movies about comets, supernovae, nova explosions, cosmic structure formation and other topics studied at MPA. For the first time, film sequences produced with 3D visualization techniques were publicly shown. Special colored glasses allowed the spectator to “fly through” a rotating cluster of galaxies or “sit inside” the convecting core of a supernova explosion. A particular highlight of the event for the MPA representatives was the opportunity to meet the Minister of Education and Research, Mrs. Edelgard Bulmahn, and a group her state secretaries, who enjoyed some of the 3D movies in the Cosmic Cinema on their walk through the exhibition.

Some of the movies shown in the Cosmic Cinema were also used in the “Science Tunnel”, a presentation of science on different scales, created by the Max-Planck-Society for the World Exhibition in Hannover. Cosmology was explained as a link between the smallest entities, the elementary particles which were created in the Big Bang, and the largest structures in the Universe, the galaxy clusters whose formation is governed by gravity.

The Jahr der Physik was also celebrated with a series of public evening lectures, which were organized by the Max-Planck-Institutes in the Munich area and the Ludwig-Maximilians University. Once a month a public talk attracted an audience of more than 400 people to the Bavarian Academy of Sciences. The goal of the talks was to educate a wider audience about the future potential of modern physics, in accord with the motto of the nationwide BMBF inititiative: "Wissenschaft im Dialog".

In September 2000 the new building of the MPI für extraterrestrische Physik was completed, improving the office and laboratory situation of both institutes and allowing MPA to adjust to its growing space needs. In particular, the PLANCK project can now be easily accommodated and computer installations and the library will receive much-needed additional space. In-house construction and moving began at the end of 2000 and will extend well into 2001, possibly until late fall. As part of the ongoing reconstruction work, a completely new local computer network was also established.

1.4 How to reach us

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

- Electronic address:

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

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

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

- MPA (reference) library:

  phone: +49-89-30000-2305/6
  FAX: +49-89-30000-2235
  email: lib@mpa-garching.mpg.de
  URL: http://www.mpa-garching.mpg.de/libris.html
  homepage: only local access

Figure 1.1: Federal Minister of Education and Research, Edelgard Bulmahn, visiting the “Cosmic Cinema” at the URANIA in Berlin.

2 Scientific Highlights

2.1 Disks Around Binaries

Mass transfering binaries are a long-standing subject of research at MPA. Such binaries contain a compact star (white dwarf, neutron star or black hole), which accretes mass from a normal companion star orbiting around it. This class of objects includes the X-ray binaries (and among those the black hole transients and so-called 'microquasars'), the ordinary novae and dwarf novae, and the more recently discovered 'supersoft sources'.

The transfer of mass from the companion to the compact star happens because the binary slowly loses angular momentum, which makes the orbit shrink, forcing the stars closer together. The rate of mass transfer is proportional to the rate of angular momentum loss. One such source of angular momentum loss is the emission of gravitational radiation, but this is only a small effect. Most mass transfering binaries show a transfer rate much larger than can be explained by gravitational radiation alone. In Cataclysmic Variables (CV), binaries, in which the primary star is a white dwarf, the dominant loss in most systems is believed to be due to a *magnetic stellar wind* from the companion star. This is analogous to the solar wind, but is much stronger due to the rapid (orbital) rotation of the star. The process is called *magnetic braking* and its consequences were worked out 20 years ago. It has become the standard interpretation of much of the phenomenology of Cataclysmic Variables and X-ray binaries. This includes the approximate mass transfer rates and the famous 'period gap': the relative absence of CVs with orbital periods of 2–3 hrs.

However, a number of observational facts disagree with this picture. The weight of these anomalies has accumulated over the years and has now become a challenge to the standard view of magnetic braking as the basis for the mass transfer process. One of the problems is the large spread in mass transfer rates (a factor of 100 or more) observed in systems which otherwise have identical parameters. This spread is hard to understand since the mass transfer rate is determined by the average angular momentum loss rate over a period of 10^5 yrs. Magnetic braking, when averaged over such long periods, is believed to vary by only a small amount.

A second problem is the nature of the companion stars. The ongoing loss of mass is expected to affect their structure. For the rates indicated by magnetic braking, the effect is rather small and should not be observationally detectable New improved observations have shown, however, that the secondaries in many systems are strongly affected, as if they had been subjected to larger mass loss rates, not just recently, but systematically over significant periods in the past.

Finally, observations of many systems with high mass transfer rates show evidence of *outflows*, through the anomalous shape of their spectral line profiles. The flows appear to originate from the accretion disk. Such outflows are especially evident in the so-called *supersoft sources*. These are binaries in which the white dwarf accretes at a rate just high enough to sustain the nuclear burning of hydrogen into helium in their envelopes without expanding into red giants. They are strong sources of very soft X-rays. Several of them have binary parameters similar to ordinary CVs, except for their very high mass transfer rates.

Henk Spruit, Ron Taam (Northwestern University) Friedrich Meyer and Emmi Meyer-Hofmeister have studied the consequences of these outflows for the evolution of mass transfering binaries. The model they explored assumed that there is a spread in the velocity of the outflowing material. Since the typical observed speed exceeds the orbital speed of the binary, but not by a large factor, it is likely that a fraction of the material in the outflow has velocity sufficient to carry the gas beyond the companion star, but not high enough to escape from the system. Such material would accumulate just outside the orbit of the binary, in the form of a *circumbinary (CB) disk* (see Fig. 2.1). Even if only 1% of the mass transfer is fed into this cicumbinary disk, it would accumulate a substantial mass over the hundreds of millions of years that a CV is active.

The tidal torques exerted on the CB disk by the gravitational field of the binary transfer angular

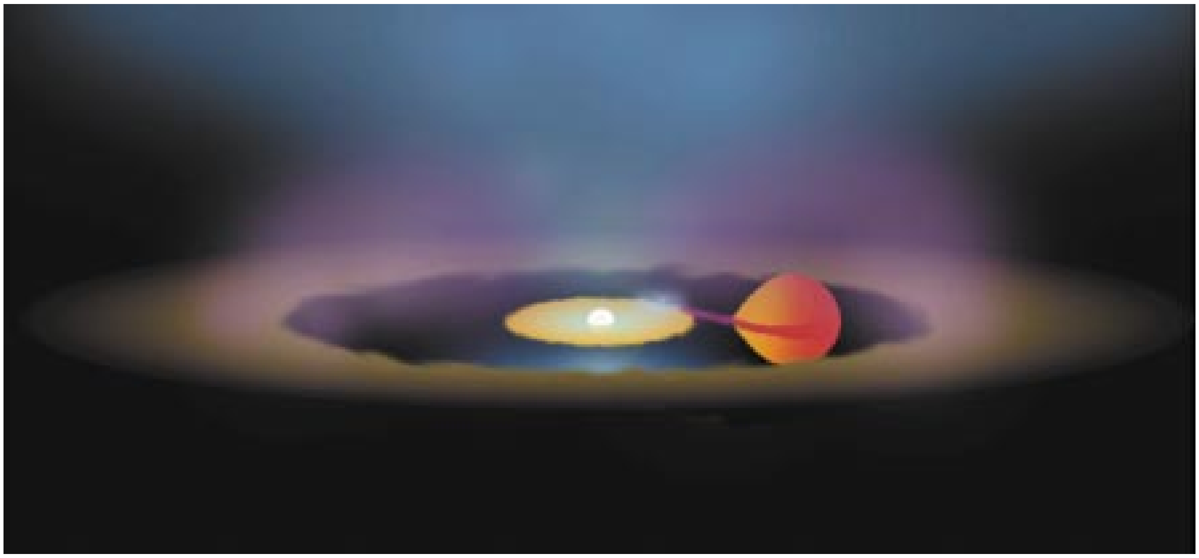

Figure 2.1: Artist's impression of a Cataclysmic Binary surrounded by a circumbinary disk. The white dwarf at the center is surrounded by an accretion disk, which is fed by mass transfer from the companion (red). Mass leaves the system in the form of a bipolar flow, originating on the accretion disk (blue fluff). Some of this outflow is slower (purple fluff) and does not leave the system but over the course of millions of years accumulates in an *external* or *circumbinary* disk. The tides raised in this disk by the binary orbiting inside it extract angular momentum from the binary causing the companion to transfer mass at a large rate.

momentum from the binary to the CB disk, which then slowly spreads outward while the binary orbit shrinks. The presence of the CB disk therefore enhances the mass transfer rate. Since the clearest observational evidence of outflow occur at the largest mass transfer rates, it is reasonable to assume that the mass fed into the CB disk also increases with the transfer rate. There is then a positive feedback: an increase in mass of the CB disk increases the transfer rate from the secondary to the primary, which again increases the rate at which mass is added to the CB disk. With analytical and detailed numerical models, it was shown that this mechanism indeed produced the anomalously large mass transfer rates observed in many systems. These would be systems in which there has been suffient time for a substantial CB disk to develop, and for the feedback process to become effective.

Apart from explaining the large transfer rates in CVs, CB disks may play an important role in black hole transients. These are binaries like CVs, except that the accreting star is a black hole instead of a white dwarf. The accretion is not steady but happens in outbursts lasting about a month and repeating on a time scale of centuries. The main difference is the much larger energy flux from the accretion process, a consequence of the deeper gravitational potential of the black hole. The irradiation of the CB disk by this flux during an outburst 'evaporates' the inner regions of the CB disk. This reduces the interaction of the CB disk with the binary, so that the mass transfer rate is reduced. This feedback process is thus the opposite of what happens in the CVs discussed above. Instead of increasing the mass transfer rate, it tends to keep the long-term averaged rate within a limited range. Detailed calculations of the accretion disks in black hole binaries shows that this range of transfer rates is just what is needed to explain the long recurrence time of the outbursts.

If the CB scenario is correct, all CVs with anomalously large mass transfer rates, many CVs with more normal rates, and the black hole binaries must be surrounded by CB disks, with masses up to $10^{-3}M_{\odot}$. These disks have somehow escaped detection so far. A calculation of their predicted luminosities, however, shows that this is not surprising. The energy dissipation rate in a CB disk is much lower than in the accretion disk itself, since it happens at a large distance from the central object, in a much weaker gravitational field. In addition, this dissipation is spread out over a large area. The best chance of observing CB disks is therefore in the mid-infrared, around 3μ. An attempt to detect CB disks in this way will be carried out at the William Herschel telescope on La Palma this summer. (Henk Spruit and Friedrich Meyer)

2.2 New Class of Low Frequency Quasi–Periodic Oscillations: Signature of Nuclear Burning or Accretion Flow Instabilities?

When matter falls onto a neutron star and hits the surface it releases a vast amount of energy, of the order of 10 or 20 per cent of its rest mass. This energy is eventually converted to radiation and can be observed by X–ray satellites. A much less powerful source of energy is the thermonuclear fusion of the falling matter. Typically a fraction of a per cent of the rest mass of accreting matter can be released through this mechanism. Although nuclear reactions provide on average only 1 per cent of the total energy budget of the accreting neutron star, they sometimes lead to a spectacular phenomena known as an X–ray bursts. Matter falling onto a neutron star usually consists of hydrogen (80%), helium (10–20%) and small admixture of heavier elements like carbon, nitrogen and oxygen. Hydrogen is an efficient thermonuclear fuel and it ignites easily when the matter hits the surface of the star and spreads. Most of the hydrogen is quickly converted into helium. Burning of helium is much more difficult. Very high temperatures and densities are required to ignite it. As a result, a large amount of helium may accumulate on the neutron star surface. The temperature rises and at some moment the critical conditions for helium ignition are reached and all the helium, accumulated during hours or days, explodes instantly giving rise to a spectacular flare in the X–ray band, lasting for 10–100 seconds. Since actual burning occurs in deep layers under the star's surface, the spectrum emitted during X–ray bursts is simply a black-body with a very high temperature of about 10 million degrees.

Observations, supported by numerical simulations, suggest that when matter falls onto a neutron star at a low rate, a large amount of helium will accumulate before the explosion. If on the other hand the rate of matter infall is high, then the temperature in the matter settling on the neutron star surface is high and helium (like hydrogen) burns immediately without accumulation. In this case no X–ray bursts are observed.

What happens at intermediate mass infall rates? The peculiar behavior found recently for the X–ray source 4U1608-52 may answer this question. This object is a neutron star in a binary system and the its matter infall rate changes by a large factor (see Fig. 2.2) on time scales of days and months. One can therefore observe the same source in states with different mass accretion rates.

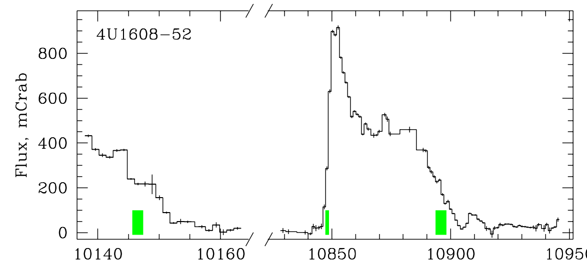

Figure 2.2: A long term light curve of 4U1608-52 according to the data of the All–Sky–Monitor on board Rossi X–Ray Timing Explorer. The gray boxes mark the dates when slow quasi–periodic oscillations were detected.

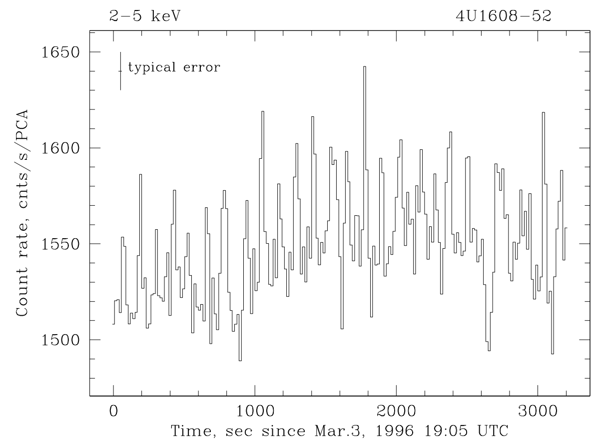

Figure 2.3: A segment of the X–ray light curve when quasi-periodical oscillations are clearly seen.

A small segment of the X–ray light curve of 4U1608-52 is shown in Fig. 2.3. One can clearly see quasi–periodic variations of the X–ray flux with a period of about 2 minutes. While variability of the X–ray flux, associated with the instabilities in the accretion flow, is a generic property of compact objects, the properties of these 2 minute variations are rather unusual. First of all the variations are stronger at the lowest energies (variations are usually larger at the highest energies). Secondly, the strong quasi–periodic variations seem to be present only when the total flux from the source reaches a certain limiting value as shown in Fig. 2.3 and Fig. 2.4. This value also corresponds to the limiting flux at which X-ray bursts are apparently quenched (Fig. 2.4) Finally the amplitude of flux variations is of the order of one or few percent – very similar to

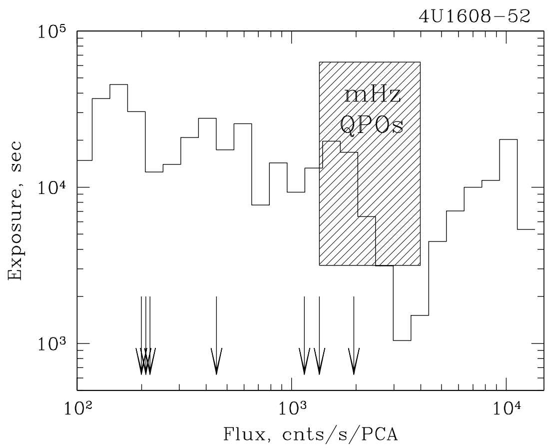

Figure 2.4: The exposure time (PCA instrument on board Rossi X–Ray Timing Explorer) for 4U1608-52 observations at different flux levels. Arrows mark persistent fluxes of the source when X–ray bursts where observed. Shaded region shows the range of fluxes when slow quasi–periodic oscillations were observed. Approximately at the same flux level X–ray bursts are quenched.

the expected contribution of nuclear burning to the energetics of the accreting neutron star. A search through the archival data revealed several other accreting neutron stars exhibiting similar variations of the X–ray flux. All of them have surprisingly similar period of flux variations ($\sim$ 2 minutes) and similar mass accretion rates.

It is therefore tempting to associate these variations of the X–ray flux with the quasiperiodic nuclear burning of helium on the neutron star surface. This regime of nuclear burning would then bridge a gap between the explosive helium burning regime at low accretion rates and the steady regime at high accretion rates. This interpretation would require serious update of the theoretical model of helium burning. An alternative and less exotic explanation that the observed variations are caused by some instabilities in the flow of infalling matter. This cannot be ruled out at present. (Eugene Churazov, Marat Gilfanov, Mike Revnivtsev and Rashid Sunyaev).

2.3 Mining the Sky – Historical Supernovae and ROSAT Sources

The explosion of a star produces a spectacular astronomical phenomenon – a supernova. For some time the exploding star becomes as bright as the whole galaxy in which it is embedded. In our own galaxy, the Milky Way, a supernova might even be visible in broad daylight. Only a few supernovae in historical times have been identified in the Milky Way and apparently no star has blown up during the last 300 years. Astronomers are eagerly waiting for the next such event, which should reveal to them the secrets of the physics in the center of the star just before the explosion, the explosion mechanism, and the dynamics of the expanding shell of gas. Modern astronomers have to be content with two supernovae in neighbouring galaxies: in the Large Magellanic Cloud in 1987, and in Andromeda in 1895. More information on historical supernovae in the Milky Way can be gained by an interesting combination of advanced satellite astronomy and ancient Chinese records.

More than 3000 years ago, ancient Chinese astronomers carefully observed the sky and recorded what they saw. More than 10.000 celestial events have been recorded. Ten years ago a book about these events (Zhuang and Wang, 1987) was compiled from the ancient chronicles and other ancient documents. This database of ancient records is a useful tool for identification and statistical studies of celestial events and objects. Among those are a substantial number of supernova candidates.

The ROSAT satellite is a modern instrument devoted to observing the sky in X-rays. This satellite has discovered many extended sources of X-ray emission which bear witness to a supernova explosion. The sources are formed by interstellar gas heated up by the shockwave of the supernova. The simple picture of an expanding blast wave that shocks, heats, and accelerates the ambient medium can serve as a model to analyse the observations. The solution – known as the Sedov solution– depends only on the blast wave energy and the density of the ambient medium. The age, size, and temperature of the supernova remnant are strongly correlated, and thus using the Sedov solution, the temperature, or more generally the X-ray spectrum, of ROSAT X-ray sources, as well as the size of the remnant, can be used to infer its age. Some of the sources appear to be relatively young. Some may even have formed in historical times. One example is the source discovered by ROSAT RXJ0852-4642, which may be just 700 years old . By looking at ancient Chinese documents, we have tried to search for evidence of historical supernovae at or close to the positions of the most conspicuous ROSAT supernova remnant candidates.

Some results have been obtained for the three sources listed in Table 2.1. Initially we thought

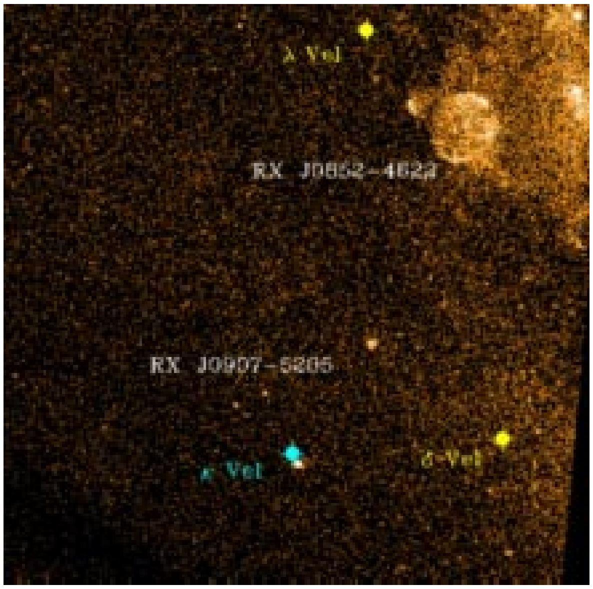

Figure 2.5: X-ray image of the Vela constellation with the supernova remnants RX J0852-4622 and RX J0907-5205 discovered with ROSAT. For comparison the stars λ Velorum, δ Velorum and κ Velorum are shown as well.

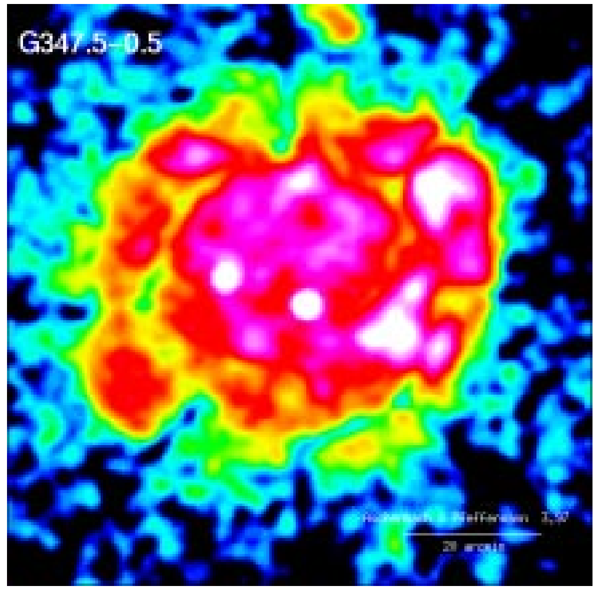

Figure 2.6: X-ray image of the supernova remnant RXJ1714-3939 or G347.5-0.5 discovered with ROSAT.

that the youngest sources would be most easily identified, because the records become more complete as time goes on. However, the most reliable evidence for an identification is for RXJ1714-3939, which is the oldest source in our sample.

RXJ1714-3939

According to its spectrum, the age of the X-ray classified supernova remnant RXJ1714-3939 (Fig. 2.6) is about 3000-5000 years . We have found a SN record, inscribed on tortoise shells or bones, of an event which appeared in the celestial region of the ROSAT source (Fig. 2.7).

The inscription reads: On the Jisi day, the seventh day of the month, a big new star appeared in the company of the Huo star (Antares). The inscription on tortoise shell bones was common practice in the Yin dynasty about 3300 years ago. The time of the apppearance of the new big star is consistent with the estimate of the age of the X-ray supernova remnant. Furthermore, the location of the X-ray source is within the area mentioned in the ancient document. The fact that the age estimates agree so well, also tells us that the Sedov solution is an accurate description of the physical characteristics of the supernova blast wave. The new star seen in Antares has been regarded as a supernova by science historians in China since the inscription had been found. However, up to now it has not been possible to associate the event with a supernova remnant. Thanks to the observations of ROSAT, we now have a candidate for an identification. If true, this would be the first supernova recorded by human astronomers and subsequently identified with a modern instrument.

RXJ0907-5205: a missing star

In Gan De's catalogue drawn in the 5th century BC, the constellation Tianshe contained six stars. We know the configuration of the Tianshe constellation only from some ancient sky maps whose makers might have seen the atlas corresponding to Gan De's catalogue. However, Tianshe does not appear on the astronomical map based on observations in the Song dynasty. This map was cut on a stone tablet and kept in Suzhou. We notice that only five stars are drawn in the atlas. There is no star in the position of Tianshe 4 in the 1575 atlas, nor is there one in the sky at the present day.

Therefore we suggest that the star Tianshe 4 exploded as a SN after the 5th century BC, and gave rise to the supernova remnant RXJ0907-5205. We note that the position of the X-ray source is offset from that of Tianshe 4 by about two degrees (Fig. 2.5). But this is about the error of the position of stars in an ancient atlas.

Table 2.1: ROSAT sources possibly associated with historical supernovae

	X-ray source	R.A.	Dec.	est. age
1	RXJ0852.0-4642	08 52 00	-46 22	700 yrs
2	RXJ0906.7-5205	09 06 40	-52 06 59	1800 yrs
3	RXJ1714.2-3939	17 14 10	-39 38 36	3000-5000 yrs

Figure 2.7: Bone or tortoise shell inscriptions from the 14th century BC.

RXJ0852-4642: the search for the SN event

According to its X-ray spectrum, RXJ0852-4642 is likely to be a very young supernova remnant. Its age is estimated at about 700 years, i.e. the X-Ray source was formed in the 13th century. In this era, most important astronomical events were being recorded regularly in China. Unfortunately the position of RXJ0852-4642 is very low in geographical latitude, so the supernova could have been missed. After carefully checking the Chinese ancient documents, we found no record of the appearance of a guest star in that period.

However, there are records of events occurring at approximately the right time that may be connected with this remnant. In 1529 a description of a so-called "white rainbow" that appeared in southern night sky was recorded. Perhaps a SN appeared but was obstructed by clouds and mountains. The SN might not have been seen directly, but may have lit up a part of the sky, so that the event could have been likened to a white rainbow.

In the Yaiyuan County Chronicle of the Shanxi province it is recorded that 'A white rainbow appeared in the southern sky towards the Heaven River (Milky way) and westward to the horizon, throughout the night during 90 days from the 12th month 17th day of the Jiajing epoch, in the 7th year in the Ming Dynasty.' Similarly in the Changle County Chronicle of the Shandong province it is written that 'White gas like a rainbow, extended across the southern sky eastward to the Heaven River at night'. Many other records have been found describing a white rainbow.

In the same period two events were recorded as "long star". The term "long star" is often thought to refer to comets in Chinese documents. But among more than 300 comet records only 7 events were recorded as long stars. This shows that the "long star" event might be different from a comet. All those records of an unusual event on the night sky at the position of the X-ray source give some support to the suggestion that a supernova explosion has occurred in 1529

Alternatively, RXJ0852-4622 may correspond to a guest star event in the Tianmiao constellation that was recorded twice in 1065. Because the guest star was described as a lump, we infer that the guest star was very bright so that it can be regarded as a supernova.

However, the Tianmiao constellation is far away from the position of the X-ray source. So this identification may not be very secure. (Gerhard Börner, Li Qibin, Bernd Aschenbach)

2.4 How do Massive Stars Explode?

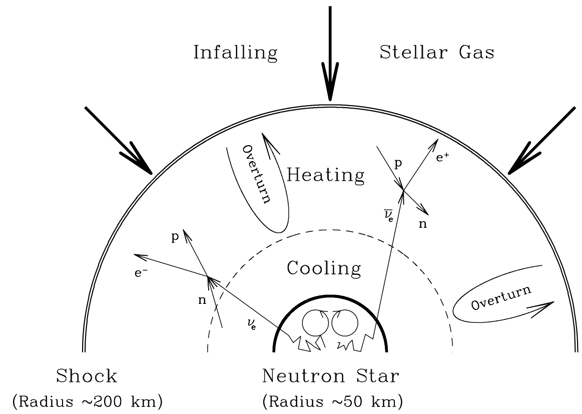

Figure 2.8: Competing processes that determine the destiny of the stalled supernova shock: Gas infall from the collapsing star damps the shock expansion. The gas between the neutron star and the shock is cooled and heated mainly by the emission of electron neutrinos and the absorption of antineutrinos in processes with free nucleons. Only when the neutrino heating is strong enough, will an explosion be triggered. Convective transport processes can occur inside the neutron star and in the heating region.

Stars with masses of roughly more than ten times the mass of our Sun end their lives in spectacular supernova explosions, which can outshine a whole galaxy for a period of several weeks. Stellar fragments are ejected at a tenth of the speed of light and heavy elements and radioactice nuclei are swept into the circumstellar space to form a new generation of stars and planets.

As brilliant as it may be, such a catastrophic disruption of a star is only a weak side effect of a much more energetic event: The iron core of the massive star collapses to a neutron star or a black hole, a compact remnant only 20 kilometers in size left behind at the center of the diffuse nebula of expanding stellar gas. In this process ten thousand times more energy is liberated in neutrinos than is radiated in photons. Neutrinos are elementary particles that are produced in great abundance by particle reactions inside the hot, nascent neutron star.

When the collapsing stellar core reaches the density of nuclear matter, the equation of state suddenly stiffens and the infall stops abruptly. At that moment a shock wave is launched in the gas that crashes supersonically onto the forming proto-neutron star, and starts to travel outward. It has to overcome severe energy losses due to the disintegration of iron nuclei to free nucleons, and due to additional neutrino emission from the shock-heated gas once the shock propagates into neutrino-transparent regions. There is general agreement that these energy losses are so dramatic that the running shock dies and turns into a standing accretion shock. The prompt hydrodynamic shock front is unable to leave the stellar core and thus does not lead to a successful supernova explosion.

Although neutrinos extract energy from the prompt shock at very early times, the situation changes only fractions of a second later. When the shock has been pushed to larger radii by the gas that accumulates in the postshock region, the temperature behind the shock has decreased. Hot neutrinos, streaming up from the central neutron star, can now deposit a small fraction of their energy in the cooler stellar medium. Although the neutrinos interact only weakly with the stellar gas behind the shock, the energy being carried by neutrinos is huge, and enough energy may be deposited within a region of a few hundred kilometers in radius to power the explosion of the star.

The processes involved are very complex and are not satisfactorily understood. Hydrodynamic simulations, using large computer codes on top-end supercomputers, have produced discrepant results. It is of fundamental importance to deepen our insight into the mechanism of the explosion, because important questions are inseparably linked to it, e.g., whether a neutron star or a black hole is formed and how much radioactive material is produced by the supernova.

A simple, analytic model was therefore developed at the Max-Planck-Institute for Astrophysics to describe the complex processes which cause the supernova explosions of massive stars. The model can help one understand the role of neutrinos in the explosion, and supplements more detailed, but also less transparent, supercomputer calculations.

Shortly after formation, the supernova shock is influenced by the competing effects of gas infall, which depends on the structure of the collapsing star, and neutrino heating and cooling, which change the energy behind the shock (Fig. 2.8). When the mass infall rate is high, the shock is pushed outward by the pressure of the gas accumulating behind it. Only for sufficiently large neutrino luminosity from the neutron star can neutrino heating dominate neutrino cooling between neutron star and shock. In this case, the mass and the energy in this region will continue to grow and drive the shock farther out, so that the post-

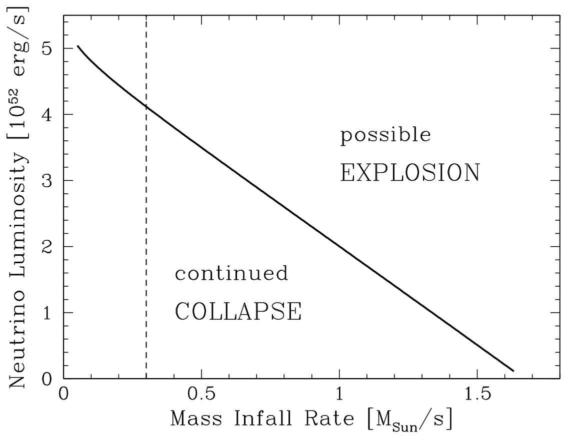

Figure 2.9: Phase diagram for successful explosion or continued stellar collapse in dependence upon the rate at which gas falls into the shock and upon the neutrino luminosity of the nascent neutron star. The mass of the neutron star was assumed to be 1.25 solar masses.

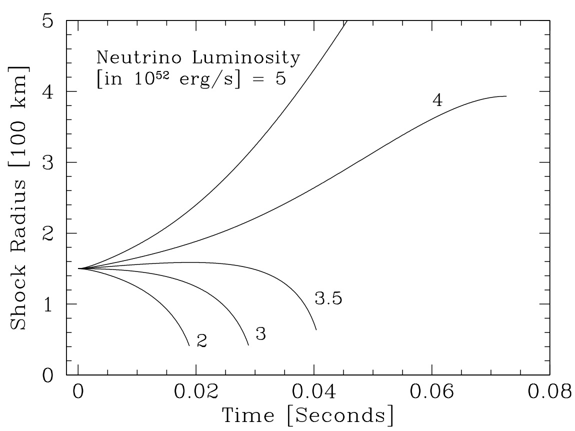

Figure 2.10: Shock positions as functions of time for different values of the neutrino luminosity of the neutron star (according to labels) and fixed value of the rate at which gas falls into the shock (marked by the dashed line in Fig. 2.9). For neutrino luminosities above the critical value (where the dashed line crosses the solid line in Fig. 2.9) explosions can occur.

shock layer can finally absorb enough energy to power a healthy supernova explosion. If the neutrino luminosity from the neutron star is too low, the neutrino energy loss from the cooling layer is catastrophic, and the gas is quickly accreted by the neutron star. Therefore the shock has to recede because the matter in the gain layer falls inward and cannot support the shock expansion. Figure 2.9 illustrates the "phase diagram" for the evolution of the collapsed stellar core. The critical line separating both regions of parameter space is indicated on the plot. The bifurcation of the evolution that occurs at the threshold value of the neutrino luminosity can clearly be seen from the shock trajectories predicted by the analytic model for a fixed value of the mass accretion rate (Fig. 2.10).

The analytic models not only cover those cases where hydrodynamic models produce explosions, but also lead to general conclusions on the properties of neutrino-driven supernova explosions. For example, neutrino-driven explosions will not be very powerful, because the energy per nucleon in the heating layer seems to be limited to a few MeV per nucleon. The nucleons are unable to absorb more energy from neutrinos before they move away from the region of strong neutrino heating. Since the mass in this region is typically only a tenth of a solar mass, this implies that the explosion energy will be of the order of few 10^{51} erg at most.

Although the analytic discussion can shed light on principle aspects and interdependences, numerical simulations are needed for quantitative investigations. In particular, the complex neutrino physics and neutrino transport require careful treatment. A new method has been developed at MPA for determining the time and energy dependent solution of the Boltzmann transport equation. This allows one to describe neutrino effects very accurately, both in the diffusion and free-streaming regimes and in the intermediate transition region. As a result, the numerical deficiencies in the supernova models are for the first time smaller than the uncertainties of the input physics. However, this level of sophistication has its price: The method is computationally expensive and has only been applied in spherically symmetric simulations, which disregard the effects of convection in the neutron star and in the neutrino-heating region behind the shock.

The results for the most advanced spherically symmetric models are disappointing. In spite of helpful effects due to the accurate treatment of neutrino transport, which increase the neutrino heating behind the shock compared to previous ap-

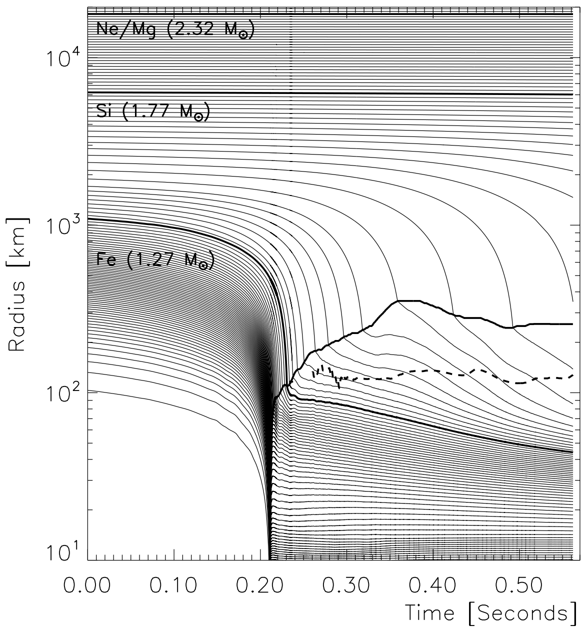

Figure 2.11: Trajectories of selected mass shells inside the collapsing core of a 15 $M_\odot$ star. The shock position is indicated as well as the "gain radius" (dashed line), which separates the neutrino cooling region inside from the neutrino heating layer above. The outer boundaries of the iron core, silicon shell, and of the neon plus magnesium layer are also marked.

proximate (flux-limited) diffusion calculations, the models do not develop explosions. In Fig. 2.11 the mass shells of the collapsing core of a $15\,M_\odot$ star are shown as functions of time. The shock moves out to more than 300 km, but then turns around and finally settles to a radius of only about 200 km.

Despite the negative results of the recent simulations, it would be premature to discard the possibility of neutrino-driven explosions. Certainly, there is no observational proof that supernova explosions of massive stars are caused by neutrino-energy deposition behind the shock front. Although the emission of neutrinos over a timescale of several seconds was confirmed by the historic measurement of two dozen neutrinos from Supernova 1987A, there were too few events to extract information about the role of neutrinos in the explosion.

The analytic models demonstrate , however, that there is indeed a reasonable region of the parameter space where the conditions for an explosion can be obtained. The crucial question is, of course, whether this favorable region is actually reached by the collapsing star.

At the moment, a new generation of more complete and more precise supernova models is in the process of being developed. These will combine highly accurate neutrino transport with multi-dimensional fluid dynamics. The latter has been demonstrated to be important by previous simulations, which showed vigorous convection inside the nascent neutron star and in the neutrino-heating region behind the shock. Both convective regions in the collapsed stellar core have helpful consequences for the explosion. Neutron star convection raises the neutrino luminosity, and postshock convection transports energy from the layer of strongest neutrino heating to the region immediately behind the supernova shock. However, the older simulations were performed with a radically simplified treatment of the neutrino transport and interactions. Moreover, very important physics is still missing in the models. Nucleon correlations in the dense medium will reduce the neutrino opacities, again favoring higher neutrino luminosities. General relativity has not been satisfactorily included in self-consistent multi-dimensional models, and it is possible that it might also improve the conditions for neutrino-driven explosions. Interesting new results await us around the next corner of the long road to a standard model for the supernova explosions of massive stars. (Hans–Thomas Janka and Markus Rampp)

2.5 Models of Thermonuclear Supernova Explosions

Classical type I supernovae, commonly referred to as SN Ia, are generally believed to be the result of the thermonuclear disruption of white dwarfs made of carbon and oxygen with masses close to the critical Chandrasekhar-mass of $1.39\,M_\odot$. Several observational facts strongly support this view, including the absence of hydrogen lines in the spectra of these objects, their occurrence in old populations of stars, and the homogeneity of their light curves and spectra. Moreover, thermonuclear explosions can, in principle, easily account for the production of more than 0.5 solar masses of ^{56}Ni and enough intermediate-mass elements such as silicon, sulfur, and calcium, to explain the main features of the outbursts. Because of their enormous brightness and their apparent homogeneity as a class, type Ia supernovae at high redshifts have become an important tool for measuring cosmological parameters. The local expansion rate and geometrical structure of the Universe were recently determined using supernovae lightcurves, with the surprising result that the Universe seems to be in a phase of *accelerated expansion*, caused by either a non-vanishing cosmological constant or an unknown form of energy with negative pressure. Considerable attention has been focused on models of these events over the past couple of years and research at MPA has also contributed to our present understanding of thermonuclear supernova explosions.

Thermonuclear explosion models are limited by the fact that nuclear burning in a self-gravitating object, such as a star, is self-regulating. A local temperature fluctuation in a star in hydrostatic equilibrium leads to an increase of the nuclear energy generation rate and this causes the pressure to increase. The star expands and consequently the temperature and energy generation rate drop if the gas is non-degenerate or dominated by radiation. In degenerate matter, the situation is more favorable for explosions because a large temperature increase leads to only a moderate increase in pressure.

However, there is another problem. If the rate at which nuclear fuel is consumed and the propagation speed of the burning front ("flame") after ignition is much smaller than the sound velocity, the star expands. The temperature and the rate of fuel consumption drop. It has been demonstrated in many numerical experiments that a Chandrasekhar mass C+O white dwarf only explodes if the burning front propagates with a velocity much faster than its laminar velocity ($\sim 100\,\mathrm{km\,s^{-1}}$). Therefore, models have been proposed in which the burning front begins to propagate with subsonic velocity due to heat conduction, but later speeds up to a fair fraction of the sound velocity as a result of turbulence. This mechanism of flame front acceleration is well known from combustion engines and also seems to work in stars. These models, called deflagration models, fit certain observational data very well, at least in their simple parameterized versions. However, if deflagrations are the answer, the physics of thermonuclear supernovae is very complex, due to the vastly different scales involved, ranging from the width of the front ($\simeq 10^{-3}\,\mathrm{cm}$) to scales comparable ro the radius of the white dwarf ($\simeq 10^{8}\,\mathrm{cm}$).

Numerical simulations require multi-dimensional hydrodynamics. They are very expensive and are unable to resolve all relevant scales. Despite considerable progress in modelling turbulent combustion for astrophysical flows, the correct numerical representation of the thermonuclear deflagration front is still a weakness of the simulations. Most methods are based on finite-volume techniques and the reactive-diffusive flame model, which artificially stretches the burning region over several zones of the computational grid to ensure an isotropic flame propagation speed. However, the soft transition from fuel to ashes stabilizes the front against hydrodynamical instabilities on small length scales, which in turn results in an underestimation of the flame surface area and of the total energy generation rate. Moreover, because the nuclear fusion rates depend exponentially on temperature, one cannot use the zone-averaged values of the temperature obtained this way to calculate the reaction kinetics.

We therefore decided to use a front tracking method to avoid some of these weaknesses. The method is based on the so-called *level set technique*, originally introduced by Osher and Sethian. They used the zero level set of a n-dimensional scalar function to represent $(n-1)$-dimensional front geometries. In contrast to the artificial broadening of the flame in the reaction-diffusion-approach, this algorithm treats the front as an exact hydrodynamical discontinuity. We have demonstrated that such a method can be applied to the supernova problem. However, we have also shown that even if one attempts to model the physics of thermonuclear burning on unresolved length scales by physically-motivated "Large Eddy Simulations" (LES), one still has to perform calculations with very high spatial resolution in order for the solution to converge. Here we present the first results of 3-dimensional simulations based on this approach. Computations in three dimensions are necessary because in two dimensions convective and turbulent structures are incorrectly described. For instance, they have a smaller surface-to-volume ratio than in 3D.

Our calculations were carried out on a Cartesian grid of 256^3 grid zones. The innermost zones had a spacing of $\Delta = 1.5 \times 10^6\,\mathrm{cm}$, which increased by 10% from zone to zone in the outer parts. The white dwarf, constructed in hydrostatic equilibrium for a realistic equation of state, had a central density of $2.9 \times 10^9\,\mathrm{g/cm^3}$, a radius of 1500km, and a mass of $2.8 \times 10^{33}\,\mathrm{g}$. It consisted of equal amounts of carbon and oxygen. To save computer time, only one octant of the star was simulated.

In the first simulation, the burning front was ignited at the center with an axisymmetric perturbation. Figure 2.12 shows a snapshot of the front geometry after 0.6 s. It is evident that the initial axial symmetry has disappeared completely, resulting in a larger flame surface than in a 2-dimensional simulation. As a result, the fuel consumption rate

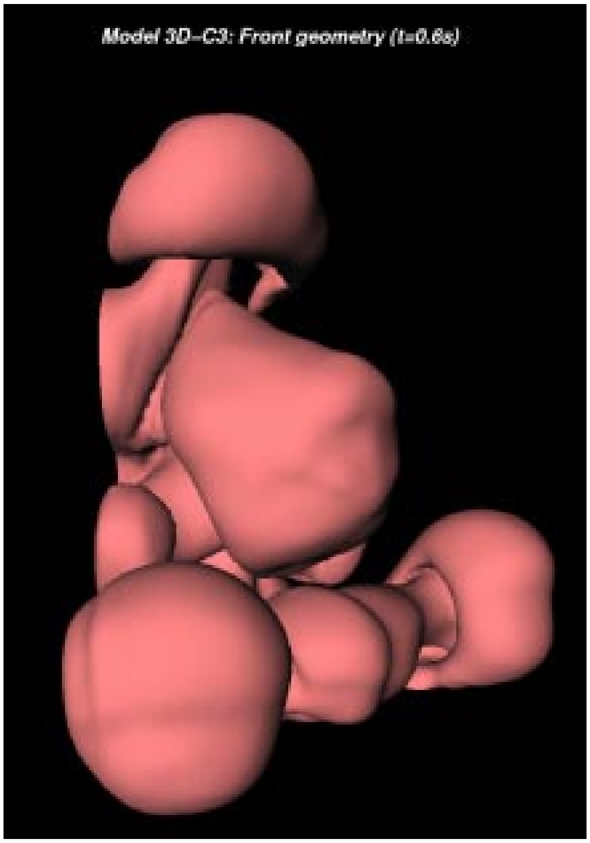

Figure 2.12: Burning front in a type Ia supernova simulation 0.6 s after the nuclear flame was ignited at the center of the white dwarf. The "mushroom-like" Rayleigh-Taylor structures are clearly visible.

and the total energy release is considerably higher in 3-dimensinonal than in a 2-dimensional simulations (see Fig. 2.13).

Although this simulation leaves behind a white dwarf that is unbound, the explosion energy and the expansion velocity of the partially burnt gas are too low and one is unable to to fit the observed lightcurves and spectra of type Ia supernovae. We then performed a second simulation with modified initial conditions. Since the thermonuclear explosion of the white dwarf starts in an inner core that is highly convective, one expects a distribution of "ignition spots" spread over part of the convective core. This is more realistic than the connected central burning zone of our first simulation. Snapshots of the geometry are shown in Fig. 2.14 and 2.15.

Figure 2.16 shows that the simulation results are in accord with our expectations. The explosion energy, which is also a measure of the amount of ^{56}Ni produced, is in good agreement with the observations of type Ia supernovae. Moreover, the fact that the explosion energy depends sensitively

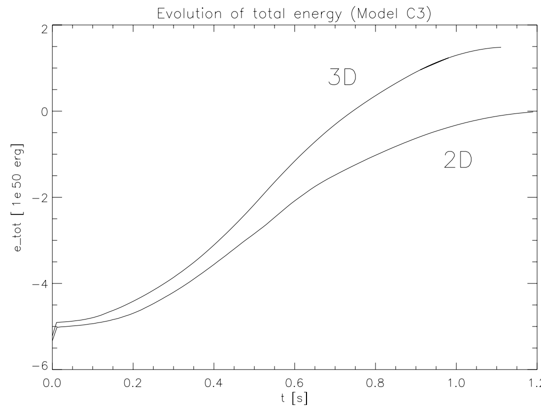

Figure 2.13: Total energy of supernova models computed in two and three spatial dimensions, respectively. While the 2d-model is barely unbound at the end of the simultion, the 3d-model explodes.

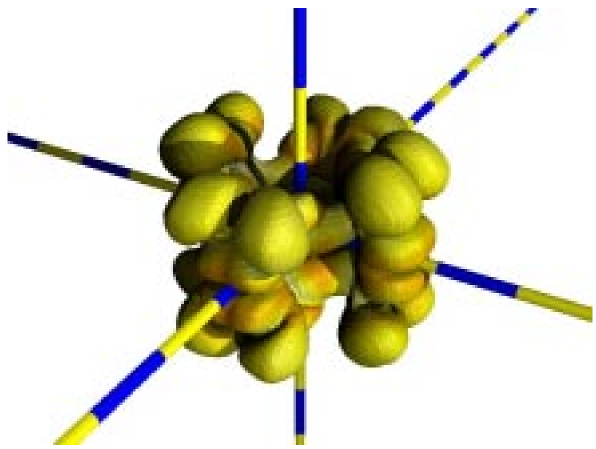

Figure 2.14: Structure of the burning front of a model with many off-center ignition spots. The snapshot is taken 0.2 s after ignition. The length-scale is shown in color on the crossing bars. The color-coding of the burning front displays its velocity: Red means low and yellow high velocities.

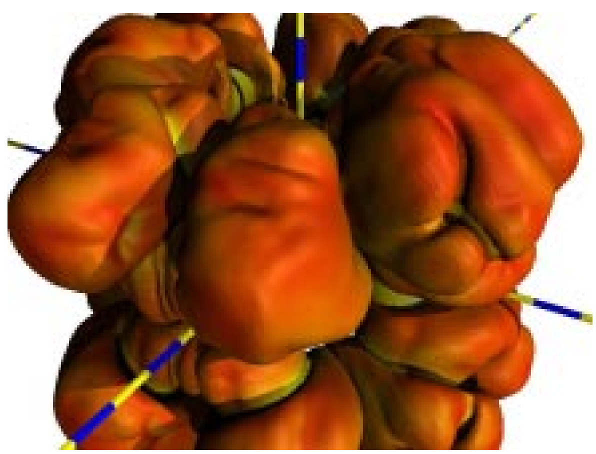

Figure 2.15: Same as previous figure, but after 0.48 s.

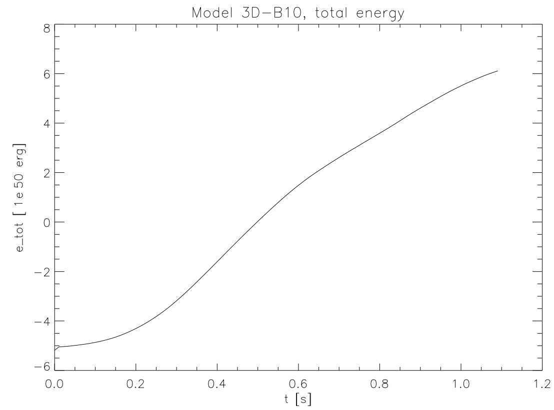

Figure 2.16: Total energy of a 3-dimensional model with modified ignition. Now the explosion energy is in good agreement with observed type Ia supernovae

on the ignition conditions can help explain the observed variance of nickel masses. (Martin Reinecke and Wolfgang Hillebrandt)

2.6 The Longterm Evolution of Extragalactic Jets

Extragalactic jets are well collimated gas flows that are generated in the centers of active galaxies. Many of these jets are observed to propagate with a velocity near the speed of light close to the source. During their lifetimes of a few tens of millions of years they transport tremendous amounts of energy millions of light years into intergalactic space. At the head of the jet, the kinetic energy of the beam is dissipated and partly converted to radiation. These are the 'radio lobes' seen in radio telescope images. Little is known about the process by which the jets are generated. It is very likely that accretion of matter onto a supermassive black hole at the center of the galaxy provides the energy needed to power the jets.

Several mechanisms have been proposed that can produce and collimate a relativistic jet, and these mechanisms would lead to different jet compositions. Thus, if one knows whether the jet consists of electrons and protons (i.e. ionized hydrogen) or of electrons and positrons (i.e. a pair gas), one would learn a great deal about the jet formation process.

Hydrodynamic simulations of relativistic jets were not feasible until the early 1990s, when appropriate numerical methods became available. The main obstacle are the relativistic hydrodynamic equations, which are substantially more complicated and more strongly coupled than the non–relativistic ones. Moreover, previous simulations described the thermodynamic state of the jet by means of a simple ideal gas law with constant adiabatic index. Studying compositional effects in jets requires the more complicated Synge equation of state which describes a relativistic Boltzmann gas consisting of electrons e^-, positrons e^+ and protons p. The production (annihilation) of electron positron pairs can be neglected due to the low gas density of the intergalactic medium. Mixing is the only way to change the composition.

At the Max–Planck–Institut für Astrophysik, simulations of the long-term evolution of axisymmetric jets with different compositions have been carried out. The aim has been to find similarities and differences in the evolution and morphology of jets of different composition. The simulations employed the Synge equation of state and covered about half of the jet's total evolution time. This is twice as long as any previous simulation. These simulations cover a time span of about 5.3 million years, and were performed on a computational grid of 3.6 million computational zones. Axial symmetry around the direction of jet propagation was assumed. The simulations required about 150 hours of computing time on the NEC SX-5 supercomputer of the Rechenzentrum Garching (RZG). A full 3D treatment of the jet evolution would have required several billion zones and would have taken about 30 years on the same machine.

The simulations involve free parameters which can only be constrained by observational data. The parameters were chosen so that the kinetic power of the simulated jets (which can be converted to radiation) was typical of powerful extragalactic jets ($L_{kin} \approx 10^{46}$ erg/s), and the initial jet propagation velocity was 0.2 c. The ambient medium had a density of 1000 protons per cubic meter (or $1.67\,10^{-27}$ g/cm^3), a temperature about 10 million degree Kelvin, and consisted of ionized hydrogen (i.e. nonrelativistisc protons and electrons). The composition and thermodynamic state of the beam was varied.

Long term simulations were performed for a cold baryonic jet (ionized hydrogen), a cold pure leptonic jet (only electron positron pairs) and a hot pure leptonic jet. All simulated jets were very light, i.e. their density was much smaller than that of the ambient medium ($10^{-5} \ldots 10^{-3}$), and their beam Lorentz factor was ~ 10.

The simulations show that the gross morphology and dynamics of jets of different composi-

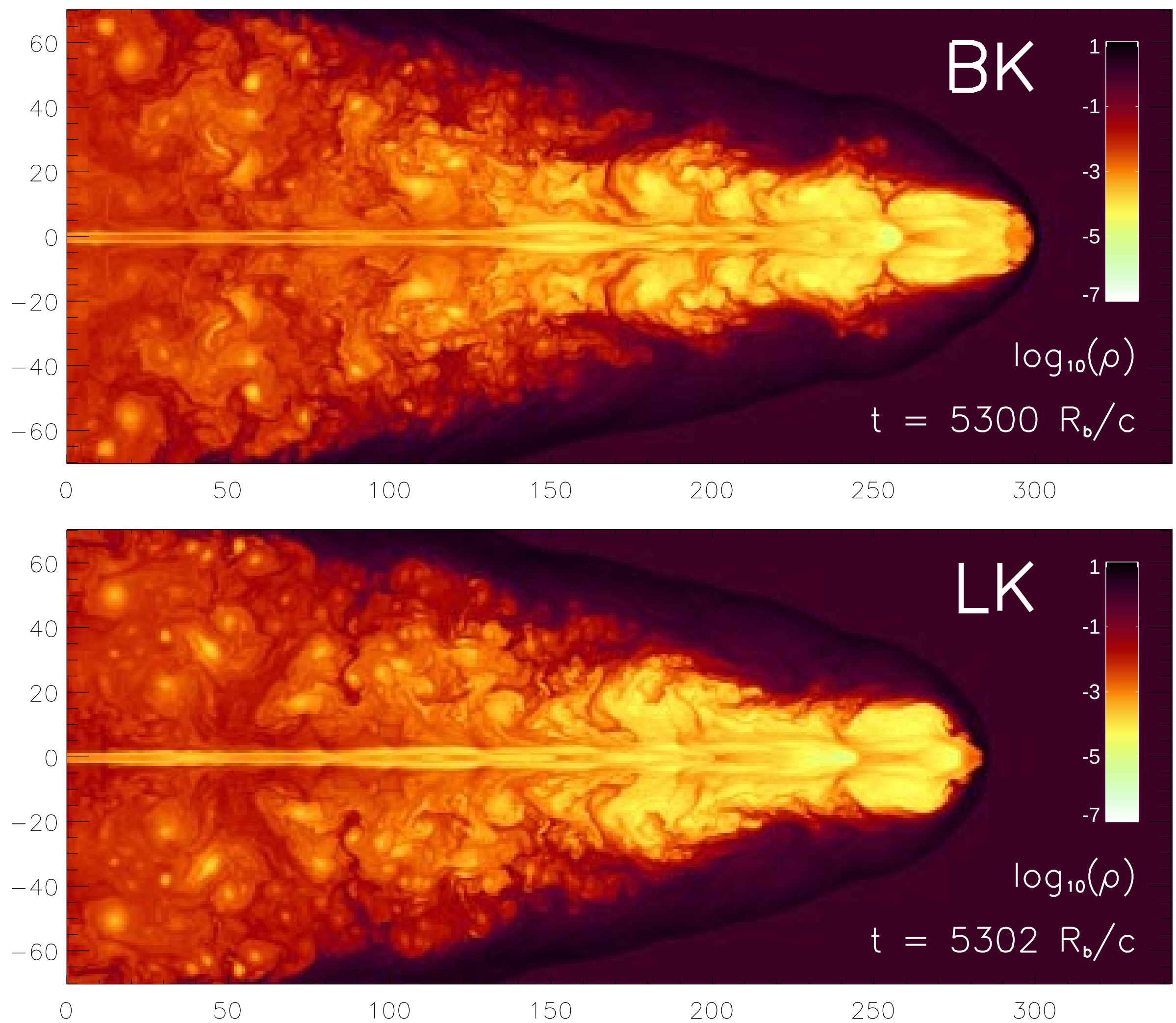

Figure 2.17: Rest mass density of a powerful jet of ionized hydrogen (top) and of an electron positron jet (bottom) at an age of 5,3 million years (axis units: 100,000 light years). The relativistic jet drives a bow shock (dark shape) into the intergalactic medium. The beam is surrounded by a turbulent cocoon where jet and ambient material mix.

tion are very similar. The values and distribution of dynamically important quantities, like density and pressure, differ very little between the models (Fig. 2.17 and 2.18). Substantial differences are only observed for the beam (due to different initial conditions).

The overall dynamical evolution of the different jet models is also very similar. It consists of two phases: 1) an early phase when vortex shedding at the jet head has not yet started and when the jet propagation speed can be quite accurately estimated from a 1D ram pressure argument. 2) a subsequent phase when the jet strongly decelerates, exhibits semi-periodic vortex shedding and begins to inflate an extensive lobe.

If the deceleration of the jet is taken into account, the results of the simulations are in good agreement with a simple analytical estimate proposed by Begelmann and Cioffi more than a decade ago. They assumed a constant kinetic power and a constant propagation speed for the jet. They also assumed that the pressure in the cavity blown by the jet was equal to the ram pressure of external medium, and derived the change in the width and the pressure of the cavity as a function of time.

In agreement with the analytic model, the jet propagation speed v_h evolves during the 1d phase as $v_h \propto t^{\alpha}$, with $\alpha \approx -0.15$. This also holds for the subsequent 2D phase, where $\alpha \approx -0.35$. Worse agreement is found for the width of the cavity, which grows slightly slower than predicted by the estimate. This is because not all the kinetic energy of the jet is converted into internal energy. Instead, it drives the backflow in the cocoon.

For the range of initial conditions covered by the simulations so far, surprisingly few differences were found for the evolution and morphology of jets of different composition. The development of the jet is already well defined from its power and initial speed, as well as the properties of the (homogeneous) ambient medium. Whether this is also true for other choices of initial conditions will be investigated in future simulations.

Although different composition does not lead to important differences in the dynamics and morphology of the jets, their temperature distribution and evolution are strongly affected. A detailed analysis shows that jets of different compositions may be distinguished using high resolution spectroscopic observations in the X-ray. (Ewald Müller and Leonhard Scheck)

2.7 Self–Interacting Dark Matter

Currently popular models for the formation of structure in the universe assume that dark matter is made of vast numbers of free elementary particles which are *collisionless*, i.e. they interact with each other and with other ordinary matter only through gravity. In addition, the dark matter particles are assumed to be cold, i.e. they were non-relativistic when they decoupled from other matter at an early epoch in the evolution of the Universe.

The models have been remarkably successful in fitting a wide range of observations. While structure on large scales is well reproduced by the models, the situation is more controversial for the structure of highly nonlinear, dark matter-dominated systems. The predictions based on analytical calculations and numerical simulations appear to conflict with observations on galactic and subgalactic scales. The observation of the rotation curves of dwarf galaxies, i.e. the rotation speed as a function of the distance from the galactic centre, suggest that these systems have low density cores with shallow profiles. Recent high-resolution numerical simulations show that dark matter halos surrounding such galaxies should have steep and cuspy (nearly divergent) central density profiles. In addition, far too few galaxies are observed within our Local Group compared to the predicted abundance of dark matter halos.

Recently Spergel and Steinhardt (2000) proposed an alternative model in which the dark matter particles collide elastically from time to time as they move through galaxies and galaxy clusters. They argued that this model might agree better with the inferred amounts of dark matter at the centre of dwarf galaxies.

Stimulated by this suggestion, scientists at MPA and collaborators at CfA-Harvard and Padova Observatory carried out very large computer simulations of the formation of a galaxy cluster to study how such elastic collisions between dark matter particles might affect the observed structure and density profiles of clusters. The calculations were carried out on the T3E supercomputer of the Max-Planck Society's computer centre in Garching, using a modified version of the parallel simulation code GADGET. A variety of collision probabilities were chosen so that typical particles near the centre of the final cluster had a few, a few tens, a few hundreds, or a very large number of collisions over the lifetime of the universe. As Figure 2.19 clearly

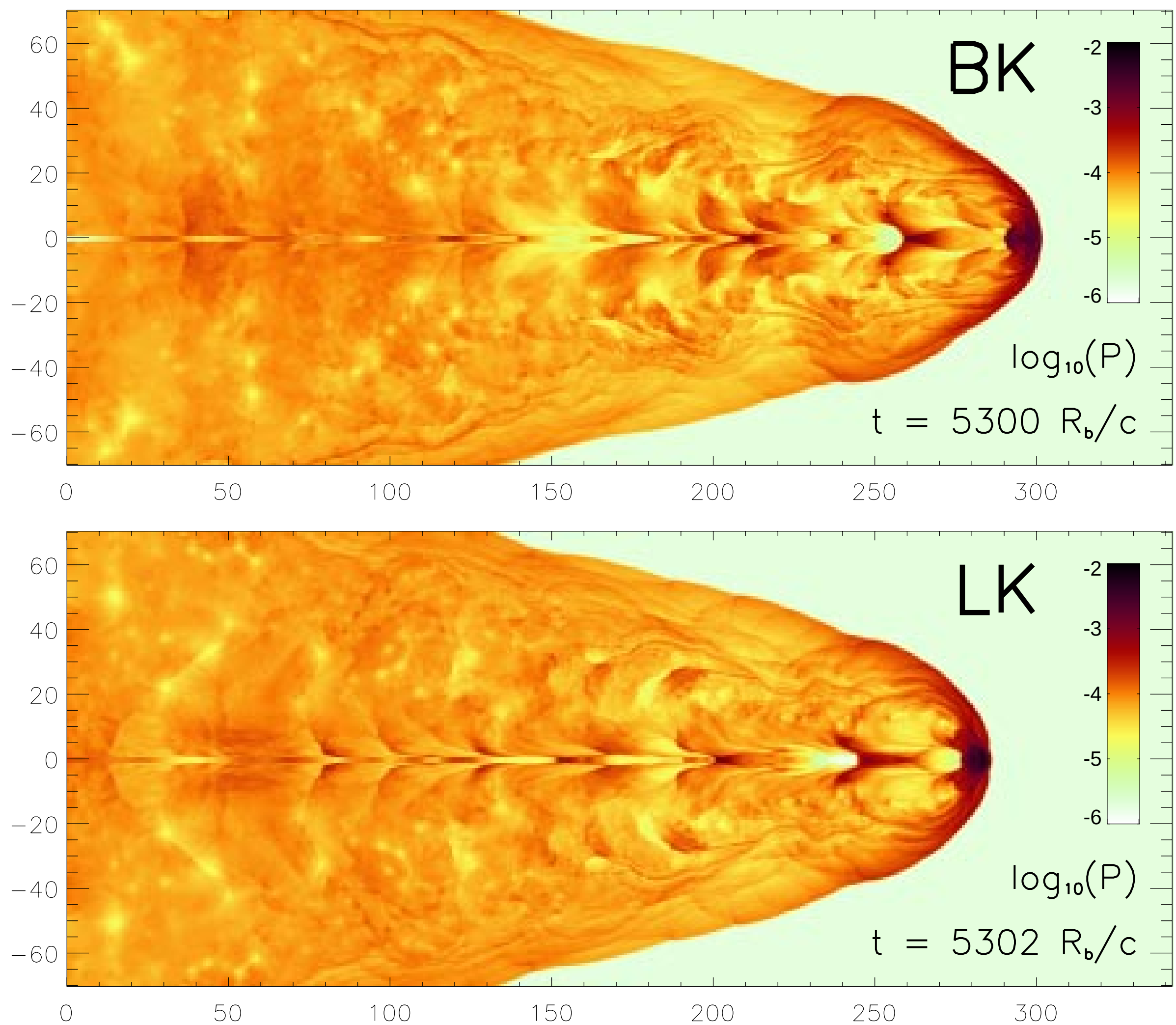

Figure 2.18: Same as Fig. 2.17 but showing the pressure.

shows, collisions between dark matter particles do indeed affect the structure of the final cluster – more frequent collisions lead to clusters which are rounder and have lower central densities.

The low central densities may appear to agree better than the collisionless case with the inferred amount of dark matter at the centre of dwarf galaxies. However, the less concentrated mass distributions also cause the clusters to be significantly less efficient at producing gravitationally lensed images of background galaxies. The gravitational field of mass clumps such as galaxy clusters cause a reflection of light bundles. The images of distant galaxies are aligned and deformed, and in the extreme case giant luminous arcs are seen. This case is referred to as strong lensing. The shapes and positions of the arcs provide a detailed picture of how matter is distributed near the cluster centre, and it can be used to tell which, if any, of our simulated dark matter distributions look like real clusters. To make a direct contact with observations, the research group at MPA carried out ray-tracing simulations of strong lensing and computed the so-called lensing cross-section – a measure of the ability of the simulated clusters to produca arcs.e

These calculations show that even a few collisions per particle over the age of the universe are enough to reduce the effectiveness of cluster lenses to the point where they can no longer produce the dramatic arcs we observe (see Fig. 2.19). These results suggest that arcs as strong as those observed in many clusters of galaxies can only be produced if collisions between dark matter particles are very rare. Therefore, in the simplest model, self-interacting dark matter can help with the density cusp problem, but it seems difficult to reconcile with the existence of the giant arcs (Naoki Yoshida).

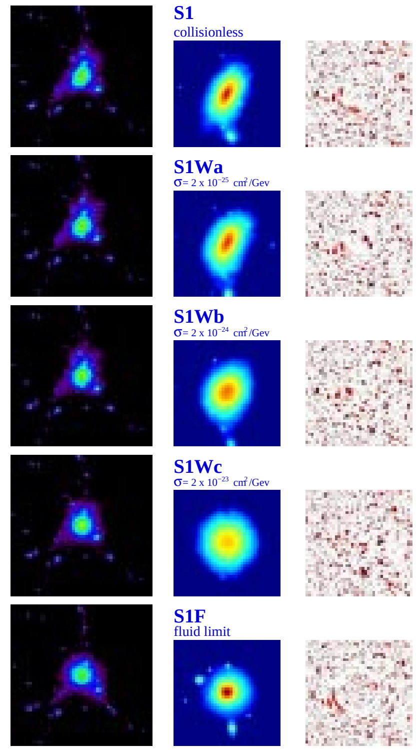

Figure 2.19: The left pictures show the dark matter distribution in our simulated clusters. The box size is 15 Mpc/h on a side. The pictures in the middle column are enlargements of their central 2 Mpc/h regions. The scattering cross-section per unit mass is given to the top of the middle panels. In the S1 simulation the dark matter particles are assumed to be collisionless. In the S1Wa simulation particles near cluster centre have about a few collisions over the age of the universe, and the corresponding numbers are 10 for S1Wb, and 100 for S1Wc, respectively. The S1F simulation is for the extreme case in that the dark matter particles strongly interact with each other and hence behave as a "fluid". The shape and concentration of the cluster centre are clearly affected by particle interactions. The right panels are the results of our ray-tracing simulation of gravitational lensing. Shown are the distorted images of background 'galaxies' - elliptical shapes distributed in redshift space such that they reproduce the redshift distribution of the galaxies in the Hubble Deep Field North and South. It is clearly seen that the dark matter interactions significantly reduce the lensing ability of clusters (except the extreme case of S1F). The number of giant arcs is substantially smaller for S1Wa-S1Wc than for the collisionless case.

2.8 Radio Signatures of Giant Shock Waves of the Cosmological Structure Formation

The large-scale structure of the Universe, marked by groups, clusters, superclusters, filaments, and sheets of galaxies, is still in the process of formation. The gravitational attraction of overdense regions, such as clusters and filaments, pulls matter (gas, galaxies and dark matter) away from its initial environment. Gas falls out of the cosmic voids

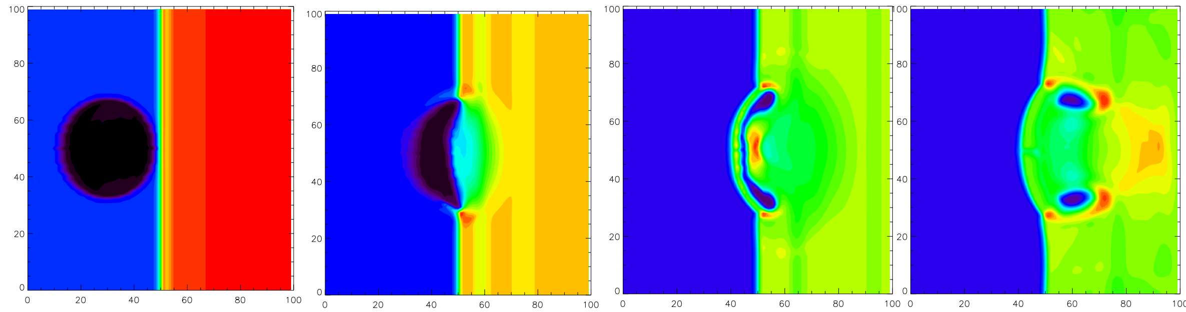

Figure 2.20: Sequence of density slices of a radio plasma blob going through an environmental shock wave.

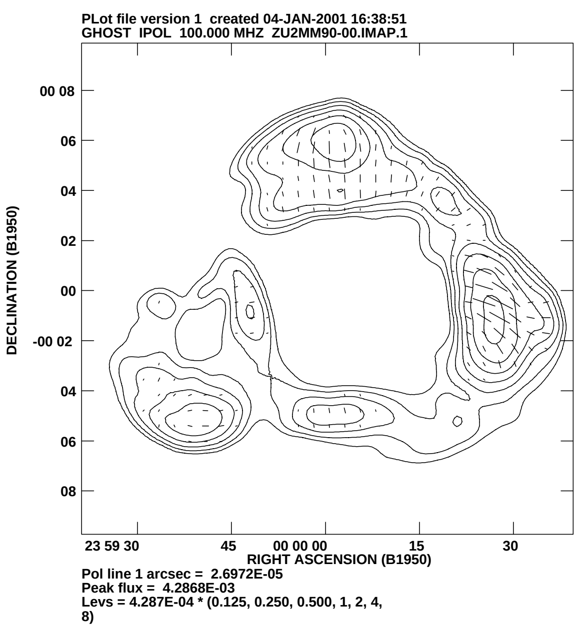

Figure 2.21: Radio map of a 3D MHD simulated initially spherical blob of radio plasma after passage of an environmental shock wave. The projection is face on. The displayed vectors give the radio E-polarization.

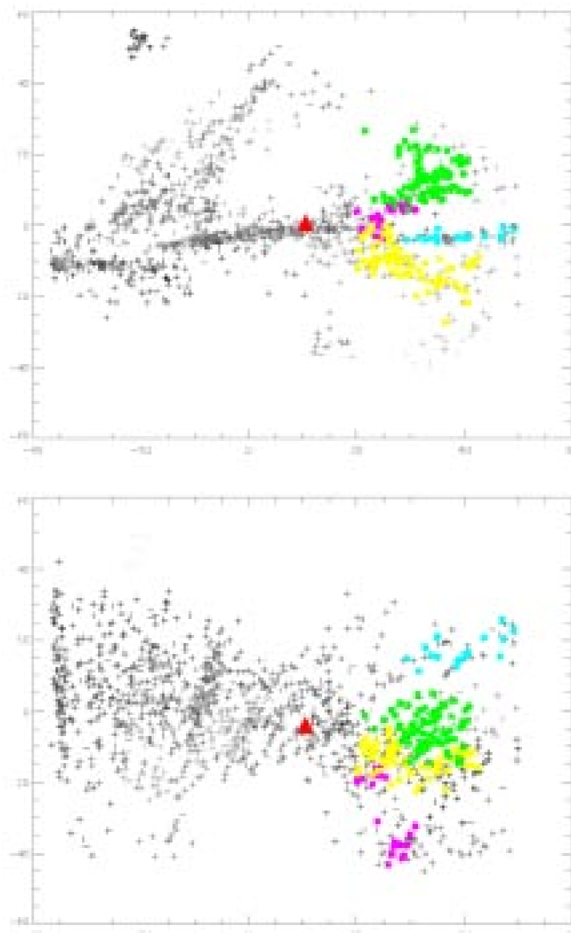

Figure 2.22: Pisces-Perseus Supercluster of galaxies in two projection of the galaxies' redshift space distribution. Top: sky projection. Bottom: view from above. NGC 315 is marked as a red triangle. The merging sub-filaments are marked by different colors. The axes give distances in units of Mpc (for $H_0 = 65\,\mathrm{km/s/Mpc}$).

onto the sheets and filaments of galaxies with velocities of a few hundreds of kilometers per second. There it is shocked when it collides with the dense gas in these structures. Within the sheets and filaments, the gas follows the gravitational potential towards the clusters of galaxies. The infalling gas collides with the intra-cluster medium with a velocity of a few thousand kilometers per second and heats it to temperatures of $10^7 - 10^8$ Kelvin, so that it is detectable by its thermal X-ray emission.

The flow of gas is not quite as uniform as the above picture suggests. A significant fraction of the gas falling onto clusters is bound inside galaxy groups and other large structures. The merging events of rich clusters are, to our knowledge, the most energetic events after the Big Bang. Kinetic energies of the order of 10^{64} erg are dissipated in giant shock waves. Only in recent years have X-ray telescopes obtained the necessary spatial and spectral resolution to detect the signatures of such shock waves in a few dense clusters.

Shock waves would have been identified 20 years earlier if the nature of the observed mysterious *cluster radio relic* sources had been understood at that time. Cluster radio relics are irregularly shaped, Mpc-sized regions of extended radio emission, found preferentially at peripheral locations in merging clusters. Relics often exhibit a high degree of linear radio polarization. The steep radio spectra indicate that the population of relativistic electrons that produce the synchrotron radio emission is old. The name 'relic' was choden to suggest that these old objects could be former radio cocoons of extinct radio galaxies. However, this explanation has an important difficulty: nearby galaxies are often too distant to have released the relic's radio plasma and to have reached their present locations. Some process must have accelerated the radio emitting electrons in-situ within the relics.

The shock waves produced by cluster mergers could easily provide the necessary energy to power the cluster radio relics. This is supported by X-ray observations, which show that shock waves exist at the locations of the cluster radio relics in several clusters (A754, A1367, A2256, A3667).

A theoretical study undertaken by Torsten Enßlin (MPA) and Gopal-Krishna (NCRA Pune, India) has shown that fossil radio plasma can be re-illuminated by the compression of an environmental shock wave up to $2 \cdot 10^9$ years after it was released. Because the sound speed in the relativistic radio plasma is high even in the fossil, non-radio emitting phase, the shock wave can only compress the radio plasma adiabatically. However, a relativistic plasma has a soft equation of state, so the compression factor can be huge. The compression shifts the cooling cutoff of the electron energy spectrum to higher energies, amplifies the magnetic fields, and therefore causes the invisible fossil radio plasma to re-illuminate.

Although this is a reasonable scenario, it is not yet proven. Recent 3-dimensional magneto hydrodynamical (MHD) simulations at the MPA (Marcus Brüggen and Torsten Enßlin) provide strong evidence in favor of this process. A hot, magnetized blob of radio plasma, embedded in a colder, fast flowing environment is transformed into a torus-like structure when it passes through a shock wave in the environmental flow (Fig. 2.20). The magnetic fields are aligned with the torus structure, leading to a characteristic radio polarization pattern (E-vectors perpendicular to the torus, see Fig. 2.21). A number of new, high resolution polarization maps of radio relics exhibit very similar torus-like morphologies with the predicted polarization pattern. The hydrodynamical process of torus formation requires that the precursor of the torus have an internal sound speed much larger than the shock speed. This occurs naturally in the above scenario, because the fossil radio plasma, which has a high internal sound speed, is revived and is able to produce radio emission in shock waves. Observations show the radio relic in the Coma cluster is morphologically connected to the radio plasma outflow from a nearby radio galaxy. This also supports the idea that cluster radio relics are made from old radio plasma.

The sensitivity of radio plasma to the environmental *'weather conditions'* can be used to probe not only the thermodynamical state of the gas, but also the flow of the intergalactic gas in density and temperature regimes undetectable by X-ray telescopes. For example, the giant radio galaxy NGC 315 exhibits morphological distortions and spectral peculiarities. An international collaboration (MPA, MPIfR Bonn, Universities of Bonn and Toronto, and IRA del CNR Bologna) interpreted these as signatures of a giant environmental shock wave. A shock wave at the location of NGC 315 would very likely result from gas flows colliding along several sub-filaments joining the main filament of the Pisces-Perseus Supercluster (Fig. 2.22).

Further theoretical studies of the interaction of radio plasma with the intergalactic *weather* are underway at the MPA. Their goal is to use radio plasma as a new, powerful tool to probe the dynamics of cosmic structure formation. (Torsten Enßlin)

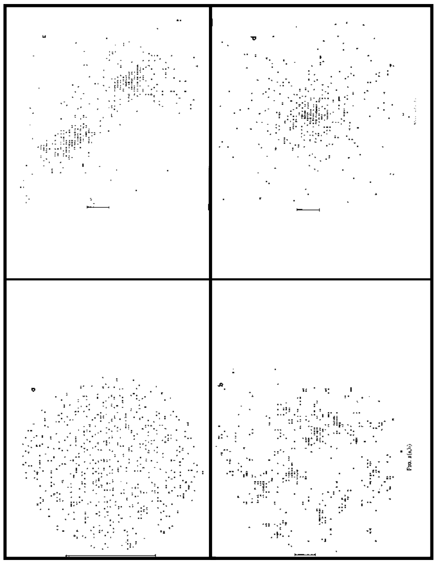

Figure 2.23: The evolution of a cluster of 700 galaxies in the 1976 simulation Simon White

2.9 High Resolution Simulations of Cluster Formation

In 1976, an article entitled "The Dynamics of Rich Clusters of Galaxies" was published in the Monthly Notices of the Royal Astronomical Society. In this paper, a young student named Simon White presented a numerical integration of the equations of motion of a system of 700 particles. Each particle represented an individual cluster galaxy, with a mass drawn from a Schechter function. The particles were inititially distributed at random in a spherical volume and given radial expansion velocities proportional to their distances from the centre of the sphere. The calculation, which took 260 minutes on an IBM 370/65, showed that the cluster formed in an extremely inhomogeneous fashion by the continual formation and amalgamation of subcondensations (2.23). Mass segregation effects in the simulation were strong, with more massive galaxies concentrated towards the centre of the cluster and less massive galaxies populating the outer regions.

Nearly 25 years later, faster and more powerful computers have led to spectacular advances in simulations of cluster formation. The figure on the back cover of this report shows an image from a modern high resolution cluster simulation carried out by Volker Springel and collaborators at the MPA. This simulation contains a total of 70 million particles, each with a mass of $\sim 5 \times 10^7\, M_\odot$. It was run using the new parallel tree-code GADGET on 512 processors of the Cray T3E at the Rechenzentrum Garching and took a total of 360 hours to complete. Rather than an individual galaxy, each particle in the simulation represents a unit of weakly interacting cold dark matter, which is now believed to constitute 80-90% of the total matter density of the Universe.

To generate the initial conditions, a lower resolution cosmological simulation of a large volume of the Universe was carried out and a suitable target cluster was selected. In a second step, the cluster was re-simulated using greatly increased force and mass resolution. Even though the initial conditions are very different to those of the 1976 calculation, the conclusion that clusters form through an inhomogeneous amalgamation of sub-condensations remains essentially unchanged. What *has* changed, is the detail with which these subcondensations can be studied in the simulation and what they are now believed to represent.

In their work, Springel and collaborators devised algorithms for identifying substructure in the cluster and tracking its evolution over time. They found that most of the dense 'subhalos' of dark matter, visible as bright dots in the figure on the back cover , originated in the cores of halos of galactic mass at high redshifts. When these galaxy halos fell into the cluster, the outer halo material was quickly tidally stripped and mixed into the general intracluster medium. However, the dense inner cores of the halos were generally able to survive for much longer periods of time. When simple estimates were made for how much gas would have been able to cool and form stars in each of these cores, the resulting distribution of galaxy masses and luminosities was found to be in remarkable agreement with observational determinations of the cluster galaxy luminosity function, all the way from the predicted numbers of faint 'dwarf' galaxies to the estimated luminosity of the bright central dominant (cD) galaxy.

The MPA group also tracked the merging of subhalos within the cluster as it formed. There is direct observational and theoretical evidence that mergers destroy disk galaxies and form bulges or spheroids. The fact that mergers between galaxies are frequent during the formation of a cluster has been proposed as a possible explanation for the origin of the so-called morphology-density relation, i.e. the observed correlation between the fraction of bulge-dominated galaxies and local overdensity. Springel and collaborators showed explicitly for the first time that mergers between cluster galaxies lead to a correlation between galaxy morphology and clustercentric distance in excellent agreement with observations. Bright elliptical galaxies were found to be somewhat more centrally concentrated than faint elliptical galaxies, but interestingly no such luminosity segregation was found for disk-dominated galaxies.

Thus in contrast with the 1976 simulation, which illustrated how a collection of fully-formed galaxies might fall together to form a cluster, the new simulations with 5 orders of magnitude increase in mass resolution, demonstrate how the galaxies themselves form as the cluster assembles through merging and accretion. In future work, the MPA group intends to make use of the same simulation techniques to study how galaxies form in lower density environments, thus providing a more complete picture of galaxy evolution in the Universe as a whole and facilitating comparisons with a wider range of observational data (Guinevere Kauffmann).

2.10 Inflation and Metric Perturbations

Two of the most obvious, yet really remarkable, statements about our universe are that it is very large and that it looks the same in all directions. To make the first statement more precise, compare the characteristic length scale for variations of the cosmic geometry, the so-called curvature radius l_c, with the Planck length l_{pl}, i.e. the typical scale where gravitational interactions become as strong as the other natural forces. Today's observations indicate that $l_c \geq 10^{61} l_{pl}$, that is the curvature radius is least as large as the present cosmological horizon, and possibly much larger (the horizon scale is defined as the distance light has traveled since the beginning of the universe). This fact is known as the "flatness problem" since an infinitely large curvature radius corresponds to a Euclidean, or flat, spatial geometry, and there is no a priori reason why our universe should be Euclidean to such high accuracy. A good example of the second statement is the temperature of the cosmic microwave background radiation (CMBR), which is identical everywhere to within one part in 10^5. This is surprising as it applies not only to neighboring points in the sky, but also to regions that had never been in causal contact at the time these conditions were set. Hence this question is known to cosmologists as the "horizon problem".

It may appear that one could solve the flatness problem by choosing a different unit, say, the cosmological horizon scale $l_h \sim ct$, where c is the speed of light and t the age of the universe. This choice obviously turns the present curvature scale into a number of order one $(l_c(t_0)/l_h(t_0) \geq 1)$, but the problem reappears if one tries to explain the universe today in terms of what it was like when the horizon size was only slightly larger than l_{pl}, that is at $t_{pl} \sim l_{pl}/c$. This is because the curvature scale grows as a power of time that is less than one as long as the energy of the universe is dominated by ordinary matter. Specifically, $l_c \sim t^n$ where $n = 1/2$ for a radiation dominated epoch and $n = 2/3$ if the dominant contribution comes from nonrelativistic particles. Consequently, the ratio of curvature and horizon scales near t_{pl} is $l_c(t_{pl})/l_h(t_{pl} \geq (10^{61})^{1-n}$. The flatness problem is therefore independent of the choice of units.

The horizon problem has a very similar origin. Just like l_c, the spatial distance l between any two points in the universe grows like t^n, so two points that are now separated by, say, $l(t_0) \approx 10^{-3} l_h(t_0)$ were at a distance of $l(t_{pl}) \approx 10^{-3}(10^{61})^{1-n} l_h(t_{pl})$ at the Planck time. Since light could not have traversed this distance if $n < 1$, the points would not be in causal contact at this time, and there is no reason why they should have almost exactly the same temperature.

As a number of people discovered in the early eighties, both problems can be solved if the universe was dominated, for some period of time, by a form of energy with negative pressure. During this time, the distance between any two points grows almost exponentially, easily solving both the flatness and horizon problems if the period lasts sufficiently long. Negative pressure is provided by anything whose energy density remains constant instead of being diluted by cosmic expansion, such as the so-called "cosmological constant" that is often attributed to the vacuum energy of space-time. In particle physics models, a phase that is temporarily dominated by a (nearly) constant energy density can be constructed by means of a scalar field that slowly evolves towards the minimum of an effective potential. The potential energy then acts as the (temporary) cosmological constant. Upon reaching the minimum of the potential, the scalar field decays into ordinary matter and marks the beginning of the standard "hot big bang" theory. The phase of quasi-exponential expansion, named "inflation" by Guth in 1981, elegantly solves some of the most worrisome shortcomings of the hot big bang model and has therefore become a part of the widely accepted standard paradigm of cosmology. This paradigm has developed in spite of cosmologists not having discovered any fundamental scalar particles in nature to date.

It was soon realized that inflation has a useful side-effect: quantum fluctuations of the scalar "inflaton" field naturally give rise to small perturbations of the geometry of space-time which remain imprinted after the end of inflation. Later, after $l_{\rm h}$ has reached the extent of the perturbations, they grow to form stars, galaxies, and galaxy clusters. They are also responsible for the tiny fluctuations of the CMBR temperature. Inflation predicts, in its simplest form, that the distribution of the perturbations is nearly Gaussian and scale-invariant (in other words, the probability for a perturbation of a given magnitude is independent of its angular extent). Both predictions are in good agreement with current observations of CMBR fluctuations and the statistics of large scale structures in the universe.

There is, however, an interesting quandary related to the fact that inflation blows up a tiny speck of space-time to cosmological scales. In most scenarios, the inflationary phase lasts much longer than needed to solve the flatness and horizon problems. In fact, the quantum fluctuations whose consequences we observe today in the CMBR, should generally have wavelengths much *smaller* than $l_{\rm pl}$ at the beginning of inflation. As a direct consequence, their energy was far above the Planck energy at this time, in a regime where quantum interactions with space-time cannot be ignored. Drawing upon our understanding of quantum field theory at much lower energies to describe the state of the inflaton field in this so-called trans-Planckian regime is highly questionable.

A very similar problem exists in the theory for Hawking radiation of black holes. There, the quantum fields that are identified as Hawking particles by a far-away observer, originate from exponentially blueshifted, trans-Planckian vacuum quantum fluctuations that pass through the collapsing star and barely escape the event horizon. Various researchers have investigated the trans-Planckian problem in this context for almost a decade. A common approach, proposed by Unruh in 1995, is to replace the linear dispersion relation between energy and momentum by a modified, nonlinear one. The idea is based on the observation that in condensed matter systems that allow an effective quantum field description of collective excitations (such as phonons in fluids), on scales much larger than the mean-free-path of the microscopic constituents, the presence of microscopic degrees of freedom is often signalled by nonlinearities of the dispersion relation. In other words, one uses the well-known theory of fluids as a testbed for the unknown microscopic description of space-time itself. The general consensus of researchers in the black hole community is that the thermal spectrum of Hawking radiation is unaffected by such modifications of the dispersion relation, provided that the black hole is very large in Planck units.

By virtue of the above-mentioned similarities, the same technique can be employed to explore the trans-Planckian problem of inflation. Work at the MPA and the University of Tours, France, has demonstrated that the standard predictions for the statistics and scale-invariance of inflationary fluctuations are insensitive to Planck scale dispersion for a very large class of nonlinear dispersion relations. Specifically, if the dispersion relation changes more slowly than the field oscillates, initially trans-Plankian quantum fluctuations smoothly evolve into the "standard" quantum fluctuations known from quantum field theory, rendering existing predictions of inflation unchanged. In full agreement with the black hole results, this analysis is valid as long as the horizon scale $l_{\rm h}$ during inflation is very large in Planck units.

Ongoing work in collaboration with Achim Kempf at the University of Florida investigates a different kind of possible Planck scale modification of inflationary theory. Assuming that gravitational effects are manifested in a short distance "fuzziness" of space-time, the Heisenberg uncertainty relation for location x and momentum p of a particle (i.e., $\Delta x\,\Delta p \geq \hbar$) can be modified to give rise to a finite smallest $\Delta x \sim l_{\rm pl}$ regardless how large Δp is made. Implementing this relation in the theory of inflation, one can observe how quantum modes are "created" as their wavelength is stretched beyond $l_{\rm pl}$ by cosmic expansion. The effects of this process on the predictions of inflation are currently being analyzed.

Other work at the MPA, in collaboration with scientists from the IAP at Paris, investigates cosmic processes at the end of the inflationary epoch. Immediately after inflation the cosmic energy density is dominated by condensate which may be understood as a coherent assembly of inflaton particles. This energy density has to decay into radiation in order to reheat the universe, the remainder of which is now observed as the CMBR. For a long time it was thought that the process of "reheating" is accomplished by the decay of individual inflaton particles of the condensate. Only recently was it realized that due to the coherence of the inflaton condensate, other particles coupled to the inflaton may be excited coherently as well, in a process known as "parametric resonance". In the context of inflationary cosmology this process has been termed "preheating".

It was suggested that these coherent excitations may occur not only on subhorizon scales but also on scales larger than $l_{\rm h}$ at the time of preheating, possibly even corresponding to the scales of the presently observed large scale structure of the universe. Since resonant amplification of large scale modes appears most efficient, such processes could potentially have "disastrous" consequences for the universe, as they would destroy the cosmic near-homogeneity as observed in the CMBR. Turning these arguments around, if these suggestions are correct, and since the universe is not extremely inhomogeneous, wide classes of inflaton interactions with other particles would be ruled out. However, work at the MPA and IAP has shown that this is generally not the case. In particular, those couplings leading to efficient parametric resonance of super horizon bosonic modes after inflation, also give rise to efficient damping of the same modes *during* inflation. The net result of these competing processes is such that bosonic fields are not disastrously amplified during preheating, unless one finely tunes the coupling of the inflaton to these fields. In any case, resonant amplification of modes on much smaller scales may still occur. These modes may lead to the production of primordial black holes (PBHs) with small masses which, if produced too abundantly, are in conflict with observations. PBH formation during preheating, and the possible implications of a population of PBHs on the subsequent evolution of the universe, are currently being studied at the MPA. (Jens Niemeyer and Karsten Jedamzik)

3 Research Activities

3.1 Stellar physics

The Sun and the Solar System. The internal structure of the Sun has been studied in surprising detail by methods of *helioseismology*, which make use of the roughly 10^5 disctinct modes in which the Sun is observed to oscillate. One of these methods is *time-distance helioseismology*, closely analogous to methods of analyzing seismic data of the earth. With this method, detailed maps of small variations in the travel times of sound waves below the solar surface have been made. A difficulty lies in interpreting these maps, since changes in travel time can have different causes, of which a difference in sound speed is only one. M. Brüggen and H. Spruit have studied the effect of temperature variations below the surface on travel times. They showed that higher temperatures (higher propagation speeds) in many cases lead to *longer travel times*. This is because higher temperatures also cause the solar envelope to locally expand somewhat, increasing the path length traveled by the waves. They argue that this effect will usually dominate, so that shorter travel times have to be interpreted as caused by lower rather than higher subsurface temperatures. — M. Brüggen also studied the interaction of sound waves with the turbulence in the solar convection zone. The sound waves are scattered by the turbulent eddies in the solar convection region causing temporal fluctuations of the cross-correlation signal between two points on the solar surface. Hence one can probe both the strength and the scaling of the convection by measuring the variation in the correlation. By examining wave paths of different lengths, fluctuations on several different scales can be addressed. By using wavepaths that penetrate to greater and greater depths, the spatial variation of turbulence can be studied and one can search for latitudinal variations of the convection. The ultimate goal is to invert the scintillation of the correlation function for the structure of the turbulence beneath the solar surface.

In a project, which connects astro- and particle physics, two- and three-flavour oscillations as solution to the solar neutrino problem were investigated by H. Schlattl. For the first time, all possible solutions to the more general three-flavour case were found, each of which implies different properties for the neutrinos, for instance their mass. Determining the correct solution is not possible yet; new data from existing and future neutrino experiments are important for solving this longstanding problem.

U. Anzer and P. Heinzel (Ondrejov, Czech Rep.) continued their investigation of solar prominences. They derived estimates for the required heating of quiescent prominences and discussed the possibility of the existence of radiative equilibria. They also constructed models for 2D magnetohydrostatic equilibria for vertical threads and developed a 2D radiative transfer code which can be applied to these configurations.

The space probe *Deep Space I* has been redirected so that it will meet comet Borelly in September 2001. R. Wegmann used model calculations to predict the ion distribution and the X-ray emission to be expected during the encounter.

Single Stars. The evolution of the first stars in the Universe (Population III) was the subject of a research cooperation between MPA (A. Weiss and H. Schlattl), the Observatory of Teramo (S. Cassisi) and the Liverpool John Moores University (M. Salaris). Their model explored the evolution of metal-free stars of low mass ($M < 1.1\,M_\odot$), which were polluted with metal-rich supernova debris on their surface, and which experienced the core helium flash. They identified conditions under which this flash induces mixing between the polluted envelope and the helium-burning regions, resulting in a very carbon- and nitrogen-enriched composition. Stars with similar surface abundances to those predicted by the model are indeed observed among the most metal-poor stars and cannot be obtained by any other standard nucleosynthesis process. The goal is to to identify the extremely metal-poor stars of the Galaxy as the surviving Population III. —

Following recent simulations of the fragmentation and collapse of primordial clouds which suggest that the formation of metal free stars above 100 $M_\odot$ is possible, I. Baraffe (Ecole Normale Supérieure de Lyon), A. Heger and S. Woosley (both University of California, Santa Cruz) analysed the stability of such very massive primordial stars, and found that, if they form, they retain most of their mass during their life, and have a very different evolution and fate than their more metal rich counterparts.

The majority of metal-poor stars are Population II, found both in the halo field and most prominently in globular clusters. In previous years A. Weiss and M. Salaris (Liverpool, UK) investigated the ages of globular clusters. They have now turned to a an investigation of a major systematic uncertainty in such age determinations: the problem of whether atomic diffusion ("sedimentation") is an effective process in Pop. II stars. They investigated the fact that the Lithium abundance of metal-poor stars does not vary with metallicity or effective temperature, the so-called "Spite-plateau", contradicts stellar models that diffusion, as claimed in several papers in the literature. They have shown that new models and the consideration of observational biases lead to predicted Lithium abundances which are consistent with the Spite-plateau, even though significant depletion of Lithium has indeed occurred. In particular, the derived primordial abundance of Lithium is consistent with a high baryon content of the Universe, as found in Big Bang Nucleosynthesis models using the observed low deuterium and high helium abundances.

Other work concentrated on Lithium-rich giants in the field and in clusters (P. Denissenkov, St. Petersburg, Russia and A. Weiss), the extention of the Padua stellar model library with α-element enhanced mixtures (with B. Salasnich, L. Girardi, and C. Chiosi, Padua, Italy) and the effect of Coulomb-screening on the seismic properties of solar models (M. Flaskamp, A. Weiss, and V. Tsytovich, Moscow, Russia). —

By coupling stellar evolution and pulsation calculations for intermediate mass stars, I. Baraffe and Y. Alibert (both Ecole Normale Supérieure de Lyon) have developed models for Cepheids which yield the period–luminosity relationships in different filters (BVIJHK). Such calculations allow for a direct comparison with observations of Cepheids in the Galaxy or in the Magellanic Clouds.

M. Groenewegen's work concentrated mostly on Cepheids. First he compiled optical and infrared data for all Cepheids in the HIPPARCOS Catalog, and used this information together with the parallax data to derived Period-Luminosity relations in the $V-$, $I-$ and $K-$bands. — Second, he used the publicly available OGLE microlensing and 2MASS infrared data to derive Period-Luminosity relations for Cepheids in the Large and Small Magellanic Clouds. As a byproduct, the inclination angle and the position angle of the line-of-nodes in these two galaxies were determined. The difference between the calibrated Galactic Period-Luminosity relation and the observed one for the SMC and LMC gives the distance to these galaxies. The resulting distance moduli are 18.60 ± 0.11 and 19.11 ± 0.11 respectivel, without taking into account possible metallicity corrections.

Binary Systems. Compact binaries, i.e. binary systems in which at least one of the two components is a compact star (white dwarf, neutron star, black hole), are of considerable astrophysical interest. One of the ongoing activities in the theory of stellar structure and evolution concerns the formation and evolution of such binaries. One area of research focuses on the formation of pulsar binaries. Here, H. Ritter together with A. King and M. Davies (both University of Leicester) have worked out a self-consistent evolutionary model for the formation of short-period pulsar binaries like PSR J1141-6545 and PSR B2303+46, both of which contain a massive white dwarf companion in a highly elliptic orbit. They are also studying the likelihood of their formation by means of population synthesis techniques. Another project is to understand the absence of millisecond pulsars in binary systems with orbital periods longer than about 200 days. H. Ritter and A. King showed that this is very probably the consequence of the accreting neutron star being forced to accrete spasmodically from a very extended, thermally unstable accretion disc.

In the context of cataclysmic variables, i.e. binaries in which a white dwarf accretes from an unevolved companion star, I. Barafffe, V. Renvoizé (both Ecole Normale Supérieure de Lyon), U. Kolb (Open University, Milton Keynes) and H. Ritter have addressed the problem of whether the discrepancy between the observed minimum orbital period of cataclysmic binaries and the one resulting from theoretical calculations can be accounted for by the fact that the latter use spherically symmetric models. Using an SPH code for calculating the departure from spherical symmetry of Roche lobe filling stars for different mass ratios, it was found that compared to the spherical case, there is a general increase by about 5%-10% of the secondary's radius when it fills its Roche lobe. This effect yields an increase by ~ 5 min of the theoretical minimum period. This accounts for only about half of the discrepancy.

Also in the contex of cataclysmic variables,

H. Ritter and U. Kolb joined forces with R. Downes (Space Telescope Science Intitute, Baltimore), R. Webbink (Univeristy of Illinois, Urbana), M. Shara (American Museum of Natural History, New York), and H. Duerbeck (Free University Brussels, Brussels) to generate an updated and upgraded, web-based living version of the Catalog and Atlas of Cataclysmic Variables which has previously twice been pubilshed in the Publ. of the Astron. Soc. Pacific. —

Miscellaneous. S. Ehgamberdiev (Ulugh Beg Astronomical Institute of the Uzbek Academy of Sciences) analyzed the results of a site-testing campaign carried out during 1996–1999 at High Altitude Maidanak observatory in Uzbekistan. The good seeing, large isoplanatic angle and, especially, slow wind place Maidanak Observatory among the best international astronomical sites (such as Chile or Canarias) for high angular resolution observations by interferometry and adaptive optics.

3.2 Nuclear and Neutrino Astrophysics

In a diploma-thesis, supervised by W. Hillebrandt, M. Hagen repeated earlier core-collapse calculations of stars in the mass-range around 8 to 10 solar masses. His calculations were performed with much higher numerical resolution than had previously been possible. He showed that the outcome of the calculations, i.e. whether or not the model star exploded, depended strongly on details of the simulations, such as the incorporation of nuclear burning and neutrino transport.

The explosion mechanism of massive stars is still not fully understood. Previous work has demonstrated the importance of convection for the neutrino emission and the associated cooling of the newly formed neutron star, as well as the the neutrino heating behind the supernova shock. These studies were, however, performed with an oversimplified treatment of the crucial neutrino transport and neutrino-matter interactions.

M. Rampp, supervised by H.-T. Janka, developed a new code which solves the Boltzmann equation for the neutrino transport in combination with the equations of hydrodynamics of the stellar fluid. Simulations of stellar collapse and post-bounce evolution for different stars in spherical symmetry were carried out, but did not yield explosions. Because of the importance of convective processes, however, definite conclusions have to be postponed until multi-dimensional simulations with Boltzmann neutrino transport have been completed. In addition, the description of neutrino-matter interactions in the nuclear medium of the nascent neutron star will be improved. Nucleon recoil and blocking effects will be treated consistently and opacity-reducing nucleon correlations will be taken into account.

Analytical calculations were used by H.-T. Janka to investigate the conditions and requirements for neutrino-driven explosions. They confirm the existence of a lower threshold value for the core neutrino luminosity above which explosions are possible. The dependence of this threshold luminosity on the rate of mass accretion by the supernova shock was derived. The analytic model also showed that neutrino-driven explosions cannot be more energetic than a few 10^{51} erg, because the energy in the neutrino-heating region is limited by a value of only several MeV per nucleon.

Standard core-collapse and supernova models assume the separate conservation of electron, muon and tau lepton numbers in the supernova core. In a collaborative project, S. Hannestad (Nordita), H.-T. Janka, G. Raffelt (MPI für Physik) and Günter Sigl (CNRS, Paris) have investigated whether this is still true if the neutrino mixing angles are large, as suggested by the atmospheric neutrino anomaly. It turns out that due to a nontrivial combination of first-order and second-order refractive effects the rate of flavor conversion is suppressed and equilibrium between the different lepton flavors cannot be achieved on the infall and neutrino-cooling time scales.

K. Kifonidis, T. Plewa (MPA and Copernicus Astronomical Center, Warsaw), H.-T. Janka and E. Müller have continued their studies of nucleosynthesis and hydrodynamic instabilities in core collapse supernovae. A first set of two–dimensional numerical simulations were discussed in the Ph.D. thesis of K. Kifonidis which was supervised by E. Müller. Since then the database of core collapse supernova simulations has been extended and first type Ib supernova (explosions in progenitor stars without a massive hydrogen envelope) models have been computed. In this context, T. Plewa and E. Müller have performed a comprehensive 2d resolution study of the convective flow in the neutrino heated hot bubble during the first 100 milliseconds. The aim of the study is to determine the minimum spatial resolution and computational domain required for an adequate description of the convective flow in planned 3d simulations.

In a collaboration with S.E. Woosley (Univ. California, Santa Cruz) and R. Eastman (Lawrence Livermore National Laboratory), the type Ib supernova models were used for the calculation of first synthetic spectra and light curves. The ultimate goal of this project is to establish the link between the multidimensional simulations and observational data. For this purpose, synthetic spectra will be obtained using supernova simulations that will follow the entire evolution from core collapse to shock break out through the stellar photosphere, including a consistent treatment of the growth and interaction of hydrodynamic instabilities. To cover the early phase of the explosion, initial data from Boltzmann neutrino transport calculations of the core collapse stage will be used, which are currently carried out by M. Rampp and H.-Th. Janka at the MPA. The focus is on Type Ib events because the first preliminary studies indicate, that the amount of outward mixing of newly synthesized radioactive ^{56}Ni by Rayleigh–Taylor instabilities appears to be very promising in order to reproduce the spectra of this type of supernova.

In a further collaboration with B. Remington and his group at the Lawrence Livermore National Laboratory the core collapse supernova group at MPA is also involved in the planning of experiments with the powerful Laser facilities at Livermore. The aim of this project is to study supersonic clump propagation, which occurs in type II supernovae according to recent numerical simulations performed at the MPA, by performing actual hydrodynamic experiments.

I. Panov and D. Nadyozhin (ITEP, Moscow) used an extended nuclear reaction network to study the r-process and neutrino-driven nucleosynthesis in core-collapse supernovae. In particular they showed that inelastic neutrino-nucleus interactions produced enhanced abundances of isotopes such as ^{7}Li, ^{9}Be, ^{11}B, ^{19}F, and ^{26}Al. Their r-process code will also be used to study neutron-capture processes in explosive helium-burning using a 2D-hydrodynamic simulations carried out at MPA.

The search for radioactive nuclei from supernova explosions in deep ocean sediments by means of accelerator mass spectrometry continued (K. Knie, G. Korschinek (TU München), T. Faestermann (TU München), C. Wallner (TU München), and W. Hillebrandt). The measurements of radioactive ^{60}Fe were successfully extended to include sediments from other sites with independent dating. The earlier results of the group were confirmed with significantly better statistics. Moreover, they found evidence also for radioactive ^{244}Pu, although with still rather poor statistics. The project, which is supported by the DFG, will continue.

H. Dimmelmeier has studied general relativistic, axisymmetric, rotational core collapse. The aim of this Ph.D. project supervised by E. Müller and J.A. Font is to calculate the gravitational wave signature of such events. For this purpose H. Dimmelmeier has simulated the collapse of polytropes in two spatial dimensions within the framework of the Wilson approximation to General Relativity. In this approximation, the general relativistic hydrodynamic equations are integrated together with the Einstein field equations within the (3+1) ADM formalism describing the curvature of the three–geometry by a position–dependent conformal factor times a flat–space Kronecker delta (conformally flat gauge condition). A detailed comparison of the gravitational wave signature obtained by these first general relativistic simulations with that of previous Newtonian studies will be finished soon.

The luminous rings around SN 1987A raise basic questions as to their formation. Contrary to other suggestions, a model developed at MPA explains the formation of the outer rings and also that of the inner ring as a natural consequence of ionization of an originally cool stellar wind from a preceding red giant phase of the progenitor without any further assumption (E. Meyer).

In an ongoing collaboration between M. Ruffert (Edinburgh) and H.-T. Janka, the merging of neutron stars with stellar-mass black holes was investigated. Unlike from previous simulations, the black hole had a pseudo-Newtonian gravitational potential. This allows one to account for the existence of an innermost stable circular orbit and to include the dependence of the position of this orbit on the rotation of the black hole. The simulations confirm the Newtonian result that up to several tenths of a solar mass of neutron star matter can stay in a hot accretion torus around the black hole for longer than the dynamical timescale of the system. This is a necessary requirement for this kind of binary mergers to be a viable source of short gamma-ray bursts with durations of less than 2 seconds.

J. Rehm, supervised by K. Jedamzik, completed a Ph.D thesis on the influence of small-scale, matter-antimatter domains on the Big Bang nucleosynthesis process in the early universe. Daniel Sauer has completed a diploma thesis under the supervision of K. Jedamzik, investigating possible systematic errors which may enter in the determination of the primordial helium mass fraction by observations of extragalactic HII regions. R. Banerjee and K. Jedamzik have investigated B-balls, a new dark matter candidate, and the possibility of B-ball evaporation in the early universe creating the observed cosmic asymmetry between matter and antimatter.

3.3 Numerical Hydrodynamics

Mixing is a fundamental process which profoundly affects the evolution of stars. Nonetheless, a theory of mixing that is applicable to stellar conditions is still missing. One important mechanism responsible for mixing in stars is the shear or Kelvin-Helmholtz instability. This instability is particularly important since most stars are are rotating differentially.

Observational evidence such as the depletion of lithium in the Sun or the enrichment in CNO elements in globular cluster stars suggest that current prescriptions underestimate the efficiency of the mixing processes at work, especially in fast rotating stars. Using three-dimensional numerical simulations, M.Bruggen (in collaboration with W. Hillebrandt, MPA) studied the Kelvin-Helmholtz instability in a stratified shear layer and determined the mixing efficiency as a function of the Richardson number. They found that the mixing efficiencies differed substantially from some of the semi-analytical formalisms that are presently in use. They also performed 3D magneto-hydrodynamical (MHD) simulations of the shear instability in magnetised flows and studied the non-linear evolution of the shear instability in the presence of magnetic fields.

J.A. Font and P. Papadopoulos (University of Portsmouth) studied covariant and conservative formulations of general relativistic hydrodynamics, well-suited to state-of-the-art numerical schemes based upon Riemann solvers. Their approach was specialized for null foliations of the spacetime, within the so-called characteristic formulation of general relativity. It was subsequently applied by F. Linke, in his Diploma Thesis (together with J.A. Font, H.-Th. Janka, E. Müller and P. Papadopoulos) to the study of the gravitational collapse of spherical supermassive stars. The main result of this study has been to rule out non-rotating stars with masses larger than $5 \times 10^5 M_\odot$ as potential gamma-ray burst candidates. In a Ph.D. supervised by E. Müller and J.A. Font, in collaboration with P. Papadopoulos, Florian Siebel developed an axisymmetric hydrodynamic code based on the Bondi metric, by which the spacetime is foliated with a family of outgoing light cones. The code accurately maintains long-term stability of spherically-symmetric relativistic polytropes and, in axisymmetry, it achieves global energy conservation of a perturbed neutron star in a compactified spacetime, for which the total energy radiated away by gravitational waves corresponds to a significant fraction of the Bondi mass.

J.A. Font, in collaboration with P. Papadopoulos, studied the imprint of accretion on the gravitational wave signals from black holes. Employing a computer code which solves the coupled system of the Einstein and hydrodynamic equations in spherical symmetry, together with non-spherical evolutions of a minimally coupled, massless scalar field to mimic gravitational perturbations, they analyzed the modulation of the quasi-normal mode (QNM) black hole frequencies as a result of accretion of self-gravitating matter. It was found that the instantaneous QNM frequency is a sensitive indicator of the black hole growth, accurately reflecting a power-law time dependence in the mass accretion rate.

In collaboration with N. Stergioulas and K. Kokkotas (University of Thessaloniki), J.A. Font developed an axisymmetric hydrodynamic code to study non-linear evolution of perturbed, rotating relativistic stars. This code was used to accurately identify normal modes of oscillation via Fourier transforms, both for radial and quadrupolar pulsations in the non-rotating limit. H. Dimmelmeier and J.A. Font, with N. Stergioulas and A. Gupta (Raman Research Institute), performed a comprehensive study of quasi-radial, odd- and even-parity pulsations of uniformly-rotating relativistic stars. Together with N. Stergioulas, J.A. Font presented the first study of non-linear r-modes in isentropic, rapidly-rotating relativistic stars via 3D, general relativistic hydrodynamical evolution. Their study revealed that there is no strong non-linear coupling of r-modes to other modes at large amplitudes and, hence, there is no non-linear saturation of the r-mode amplitude on dynamical timescales. Therefore, gravitational radiation reaction could drive unstable r-modes to a large amplitude. Additionally, the spectrum of such modes was found to be discrete.

J.A. Font continued a collaboration with the Numerical Relativity group at the Albert Einstein Institute (Golm). Recently, a family of new formulations of the standard ADM (initial value problem) formulation of the Einstein equations, which separate out the conformal and traceless part of the system, was applied to different scenarios, including the 3D evolution of gravitational waves, black holes, boson stars and neutron stars. This family of new formulations was found to give more long-term evolution than ADM in all cases considered but was less accurate in the short-term for the range of resolutions employed.

M. Lisewski used the so-called "one dimensional turbulence" (ODT) model of A. Kerstein to investigate statistical properties of nuclear flames in the distributed regime. This work, a thesis supervised by W. Hillebrandt, was carried out in collaboration with S.E. Woosley (Univ. of California, Santa Cruz) and J.C. Niemeyer (MPA and Univ. of Chicago). They showed that the model is capable of reproducing observed properties of highly turbulent flames. They found that in agreement with laboratory combustion experiments, the turbulent flame speed in type Ia spernovae saturates at high turbulence intensities. Their results indicate that the transition from a deflagration to a detonation in type Ia supernovae is not likely to happen.

S.I. Blinnikov and E. Sorokina (ITEP, Moscow) have continued their work on type Ia supernova light curves and spectra, using a novel radiation hydrodynamic code. They were able to fit observed light curves well in all wave bands, including the UV. This is important for their use as probes of cosmological parameters. Moreover, their code might become the basis of an attempt to couple multi-dimensional explosion models to observable quantities.

M. Reinecke, in a PhD-thesis supervised by W. Hillebrandt, has used a novel front-tracking scheme in 2- and 3-d 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 can resolve structures of the front down to the grid scale. A simplified version of this code, together with a sub-grid model for the unresolved scales, is now able to compute type Ia supernova models without parameterizing the velocity of the burning-front. Numerical convergence was demonstrated in 2-d simulations. 3-d simulations led to explosions which with about the right energy. Deflagration-detonation transitions were not observed and, in fact, seem to be unnecessary.

M. Reinecke and A. Gröbel, in a diploma thesis under the supervision of W. Hillebrandt, continued their work on the level-set front-tracking scheme for turbulent combustion, both in stars and in technical applications. In particular, studies demonstrated that the method can handle reflecting boundaries, strongly curved fronts, degenerate equations of state, and large decompression ratios, e.g. as found in combustion of hydrogen in air. However, they also discovered numerical problems related to the adopted operator and flux-vector splitting scheme which call for further studies. In another PhD-thesis, F. Röpke investigated the possibility of "active turbulent combustion" in type Ia supernovae, which might be generated by the interaction of a flame-front of finite width with hydrodynamic flow fields. The hope is that such a process might lead to higher burning rates at low densities than is anticipated by standard flame models.

Waves and bubbles are governed by a balance of the forces of inertia, gravity and surface tension. R. Wegmann and D. Crowdy (Imperial College, London) found an explicit analytic description of the shape of a bubble in a circulating flow. Since analytic solutions are very rare one must rely on numerical calculations. R. Wegmann developed an efficient and fast numerical method for the calculation of capillary-gravity waves.

T. Plewa (MPA and Nicolaus Copernicus Center, Warsaw) and E. Müller finished a 3d version of the adaptive mesh refinement code AMRA. It was coupled to a revised version of the multi–dimensional finite volume hydrodynamic code PROMETHEUS. The new code named HERAKLES can simulate multidimensional reactive flows on RISC and vector machines with high efficiency by optimizing the usage of the cache memory and the vector registers. It has been parallelized for shared memory multi–processors. In collaboration with W. Brinkmann (MPE), HERAKLES has been used to simulate the precessing, mildly relativistic (0.26c) twin jets of the galactic binary system SS433 located within the supernovae remnant W50. The simulations of the precessing jet showed pronounced fluid instabilities, which are currently being analyzed. Because the analysis of the complex 3d flow is difficult, additional 3d simulations have been performed for simpler conical and hollow cone jets.

Investigation of relativistic jets has continued. In his diploma thesis, T. Leismann supervised by E. Müller and J.Mª. Martí (Univ. Valencia), studied the stability of relativistic jets by means of 2d hydrodynamic simulations. Stationary axisymmetric jets were perturbed leading to mass entrainment, jet deceleration, and even jet disruption. Surprisingly, it was found that jet stability depends on the Lorentz factor in a non–monotonic way, making jets with a moderate Lorentz factor (~ 4) most unstable. In his diploma thesis, supervised by E. Müller and J.Mª. Martí, L. Scheck studied whether the morphology and dynamics of a relativistic axisymmetric jet depends on its composition. His simulations showed that the observational properties of a baryonic jet and of an electron–positron pair jet are practically indistinguishable provided both jets have the same power and thrust. M.A. Aloy and E. Müller, in collaboration with J.Mª. Martí and J.Mª. Ibáñez (Univ. Valencia) and J.L. Gómez (Instituto de Astrofísica de Andalucía), have performed 3d simulations of relativistic jets in order to explain radio observations of the radio source 3C120. They find that a slowly precessing relativistic jet that interacts with a uniform medium accounts best for the observed flashing of the radio components of 3C120.

M.A. Aloy and E. Müller have continued their work on collapsar progenitors of gamma–ray bursts. They have demonstrated that a relativistic jet can be formed and propagate through the mantel and envelope of a Wolf–Rayet star as a consequence of an assumed energy deposition. New simulations are being done to investigate baryonic contamination of the jet due to mass entrainment triggered by Kelvin–Helmholtz instabilities. Due to the high resolution needed in these simulations, the GENESIS relativistic hydrodynamic code, which is used for these simulations, had to be efficiently vectorized and parallelized.

J.A. Pons and J.Mª. Martí (Univ. Valencia) and E. Müller have generalized the exact solution of the Riemann problem in special relativistic hydrodynamics for arbitrary tangential flow velocities. The solution was obtained by solving the jump conditions across shocks plus an ordinary differential equation arising from the self–similarity condition along rarefaction waves, in a similar way as in purely normal flow.

General relativity plays a major role in the description of compact objects. A subset of the Numerical Hydrodynamics group at the MPA (E. Müller, J.A. Font, M.A. Aloy, H. Dimmelmeier, F. Siebel and F. Linke), in collaboration with some additional external researchers, are carrying out general relativistic hydrodynamic simulations in different scenarios, including neutron stars, supermassive stars and black holes.

3.4 High Energy Astrophysics

X–ray binaries and AGNs M.Revnivtsev (IKI, Moscow), E.Churazov, M.Gilfanov and R.Sunyaev, using data from the Rossi X-Ray Timing Explorer, discovered a new class of quasi periodic oscillations (QPO) in X-ray bursters. The unique properties of these QPO, in particular their disappearance after Type I X-ray bursts and their narrow range of luminosities, hint at the origin of a new type of X-ray flux oscillation. An interesting possibility is that these oscillations are manifestations of a special quasi periodic regime of nuclear burning on the surface of the neutron star. This regime might occur at the boundary between quasi stable nuclear burning, which takes place at high mass accretion rates, and unstable burning, which occurs at lower mass accretion rates and results in Type I X-ray bursts.

M.Gilfanov, H.-J.Grimm and R.Sunyaev studied the X-ray luminosity function, Log(N)-Log(S) and spatial distribution of bright X-ray binaries in the Milky Way. They found a significant difference between low and high mass X-ray binaries. High mass binaries were more concentrated towards the Galactic Plane and showed clear signatures of spiral structure in their distribution. They completely avoided the Galactic bulge and inner ~ 4 kpc of the Galaxy. Due to the shallow slope of the luminosity function of X-ray binaries, their integrated emission is dominated by the $\sim 5-10$ brightest sources.

M. Gilfanov, E. Churazov and M. Revnivtsev studied the geometry and physical conditions in the innermost part of the accretion flow in black hole binaries. Using a new method of studying variability in X-ray sources (Fourier frequency resolved spectroscopy) they performed the first X-ray reverberation study of the inner accretion disk in black hole binaries and obtained important constraints on the geometry of the accretion flow and the physical size of the accretion disk in the soft and hard spectral states. Based on the data of the Rossi X-Ray Timing Explorer, they studied the relation between physical conditions in the Comptonization region, properties of the reflected component, and the characteristic frequencies of the aperiodic variations of the X-ray flux in black hole binaries. The shape of these dependencies has been used to test different models of the accretion flow. E. Churazov, M. Gilfanov and M. Revnivtsev addressed the problem of the variability of X-ray emission in the high state of Cyg X-1, in particular the large amplitude and the extremely broad range of the variability time scales of the Comptonized component and the exceptional stability of the emission from the optically thick disk. They showed that such behavior can be understood as a result of a large difference between the viscous time scale in the accretion disk and the corona.

Using $\sim$ 200 ksec of RXTE observations, M. Revnivtsev, M. Gilfanov and E. Churazov undertook a systematic study of variability of Cyg X-1 at millisecond and sub-millisecond time-scales. These time-scales approach the light crossing time and Keplerian time for the last marginally stable orbit around a Schwarzschild black hole. Significant power was detected up to frequencies of $\sim$ 300 Hz. However no strong resonances were found in the 10 Hz - 2 kHz frequency range.

H.-C. Thomas, in collaboration with D. Grupe (MPE), K. Beuermann (Univ. Göttingen), and K.M. Leighly (Columbia Astrophys. Lab.), investigated the X-ray variability in a complete sample of 113 bright soft X-ray selected AGN observed with ROSAT and ASCA.

C. R. Kaiser expanded and improved his analytical models of the radio emission from powerful radio galaxies and radio-loud quasars. These models now allow the construction of 3-dimensional maps of the synchrotron emissivity of radio galaxies. By projecting along arbitrary lines of sight, 2-dimensional maps are obtained and may be compared with observations. Thus, key parameters of radio galaxies like their age and the density of gas in their surroundings may be derived from radio observations alone.

γ–ray burst studies

The internal shock model proposed for the prompt emission of gamma-ray bursts involves shocks taking place in a relativistic wind with a very inhomogeneous distribution of the Lorentz factor. F. Daigne, in collaboration with R. Mochkovitch (IAP, France), developed a 1D Lagrangian relativistic hydrocode to follow the evolution of such a wind and performed a detailed comparison with the observations from the BATSE experiment. Their results show that the main temporal and spectral properties of GRBs can be reproduced by the model. The low efficiency of the full mechanism remains however a serious problem. This work has now been extended to take into account the effect of the external medium. The first results show that in the context of the popular "collapsar" model, the complex and very dense environment is so efficient at decelerating the relativistic wind, that the internal shock phase cannot occur. This puts some very interesting constraints on the model.

Magnetic fields are now believed to play a major role in the 'central engines' powering Gamma-Ray Bursts. F. Daigne, G. Drenkhahn (PhD student with Spruit) and H. Spruit developed general-relativistic MHD outflow models to address two questions: i) how efficiently the magnetic energy flux provided by a rapidly rotating magnetic object is converted into kinetic energy of outflow, and ii) how much of the magnetic energy flux is dissipated by internal reconnection processes in the more distant optically thin parts of the outflow. The results show that significant efficiencies are obtained for both these conversion processes. As a result, outflows with a large bulk Lorentz factor and a significant efficiency of conversion of energy into radiation are possible.

K. Postnov (Moscow state university), his collaborators in Moscow and H. Spruit compared the distribution of low-mass X-ray binaries (LMXB) in M31 and our own galaxy with the observed distribution of Gamma-ray Bursts with respect to their host galaxies. The GRB distribution resembles the LMXB distribution more closely than the current star formation rate in these galaxies.

Clusters of galaxies

E. Churazov, W. Forman (SAO/CfA), C. Jones (SAO/CfA) and H. Böhringer (MPE) used ROSAT HRI data to analyze the complicated substructure in the X-ray surface brightness within $\sim$5 arcminutes around NGC 1275 – the dominant galaxy of the Perseus cluster. The typical amplitude of the variations is of the order of 30% of the azimuthally averaged surface brightness at a given distance from NGC 1275. They suggested that this substructure is related to the past activity of NGC 1275. Bubbles of relativistic plasma, inflated by jets, forced to rise by buoyancy forces, mix with the ambient intracluster medium (ICM), and then spread. The overall evolution of the bubble may resemble the evolution of a hot bubble during a powerful atmospheric explosion. From a comparison of the time scale of the bubble inflation to the rise time of the bubbles and from the observed size of the radio lobes which displace the thermal gas, the energy release in the relativistic plasma by the active nucleus of NGC 1275 can be inferred. Approximate modeling implies a nuclear power output of the order of 10^{45} erg s^{-1} averaged over the last $\sim 3 \times 10^7$ years. This is comparable with the energy radiated in X-rays during the same epoch.

Motivated by the hypothesis that the central radio source influences the X-ray emitting gas, E. Churazov, M. Brüggen, C. Kaiser, H. Böhringer (MPE) and W. Forman (SAO/CfA) studied the galaxy M87. The morphology of the X-ray and radio emitting features in the central 50 kpc region around M87 strongly suggests that buoyant bubbles of cosmic rays (inflated by an earlier nuclear active phase of the galaxy) are slowly rising through the cooling gas. Because of the absence of strong surface tension, the initially spherical bubbles transform into tori as they rise through an external medium. Such structures are identified in the radio images of the halo of M87. During their rise, the bubbles lift relatively cool X-ray emitting ambient gas from the central regions of the cooling flow to larger distances. This gas is colder than the ambient gas and has a higher volume emissivity. As a result, rising "radio" bubbles may be trailed by elongated X-ray features, as observed in M87. Numerical hydrodynamical simulations confirmed the predictions of this model and demonstrated the striking similarity of the evolution of the buoyant bubbles in the cluster's cooling flow and powerful explosions in the Earth atmosphere.

Several projects were devoted to an understanding of the fate of the relativistic plasma released into the intergalactic medium by active radio galaxies. The strength and spectrum of the CMB Comptonization by such a plasma was estimated by T.A. Enßlin and C.R. Kaiser. The deflection of ultra high energy cosmic rays by the magnetic fields of a fossil radio plasma was investigated by G. Medina-Tanco (Uni. de São Paulo, Brazil) and T.A. Enßlin. This project used the results of a numerical simulation of the local Universe by S. White, V. Springel, and others. The possible detection of a large-scale structure shock wave by a deformed radio galaxy was investigated by an international collaboration (T.A. Enßlin, P. Simon, P.L. Biermann (MPIfR, Bonn), U. Klein, Sven Kohle (Uni. Bonn), P.P. Kronberg (UoT, Toronto, Canada), K.-H. Mack (IRA, Bologna)). The revival of the synchrotron emission of fossil radio plasma compressed in structure formation shock waves, was studied as an explanation for the observed cluster of galaxy radio relics by T.A. Enßlin and Gopal-Krishna (NCRA, Pune, India).

Multi frequency observational programs on clusters of galaxies with radio relics were performed by T. Enßlin in collaboration with T. Clarke (NRAO, Socorro, New Mexico) and N. Kassim (NRL, Washington, USA). High resolution magnetic field and foreground rotation measure maps of the cluster radio relics in the cluster Abell 2256 were obtained. These maps will be used to study intergalactic magnetic fields in great detail.

An improved method to analyze the morphology of radio halos of clusters of galaxies was developed and applied to four clusters by F. Govoni, L. Feretti, G. Giovannini (IRA, Bologna, Italy) and T.A. Enßlin. A comparison of the resuts to synthetic radio halos from MHD simulated clusters of galaxies already rule out some classes of hadronic radio halo formation models (K. Dolag and T.A. Ensslin).

3.5 Accretion

The heading *accretion* covers a range of theoretical and observational studies of hydrodynamics and radiation processes in mass transfering binaries (X-ray binaries, including the black hole candidates, Cataclysmic Variables, and protostars). The work at MPA in this field receives strong impetus from the collaboration in a European Research Network (funded by the European Commission) and the ongoing collaboration between the MPA and the Space Research Institute of the Russian Academy of Sciences.

Accretion hydrodynamics and radiation

C.P. Dullemond and P. Armitage simulated the 2-D turbulent gas flows in advection dominated accretion disks (ADAFs), and used a multi-dimensional radiative transfer code to compute the time-dependent optical/UV/X-ray spectra emerging from these flows. These simulations appear to confirm the gross features of the much simpler 1-D ADAF models that are currently widely in use, and thus provide a theoretical verification of the validity and limitations of their predictions.

Although most of the research on accretion disks at MPA focuses on X-ray binaries and Cataclysmic Variables, much of the physics of these disks can be readily applied to protostellar disks as well. In this context, C.P. Dullemond carried out analytic and numerical studies of the dynamic stability of irradiated protostellar disks. He also modeled the dynamic and observational effects of self-shadowing in these systems. The latter study was carried out in collaboration with C. Dominik (University of Amsterdam).

One of the interesting phenomena of accretion flows around black holes is the transition from accretion via a cool, geometrically thin disk to a vertically extended, hot accretion flow. In the innermost region around a black hole either type of flow can appear depending on the accretion rate. Spectral transition as observed for example in Cygnus X-1 can be understood in this context based on a physical model developed at MPA (F. Meyer and E. Meyer-Hofmeister). The change to an advection-dominated accretion flow (ADAF) and the resultant truncation of the outer thin disk is important for the evolution of accretion disks in black hole X-ray transients and their long outburst recurrence time. An additional new aspect concerning these long outburst cycles is the possible existence of a circumbinary disk as a major source of braking of the binary orbit. - Application of the work on the thin disk - ADAF transtion to accretion onto supermassive black holes allows one to study the truncation of the geometrically thin disks in low-luminosity Active Galactic Nuclei.

The X-ray spectra of black hole binaries and neutron star binaries usually show evidence of a hot optically thin plasma in addition to a cool optically thick accretion disk. The origin of this hot plasma is contentious. In many proposed models (both of the 'coronal' and the 'ADAF' variety) a significant fraction of the accretion energy goes into producing a two-temperature plasma with very hot ($\sim 3-30$ MeV) protons and hot (100 keV) electrons. For his PhD thesis, B. Deufel (with H. Spruit and K. Dullemond) investigated the interaction of the very hot proton plasma with a nearby cool accretion disk. He showed that 'illumination' of the disk by the protons produces a layer of optical depth ~ 1 and temperature ~ 100 keV which produces (by inverse Compton scattering) spectra very much like the observed hard X-ray spectra. The interaction of such protons with a neutron star surface also produces hard spectral components similar to some observed. This is in contrast to the commonly adopted view that a neutron star surface produces only a completely thermalized (~ 1 keV) spectrum.

S. Grebenev (Space Research Institute, Russian Academy of Sciences) performed computations of X-ray emission spectra formed in the boundary layer of an accretion disk around a neutron star, taking into account free-free processes and Comptonization. The treatment is based on the hydrodynamic solution of Popham and Sunyaev (2001) for the boundary layer structure. The computed spectra are strongly diluted as compared to the Planckian ones corresponding to the same surface temperature. In particular, a strong Wien component is formed in the high energy part of the spectrum at high accretion rates. The spectra are in general harder than those observed from X-ray sources. This discrepancy apparently results from the unrealistically high value of temperature given by the simplified solution of Popham and Sunyaev, which neglects the effects of opacity and the dependence of radiation intensity on frequency.

The angular rotation velocity of a weakly-magnetic neutron star strongly affects the energy release both on the stellar surface and in the surrounding accretion disk. N. Sibgatoulline (Moscow State Univeristy) and R. Sunyaev derived simple approximation formulas that illustrate the dependence of the efficiency of energy release on the frequency and sense of rotation for various neutron-star equations of state. In the case of neutron star and disk counterrotation, the energy release during accretion can reach values as high as $0.67\dot{M}c^2$ (here, $\dot{M}$ is the accretion rate). The sense of neutron star rotation is also a factor that strongly affects the observed ratio of nuclear energy release during bursts, to the gravitational energy release between bursts in X-ray bursters. It was suggested that X-ray binary systems with counterrotation may exist in the Galaxy.

G. Lipunova and N. Shakura (Sternberg Astronomical Institute, Moscow State University) studied the viscous evolution of accretion disks in binary systems. A time-dependent disk with a fixed tidally-truncated radius was considered at outburst, using the standard model (Shakura & Sunyaev 1973). The vertical structure of the disk can be accurately described in two regimes of opacity: Thomson and free-free. Fully analytical solutions are obtained, which are characterized by power-law variations of the accretion rate with time. These solutions permit the asymptotic description of the disk evolution in flaring sources in the periods after outbursts while the disk is fully ionized. The X-ray flux from a multicolor (black-body) alpha-disk is shown to vary quasi-exponentially, which is in qualitative agreement with the observed light curves of X-ray novae.

S. Sazonov (Space Research Institute, Russian Academy of Sciences) and R. Sunyaev demonstrated that scattering by the inner accretion disk of the X-ray radiation generated near the surface of a spinning neutron star has observable effects on the waveforms of millisecond X-ray flux oscillations produced for example during type-I bursts or in the millisecond pulsar SAX J1808.4–3658. The main signature of scattering from a thin disk is that the pulse of the scattered flux leads (if the star rotates in the same sense as the disk) or lags (in the contrary case) the primary pulse of direct emission by a quarter of a spin cycle. This is caused by Doppler boosting of the radiation in the sub-relativistic Keplerian flow. The disk-scattered flux is revealed better in energy-resolved waveforms and in the phase dependence of the polarized flux component. This phenomenon permits direct testing of the presence of standard thin disks near the neutron stars in LMXBs and should be observable with future X-ray timing experiments having a few times better sensitivity than RXTE and also with sensitive X-ray polarimeters.

Up to 50 per cent of the X-ray radiation emitted by the layer of spreading matter on the surface of a weakly magnetized accreting neutron star is intercepted by the inner regions of the accretion disk. Most of this radiation is then reflected from the disk after a few Thomson scatterings. This should affect the properties of the X-ray emission of LMXBs, as well as the structure of the inner disk. A. Voevodkin and S. Sazonov (Space Research Institute, Russian Academy of Sciences), using the spreading-layer model of Inogamov and Sunyaev and the standard alpha-disk model, calculated the relative contributions of the different emission components to the total observable luminosity of a LMXB as a function of the binary's inclination angle. They also computed the radial distribution of the illuminating flux (coming from the star) on the disk and showed that within a few kilometers from the stellar surface, this flux is of the same order or larger than the intrinsic X-ray flux from the disk. They are currently studying how strongly this external pressure affects the vertical structure of the disk.

M. Revnivtsev (Space Research Institute, Russian Academy of Sciences) and R. Sunyaev suggested a new method to distinguish an accreting neutron star from a black hole: by the variability of the X-ray flux. The power density spectra of a set of 9 neutron star and 9 black hole binaries in the low/hard spectral state were analyzed, using publicly available RXTE data. A significant power at frequencies close to one kHz was revealed in all the neutron star objects, whereas the black hole objects all showed a strong decline in the power spectra above 10–50 Hz. The extremely fast variability demonstrated by neutron star binaries possibly originates in a radiation-dominated spreading layer on the neutron star surface.

M. Revnivtsev (Space Research Institute, Russian Academy of Sciences) et al. have found a strong QPO feature at 0.085+/-0.002 Hz in the power spectrum of the X-ray transient XTE J1118+480. The QPO was detected in PCA/RXTE data with an amplitude close to 10% rms and width 0.034+/-0.006 Hz. The shape of the power spectrum is typical for black hole candidates: almost flat at frequencies lower than 0.03 Hz, roughly a power law with a slope 1.2 from 0.03 to 1 Hz, with steepening to 1.6 at higher frequencies. The hard energy spectrum detected up to 150 keV and the absence of significant X-ray variability at the high frequencies above 100 Hz strongly support the identification of XTE J1118+480 as a black hole transient.

Magnetic fields

Magnetic fields probably play a major role in many forms of accretion. This is most obvious in cases where the accreting object itself has a strong magnetic field, such as the accreting white dwarfs in AM Her systems (field strengths of $10^3 - 10^4$ Tesla) and accreting neutron stars in X-ray pulsars ($10^7 - 10^9$ T). The accretion disk itself also has magnetic fields, which are probably responsible for both its anomalously high viscosity and its ability to produce outflows such as the relativistic jets in AGN.

Advances in computing capability make it possible to use ab initio MHD simulations to study magnetic angular momentum transport processes in accretion disks directly. P. Armitage, in collaboration with C. Reynolds (University of Colorado) and Jim Chiang (NASA/Goddard), carried out 3-D simulations of accretion flows crossing the innermost stable orbit around black holes. Many of the standard results derived from simplified models were recovered, suggesting that these approximations suffice for thin disks.

The growing evidence for a magnetic origin of the friction in hot accretion disks received further support from work on the very peculiar sequence of mini-outbursts that followed a major outburst of the dwarf nova EG Cancri. Results by F. Meyer and Y. Osaki (University of Nagasaki) showed that this strange phenomenon is explained by the resistive decay of the magnetic field in the disk.

Saul Rappaport (MIT) and Henk Spruit reconsidered the long standing problem of the accretion from a disk onto the magnetic field of the accreting object (strongly magnetized neutron star or white dwarf). They showed that several commonly held views are incorrect. For example, the accreting mass need not be expelled from the system when the inner edge of the disk lies outside the so-called corotation point (where the Kepler frequency equals the stellar rotation frequency). Also, accretion of mass does not necessarily imply accretion of angular momentum: accretion is compatible both with spinup and with spindown of the star, in agreement with observation.

H.-C. Thomas in collaboration with K. Beuermann and K. Reinsch (Univ. Göttingen), and

V. Burwitz (MPE) continued their study of highly magnetic Cataclysmic Variables (Polars), including measurements of circular polarization in seven newly discovered objects.

U. Anzer and G. Boerner, in collaboration with N. Pogorelov, I. Kryukov and G. Bisnovatyi-Kogan (Academy of Sciences, Moscow) investigated the accretion onto stellar magnetospheres. They simulated the interaction of such flows with a magnetosphere using a simplified model. For the inner boundary, a solid sphere which has two completely absorbing holes at the magnetic poles was assumed. They studied flows with and without rotation. They found that both steady and nonsteady solutions can exist.

Outflows from disks

Mass-transfering binaries such as Cataclysmic Variables (CVs) and black hole transients often show evidence of both outflows and accretion onto the compact object through an accretion disk. The relativistic jets observed in quasars and the so-called galactic microquasars (see highlights section of the 1999 Annual report) are spectacular examples, but slower and less collimated outflows also occur. These outflows are probably produced by the accretion disk itself, but the observations show that the relation between the two is not very direct. Not all disks produce observable outflows, and most that do, don't do it all the time.

In CVs, evidence for the presence of slow, weakly collimated outflows is seen in many systems. Henk Spruit (with R. Taam, Northwestern University) proposed that a part of this outflow feeds a so-called *circumbinary* disk or *external* disk. At the same time, Friedrich Meyer explored the consequences of such external disks for the outburst cycle in black hole transient systems. For more about these circumbinary disks see the Highlights section of this report.

In an attempt to find the cause of the unpredictable nature of outflows from disks, Xinwu Cao (Shanghai Observatory, visiting on the MPG-CAS exchange agreement) investigated (with H. Spruit) the stability of the coupling between an accretion disk and a magnetic outflow driven by this disk. Taking into account the changes in field line inclination at the crucial surface just above the disk where the flow is effectively launched, they find a strong instability. The stability conditions and growth rates were determined. This result indicates that stable fast jets and strong slow outflows require special conditions in the disk to be satisfied, and may only be transient otherwise.

3.6 Interaction of Radiation with Matter

E. Churazov, M. Haehnelt, R. Sunyaev and O. Kotov (IKI, Moscow) analyzed the contribution of the resonant scattering to the soft X–ray background. For the low density filamentary and sheet-like structures in the warm ($\sim 10^4$ to $\sim 10^6$ K) intergalactic medium predicted by numerical simulations the resonant line scattering of X-ray background photons by He and H-like ions of heavy elements can exceed the "local" thermal emission by a factor of a few or more. Due to the conservative nature of scattering this resonantly scattered radiation can only be identified if a significant fraction of the XRB is resolved and removed. While the combined spectrum of the resolved sources will contain X-ray absorption features, the residual background will contain corresponding emission features with the same intensity. At the relevant densities and temperatures the lines of He and H-like oxygen at 0.57 and 0.65 keV are most promising. These lines (which have a typical width of $\sim$ 1-2 eV) may contain up to 50% of the total 0.5-1 keV emission of the filament. On average, up to a few percent of the soft XRB could be resonantly scattered by this phase of the IGM and resonantly scattered photons should account for a significant fraction of the truly diffuse background at low energies. Close to bright X-ray sources like galaxy clusters or AGN the flux of scattered radiation will be further enhanced. Off-line blazars are the most promising illuminating sources. The scattered emission from AGN may also constrain the duration of the active phase of these objects.

S. Sazonov (Space Research Institute, Russian Academy of Sciences) and R. Sunyaev continued their study of the Compton scattering in hot astrophysical plasmas. They showed that the ensemble-averaged differential cross-section for Compton scattering of low-frequency radiation by an isotropic distribution of relativistic electrons does not resemble the Rayleigh phase function. In particular, scattering by an ensemble of ultra-relativistic electrons obeys the simple law $p = 1 - \cos\alpha$, where α is the scattering angle; hence photons are preferentially scattered backwards. A formula was also derived for the mildly relativistic corrections to the Rayleigh angular function. The back-scattering effect has implications for very diverse astrophysical phenomena. In particular, it can influence the photon exchange between cold accretion disks and hot coronae or ADAF flows near relativistic compact objects; the rate of cooling of optically thick clouds of relativistic electrons in compact radiosources; the spatial diffusion of photons in hot plasma (and consequently the shapes of Comptonization spectra and the time delays between soft and hard radiation from variable X-ray sources).

Measured values of the brightness temperature of low-frequency synchrotron radiation emitted by powerful extragalactic sources reach 10^{11} – 10^{12} K. If some non-relativistic ionized gas is present within such sources, it should be heated as a result of induced Compton scattering of the radiation. S. Sazonov (Space Research Institute, Russian Academy of Sciences) and R. Sunyaev showed that if this heating is counteracted by cooling due to inverse Compton scattering of the same radio radiation, then the plasma can attain a mildly relativistic equilibrium temperature $kT \sim 10$ – 10^2 keV. The stationary electron velocity distribution can be either relativistic Maxwellian or quasi-Maxwellian (with the high-velocity tail suppressed), depending on the efficiency of Coulomb collisions and other relaxation processes. Several easy-to-use approximate expressions were derived for the induced Compton heating rate of mildly relativistic electrons located in an isotropic radiation field, as well as for the stationary electron velocity distribution and temperature.

3.7 Galaxy Evolution and the Intergalactic Medium

Stéphane Charlot, in collaboration with G. Bruzual (CIDA Venezuela), M. Fall (STScI, USA), M. Longhetti (OAB Milan), and M. Liu and J. Graham (UC Berkeley) modelled the spectral evolution of galaxies including the effects of stars, gas, and dust. The resulting models are designed to interpret in a consistent way observed galaxy spectra in terms of physical parameters such as age, star formation rate, metallicity and dust content.

G. Kauffmann, S. Charlot and M.L. Balogh (Durham) have investigated a number of stellar population diagnostics that can differentiate whether star formation in a given population of galaxies has occurred in a primarily continuous or intermittent fashion over the past few gigayears. They have applied their methods to galaxies in the Las Campanas Redshift Survey and show there is evidence that star formation has occurred relatively continuously in massive galaxies, but in an intermittent fashion in low mass galaxies.

G. Kauffmann, in collaboration with A. Diaferio (Torino), M.L. Balogh (Durham), S. White, D. Schade (DAO) and E, Ellingson (Boulder) studied the observed properties of cluster galaxies using dissipationless N-body simulations combined with semi-analytic models of galaxy formation. The simulations were compared directly with the CNOC1 survey of galaxies from 15 X-ray luminous clusters. Gradients in galaxy morphology, colour and star formation rate agreed well with those in the data.

In collaboration with V. Springel (CfA, Harvard) and G. Tormen (Padova), S.D.M. White and G. Kauffmann studied the formation of a cluster of galaxies and of the galaxies it contains. This work was based on high resolution simulations of the formation of a Coma-like cluster in its proper cosmological context. Their highest resolution simulation is the largest simulation of a galaxy cluster ever carried out and was able to distinguish nearly 5000 dynamically distinct and self-consistently simulated galaxies within the virialised region of the final cluster. The principal result of this work was to show that a galaxy formation model tuned to reproduce the properties of isolated spirals outside the cluster could, without further adjustment, fit the luminosity function, the spatial and kinematic distributions, the colours and the morphologies of cluster galaxies. In particular it demonstrated explicitly that merging of disk systems could account quantitatively for the abundance and luminosities of ellipticals in clusters.

F. van den Bosch constructed models for the formation of disk galaxies which were used to explore the origin of the density distribution of disk galaxies. Although the models are succesfull for massive high surface brightness galaxies, they fail to produce low surface brightness galaxies with exponential stellar disks. This reflects a problem with the angular momentum distribution of protogalaxies.

F. van den Bosch and A. Burkert (MPIA, Heidelberg) computed the angular momentum distribution of low mass disk galaxies and compared them to those of cold dark matter halos. Compared to the dark matter, disks lack predominantly low angular momentum material. Since there is no straightforward way to understand this deficit, the formation of disk galaxies remains poorly understood.

H.J. Mo, in collaboration with S. Mao (Jodrell Bank Observatory), also studied how the Tully-Fisher relation of disk galaxies is connected to their dark matter profiles and to the amount of gas that can settle to halo center to form the disk. They found that the observed Tully-Fisher slope, zero-point and scatter can be accomodated in current models of structure formation. W.P. Lin (a student from Beijing Observatory supported by the CAS-MPG exchange program), together with G. Börner and H.J. Mo studied the possible origin of the QSO absorption line systems associated with galaxies.

C. Brauner (a student from University of Regensburg) has finished his diploma thesis with H.J. Mo on the role of molecular hydrogen in the formation of disk galaxies.

F. van den Bosch and R. Swaters (DTM, Washington) have started an investigation of a new method of rotation curve analysis. The method minimizes the amount of data reduction, which is the main source of systematic errors, by mimicking observations of model galaxies which are directly fit to the data.

Hydrodynamic simulations were used by A. Kritsuk (Univ. of St. Petersburg), T. Plewa (MPA and Nicolaus Copernicus Center, Warsaw) and E. Müller to study the dependence of hot gas flows in X-ray luminous giant elliptical galaxies on the efficiency of heat supply to the gas. They found that a compact cooling inflow develops, if the heating is slightly insufficient to counterbalance radiative cooling of the hot gas in the central few kiloparsecs. An excessive heating in the center, instead, drives a convectively unstable outflow whose pattern is dominated by buoyancy driven large–scale mushroom–like structures.

M. Haehnelt and G. Kauffmann extended their unified model of galaxy and quasar evolution and studied the predicted correlation between black hole mass and bulge velocity dispersion. They concluded that the small scatter in the observed relation is consistent with a picture in which both bulges and black holes form over a large range in redshift.

It is possible to study empirically the evolution of young quasars and AGN's in more quiescent galaxies dominated by older stars. H. Arp, in collaboration with E. M. Burbidge (Univ. Calif.) and Y.Q. Chu (Inst. Sci. and Tech., Hefei, China) has studied the companion objects of nearby, active galalxies. Y.Q. Chu has been using the 2.19 meter telescope of the Beiging Astrophysical Observatory and Arp and E.M. Burbidge have been using the 3 meter Lick reflector on Mt. Hamilton. X-ray sources have been identified from ROSAT and Chandra observations.

Theoretical interpretation of these observations is beeing carried out in collaboration with J. Narlikar (Inst. Inter Univ. Center for Astron. and Astrophys., Pune, India). The data so far have led to investigations of fundamental physics questions such as the nature of inertial mass, modification of relativistic equations and the role of local and cosmic time scales.

K. Dolag, with M. Bartelmann, continued to simulate the evolution of magnetic fields in the intergalactic gas in galaxy clusters. These simulations were used in collaboration with A. Evrard (University of Michigan) to study the influence of magnetic fields in clusters on the mass - temperature relation. They found a 5% decrease of central cluster temperature due to cluster magnetic fields. They were also used by K. Dolag and S. Schindler (John Moores University, Liverpool) to study the effect of non–thermal pressure support from magnetic fields on mass reconstruction from X-ray observations. K. Dolag and T. Ensslin carried out simulations with somewhat higher resolution to study the properties of the radio halos produced by a non-thermal electron population, finding that the observed steep correlation between temperature and radio luminosity of galaxy clusters is well reproduced.

T. Theuns, in a collaboration with J. Schaye (IoA) and M. Haehnelt, investigated the processes that determine the widths of Lyman-α absorption lines observed in the spectra of distant quasi stellar objects, using large hydrodynamical simulations. They determined how both temperature and the amount of small-scale power influence various statistical quantities that can be measured from QSO spectra. They argued that these measures suggest that the temperature of the intergalactic medium at redshifts ≥ 3 is high, $\sim 20k$K.

T. Theuns, H. Mo and J. Schaye (IoA) collaborated to investigate possible observational effects of galaxy feedback on the intergalactic medium. They imposed simple recipes of feedback from forming galaxies and proto-clusters, onto a very large hydrodynamical simulation, and showed that significant feedback should lead to clear observational signatures, that could be detected in observed QSO spectra.

T. Theuns and S. Zaroubi developed a method based on wavelets, to identify temperature fluctuations in the intergalactic medium, by quantifying the widths of Lyman-α absorption lines in a unique way. Such temperature fluctuations are expected in the IGM as a consequence of patchy reionization of Helium II.

M. Haehnelt in collaboration with P.Madau (Cambridge, Santa Cruz), R. Kudritzki (Munich, Honolulu) and F. Haardt (Como) has found that the recent detection of hydrogen-ionizing flux escaping from high-redshift galaxies points to a scenario where star-forming galaxies reionized intergalactic hydrogen at a redshift $z > 6$ and dominate the ionizing metagalactic flux at high redshifts. They also found that in order to explain the observed Lyman alpha opacity in the absorption spectra of QSOs, m the baryonic density of the Universe had to be as large as that that favoured by recent CMB experiments, but significantly larger than that predicted by calculations of the nucleosynthesis of light elements in the early Universe, if ionizing photons could escape from all observed high-redshift galaxies.

3.8 Large Scale Structure from $z = 0$ to the Big Bang

As part of a continuing programme to exploit their 10^9 particle "Hubble Volume" simulations, J. Colberg, S.D.M. White, N. Yoshida and their colleagues within the Virgo Supercomputing Consortium carried out an analysis of the expected clustering strength of galaxy clusters as a function of cluster mass in both high and low density Cold Dark Matter cosmologies. They found that the increase in clustering strength with mass in the simulations is in very good agreement with recent modifications of a simple analytic clustering model first introduced by H.J. Mo and S.D.M. White.

In a second "Hubble Volume" project led by N. Yoshida, these same authors used simulation output along the past light-cone of putative observers to analyse whether CDM models can plausibly give rise to apparently periodic distributions of galaxies in deep pencil-beam redshift surveys. Such apparent periodicities were found by Broadhurst and collaborators in a highly controversial study published more than a decade ago. The Hubble Volume simulations made it possible for the first time to carry out a large number of independent "Broadhurst et al surveys" on dynamically consistent simulations of the galaxy distribution in CDM universes. This study concluded that the chance of obtaining a sample as regular as that observed by Broadhurst et al is well below 10^{-3} in a CDM universe.

In a project led by A. Jenkins (Durham), the Hubble Volume simulations were combined with a large number of other simulations carried out by the Virgo Consortium in order to study the mass function of collapsed, quasi-equilibrium objects ("dark haloes") predicted in CDM cosmologies. The wide range of simulations used made it possible to give accurate results for the predicted abundance of haloes over an unprecedented four orders of magnitude in mass. This study led to the remarkable result that the abundances at all epochs in all the cosmologies studied could be represented to about 10% accuracy by a universal formula which was a slight modification of one derived analytically by Mo, Sheth and Tormen.

H.J. Mo, in collaboration with R. Sheth (Fermilab) and G. Tormen (Padova Observatory), extended the Press-Schechter formalism and the halo bias model to include ellipsoidal dynamics of collapse. An application of the model to the clustering of optical and X-ray clusters was carried out by H.J. Mo together with S. Matarrese (Padova) and L. Moscardini (Padova). As a part of his PhD thesis, R. Casas (supervised by G. Börner and H.J. Mo) used N-body simulations to study the high-order correlation functions of dark matter halos and the stochastic nature in the bias model of dark halo distribution.

The power spectrum of the galaxy distribution was analysed by G. Börner and Y.P. Jing of the partner group of the MPA at Shanghai observatory with respect to scaling properties in simulations and for the Las Campanas Redshift Catalog. G. Börner and O. Ullmann investigated the influence of selection effects in the statistical analysis of (m,z) data sets of type Ia supernovae.

Within the framework of gravitationally induced clustering, cosmic peculiar velocities are direct tracers of the total mass density distribution. Therefore, peculiar velocities enable an important test for cosmological models. Y. Hoffman (Jerusalem) and S. Zaroubi have developed a new method, based on the well known principal component analysis method, which enables a detailed comparison between theoretical power spectra and those measured from peculiar velocity catalogs. In this study they concluded that the currently available peculiar velocity catalogs (Mark3 and SFI)do not seem to be consistent with the currently favored CDM models, pointing to either a problem in our theoretical understanding or a misunderstanding of the systematics that control these data sets. S. Zaroubi has also worked with L.N. da

Costa (ESO) and his collaborators to measure the bulk flow of shells within 60 Mpc/h sphere from the newly completed early-type galaxies peculiar velocity catalog (ENEAR) and found it to be consistent with determinations from other catalogs.

In order to compare with such kinematic data, H. Mathis, S.D.M. White and G. Kauffmann, in collaboration with G. Lemson, A. Dekel (both Hebrew University, Jerusalem) and V. Springel (CfA, Harvard), have simulated the formation of galaxies and larger structures in our Local Universe. The initial conditions for these simulations assumed high or low density CDM universes *constrained* so that their heavily smoothed density field evolves into the $z = 0$ density field derived by similar smoothing of the observed galaxy distribution in the IRAS 1.2Jy redshift survey. The formation of the galaxies in these high resolution simulations was followed using the techniques developed by Kauffmann, White and collaborators. The resulting simulations show all the large structures (the Local Supercluster, the Coma supercluster, the Great Attractor, the Perseus-Pisces filament, the Local Void...) familiar from local redshift surveys. This work analyses the distribution of galaxies with respect to the dark matter as a function of their intrinsic properties (luminosity, colour, morphology...) and so elucidates how one should interpret the observed differences in clustering with galaxy type in the nearby universe.

A large number of recent papers have suggested that the fit of CDM models to the detailed structure of nearby galaxies might be improved if the dark matter particles have a finite cross-section for elastic collisions. N. Yoshida, S.D.M. White, V. Springel (CfA, Harvard) and G. Tormen (Padova) carried out high resolution simulations of the formation of a galaxy cluster for two different assumptions about the collision cross-section. In their first study this cross-section was assumed sufficiently large that the mean-free-path is short compared to galaxy scales. The dark matter then behaves like a non-radiative fluid. In this limit they argued that the resulting objects have more compact cores and a similar amount of substructure to those formed when the dark matter is collisionless. This worsens the fit to observation. In a second study they examined the case where the collision time is comparable to the age of the Universe in the inner regions of the cluster. They concluded that values of the cross-section large enough to affect the core structure of dwarf galaxies would produce cores in galaxy clusters too large to be compatible with their ability to produce giant gravitationally lensed arcs. As a result this possibility also appeared unattractive.

A. Kercek and K. Jedamzik, together with T. Abel (Harvard) and M. Mac Low (American Museum of Natural History), have performed 3-D numerical simulations on the evolution of cosmic magnetic fields before the epoch of recombination.

In the framework of inflationary cosmology, the cosmic microwave background anisotropies are believed to be related to quantum fluctuations of an asymptotically free scalar field. J. Niemeyer investigated the sensitivity of the standard predictions of inflation with regard to modifications of quantum physics near the Planck scale. There, gravitational effects may be manifested, for instance, in a nonlinear behaviour of the dispersion relation. In collaboration with A. Kempf (Univ. of Florida), he also studied the cosmological consequences of a potential short-distance uncertainty relation that may arise in the context of string theory.

3.9 Gravitational Lensing

M. Bartelmann and P. Schneider (now Bonn University) finished a large review article summarising theory and observations of the weak gravitational lensing effect, which is, among other things, responsible for the distortion and magnification of faint high-redshift galaxies by the intervening large-scale mass distribution due to differential gravitational light deflection.

Weak gravitational lensing was used to study the large-scale mass distribution in the Universe. Scientists from MPA were involved in a number of observational efforts to detect and quantify cosmic shear on wide-field imaging data. Analysing about 2 square degrees of deep CFHT imaging data, a group led by L. van Waerbeke (CITA) and Y. Mellier (IAP, Paris) and involving T. Erben and P. Schneider (Bonn), was one of the four teams who simultaneously announced the detection of cosmic shear. P. Schneider (Bonn) and T. Erben were involved in a team led by R. Maoli (IAP), L. van Waerbeke (CITA) and Y. Mellier (IAP, Paris) which used VLT/FORS data from 50 independent fields to measure cosmic shear with much reduced cosmic variance. In a first application of these results, the normalisation of the dark-matter power spectrum was derived and shown to agree very well with cluster abundance normalisation. P. Schneider is PI of an accepted HST/STIS Parallel Program with up to 1200 orbits, aiming at measuring cosmic shear on small angular scales along many independent directions.

To test the accuracy with which cosmic shear can be measured, and how strongly PSF defects affect the measurements, T. Erben and P. Schneider collaborated with L. van Waerbeke, E. Bertin and Y. Mellier (IAP) to perform extensive numerical simulations on synthetic data. The result indicates that shear of order 1% can be measured reliably, with an overall calibration uncertainty of order 10%. D. Clowe, in collaboration with D. Bacon, A. Refregier and R. S. Ellis (IoA, Cambridge), performed a similar study. Despite differences in the data analysis procedure, they found very much the same result.

L. King and P. Schneider investigated the ability of weak lensing techniques to constrain the radial mass profile of galaxy clusters. In particular, the possible distinction between power-law models and the NFW universal density profile were studied, both in individual clusters and in a statistical sense. The influence of substructure was taken into account. L. King, together with V. Springel, D. Clowe and P. Schneider, studied the gravitational lensing properties of a cluster model obtained from very high resolution N-body simulations.

M. Bartelmann, L. King (now Bonn University) and P. Schneider found that the number of gravitationally lensing haloes depends sensitively on the halo density profile. Haloes with the universal NFW density profile need less mass to produce similar lensing effects as isothermal spheres, which leads to order-of-magnitude differences in the number of haloes detectable with weak lensing techniques.

B. Ménard (MPA and IAP) and M. Bartelmann started investigating higher-order effects in the QSO-galaxy cross-correlation induced by gravitational lensing, in particular higher-order corrections to the two-point correlation function, and the three-point correlation function between QSOs and galaxy pairs. These theoretical studies will later be applied to Sloan Digital Sky Survey data.

The study of gravitational arc statistics as a cosmological probe was continued. In collaboration with M. Bartelmann, L. Moscardini, G. Tormen (Padova) and M. Bolzonella (Milan), M. Meneghetti (Padova and MPA) investigated the influence of individual cluster galaxies on arc statistics and found it to be negligible. Models of galaxy clusters composed of interacting dark matter were studied by M. Meneghetti, L. Moscardini, G. Tormen (Padova), N. Yoshida, M. Bartelmann, S.D.M. White (MPA) and V. Springel (CfA, Cambridge) in terms of their ability to form gravitational arcs. Even a very small interaction cross section makes clusters less compact and more symmetric, thereby substantially reducing the number of arcs produced.

The influence of gravitational lensing by dark-matter haloes on sub-millimetre source counts was studied by F. Perrotta, C. Baccigalupi (SISSA), G. De Zotti (Padova) and M. Bartelmann. Near the flux limit of the upcoming Planck satellite mission, gravitational lensing can increase the number of point sources by an order of magnitude due to the extraordinary steepness of the intrinsic source counts. The results depend only weakly on the dark-matter profile of the lenses.

3.10 Cosmic Microwave Background Studies

T.A. Enßlin and C.R. Kaiser have derived an exact analytical expression for the distortion of the cosmic microwave background (CMB) due to relativistic plasma. The distortions caused by the relativistic plasma of radio galaxies and by the gas heated by the expansion of the lobes of radio galaxies was estimated. Both effects may be marginally detectable with the Planck experiment.

S. Matarrese, in collaboration with C. Baccigalupi and F. Perrotta (SISSA, Trieste) and A. Balbi and N. Vittorio (Phys. Dept. Roma, Italy), calculated CMB anisotropies in models with a dynamical vacuum energy component ("quintessence"). Comparison with recent BOOMERang and MAXIMA data allowed a constraint on the present amount of vacuum energy and its equation of state.

The CMB provides an important probe of the Gaussianity of the primordial fluctuations field, an issue of great importance for understanding the origin of structure. Recently, several groups have reported detection of a non-Gaussian signal in the COBE-DMR maps. S. Zaroubi, A. J. Banday and K. M. Górski (ESO) have carried out an extensive study in order to examine whether this non-Gaussianity is of cosmological origin. Their study plausibly traced the origin of the signal to a systematic effect in the data.

Collaborative work between A.J. Banday, R.B. Barreiro, M.P. Hobson, A.N. Lasenby (MRAO, Cambridge), K.M. Górski (ESO, Garching) and G. Hinshaw (GSFC, USA) has tested for non-Gaussian signals in the COBE-DMR sky maps using an analysis based on spherical Haar wavelets. No such signals were found. Extension of this work using a different set of basis wavelets (the Mexican Hat) is now underway involving L. Cayón and E. Martínez-González (IFCA, Santander). Continuing research involving A. J. Banday, S. Zaroubi, and K.M. Górski (ESO, Garching) on the angular bispectrum of the COBE-DMR data also contradicts previous claims for the detection of non-Gaussian signals using this statistic.

A.J. Banday in collaboration with K. M. Górski (ESO, Garching), G. Giardino, K. Bennett, P. Fosalba, W. O'Mullane, J. Tauber (ESTEC, Nordwijk) and C. Vuerli (Trieste) have utilised the Planck foregrounds data base to study the spatial properties of Galactic foreground emission and to determine the likely contamination of the primary Cosmic Microwave Background (CMB) signal at Planck wavelengths. This study also allowed an evaluation of the data base architecture envisaged for Planck. The above group, together with J. Jonas (HRAO, South Africa), have studied the nature of the 2.3 GHz radio continuum and in particular its power spectrum, in order to test for possible foreground contamination of the CMB signal to be measured by Planck.

The population of galaxy clusters which Planck will see was investigated by M. Bartelmann. More than 70% of the expected $\sim$ 30000 clusters visible for Planck through their thermal Sunyaev-Zel'dovich effect will produce a significant gravitational lensing signal. The two effects can be used to extract detailed information on the formation and evolution of the cluster population. L. Moscardini (Padova) and M. Bartelmann determined the expected clustering properties of this same clusters.

A.J. Banday in collaboration with K.M. Górski (ESO, Garching), B. Wandelt (Princeton, USA), E. Hivon (CalTech, USA), M. Bartelmann and F. Hansen continue to maintain and develop the HEALPix software package for the simulation and analysis of CMB anisotropy maps. In partial fulfilment of MPA's obligations within the Planck satellite project, a group of scientists and software developers (A. J. Banday, M. Bartelmann, F. Dannemann, K. Dolag, R. Hell and W. Hovest) is contributing to, and in part coordinating, the project-wide data simulation, analysis, and archive-construction activities.

3.11 Quantum Mechanics of Atoms and Molecules, Astrochemistry

Recent advances in semiconductor technology has allowed the construction of new quantum systems, sometimes referred to as *artificial atoms*, also known as *quantum dots*. An artificial atom is essentially a number of electrons confined in a potential well. Similar systems may be obtained by confining an atom, a molecule or several such objects. Another area where spatial confinement leads to the appearance of new properties of quantum systems is the embedding of atoms and molecules in nano-cavities, as for example in fullerenes, in zeolite cages, in helium droplets, in nano-bubbles formed around foreign objects in the environment of liquid helium, etc. The development of new technologies and experimental techniques has triggered intensive theoretical studies on modelling spatially confined quantum systems. We have applied quantum-chemical models of atoms and molecules to investigate the effects of spatial confinement. The confined object is described by the Hartree-Fock and by the configuration interaction methods. The spatial confinement is defined by an external one-particle potential introduced to the N-electron Hamiltonian. We have established relations between spectral properties of confined quantum system and the parameters defining the confining potential. These relations are of interest both in the context of the fundamental knowledge of properties of quantum systems and in the context of possible practical applications. Quantum dots or artificial atoms, for example, may form a basis of new a generation of lasers. These studies are being pursued by G.H.F. Diercksen in cooperation with researchers from Calcutta, Edmonton and Torun.

Major efforts have been made in the past to develope new methods and techniques for studying problems in molecular astrophysics. Two areas of main interest are: the interpretation of molecular spectra of astrophysical interest and the investigation of basic interstellar reactions.

(1) The interpretation of rotation-vibrational spectra of small molecular systems based on highly accurate quantum mechanical calculations is still one of the most successful research fields where theory is able to assist in the interpretation of experimental results and can make useful predictions for experimentalists and observers. Whereas the high precision determination of the spectral properties

of isolated molecular electonic states was the main target of such theoretical efforts in the past, new developments are now devoted to analysing the spectra of interacting electronic states. In collaboration with P. Jensen (Gesamthochschule Wuppertal) a new method was previously developed to handle a special case of such interacting states in a triatomic molecule, namely a pair of so-called Renner-Teller degenerate electronic states. This method was recently successfully applied by W.P. Kraemer and P. Jensen to a number of triatomic molecular ions and some of the theoretical results have led to a re-interpretation of previous experimental findings. Similar calculations were now performed by Kraemer and Jensen for the silicon containing hydrides SiH_2 and SiH_2^+ which are of some astrophysical interest and for which experimental information is essentially missing. Apart from studying their nuclear dynamics, the dissociation behavior of some of the lower electronic states of these hydrides was also investigated in order to understand possible formation paths. Together with P.R. Bunker (NRC Canada, Ottawa) the Renner-Teller states of the NH_2 radical were analysed with this approach assisting experimentalists to clarify some unresolved problems.

(2) Whereas the bound rotation-vibrational states characterize essentially the behavior of stable molecular species, an understanding of a chemical reaction requires the knowledge of the rotation-vibrational resonance states of the reaction complex, which are obtained as quasi-bound states with energies above the relevant dissociation limits of the complex. For diatomic molecules the quantum mechanical determination of these states is usually rather straightforward, but it becomes already a very difficult task for general triatomics. Previously calculated potential energy surfaces on a high accuracy level of the two lowest electronic states of the HeH_2^+ complex were used to determine all bound state levels and their lifetimes (W.P. Kraemer). These calculations were now extended using different approaches by V. Spirko and M. Sindelka (Academy of Sciences, Prague) and by L. Ixaru (Institute of Physics and Nuclear Ingeneering, Bucharest) to evaluate the positions (energies) of the low-lying quasi-bound states. Apart from these energy determinations, additional efforts are presently made to modify an earlier code written by F. Mrugala (Nicolaus Copernicus University, Torun) for calculating the corresponding eigenfunctions. These eigenfunctions together with the recently obtained dipole moments of the two states and the transition moment function (W.P. Kraemer) allows the calculation of the radiative association rates for both states and of the rate coefficient for the radiative charge transfer reaction which converts the original reactants He^+ and H_2 into the final products He and H_2^+, a process which is possibly relevant for the primordial gas development.

4 Publications and Invited Talks

4.1 Publications in Journals

4.1.1 Publications that appeared in 2000

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Spruit, H.C.: Theory of solar luminosity and radius variations. In: NATO ASI C 558, Eds. M. Stavinschi and J.-P. Zahn. Kluwer, Dordrecht 2000, 289–301.

Spruit, H.C.: Gamma ray bursts from rapidly spinning neutron stars In: Gamma Ray Bursts. Proceedings 5th Huntsville Symposium, Huntsville 1999, Eds. R.M. Kippen et al. American Institute of Physics, 2000, 589–596.

Thomas, H.-C., K. Beuermann, V. Burwitz, K. Reinsch and A.D. Schwope: RX J1313.2-3259, a long-period Polar discovered with ROSAT In: Cataclysmic Variables, a 60th Birthday Symposium in Honour of Brian Warner. Proc. Oxford 1999, Eds. P. Charles, A. King and D. O'Donoghue. New Astronomy Reviews **44**(1–2) 53–54.

Weiss, A. and H. Schlattl: Age determinations of individual cluster stars In: Massive Stellar Clusters. Proc. workshop, Strasbourg 1999, Eds. A. Lançon, C.M. Boily. ASP conference series, vol. 211, San Francisco 2000, 165–168.

White, S.D.M. and V. Springel: Where are the first stars now? In: The First Stars. Proc. MPA/ESO workshop, Garching 1999, Eds. A. Weiss, T.G. Abell and V. Hill. Springer Verlag, Berlin 2000, 327–335.

4.3 Popular article and books

Bartelmann, M.: Der kosmische Mikrowellenhintergrund. Astronomie und Raumfahrt, **37/2**, 8–11 (2000).

Bartelmann, M.: Der kosmische Mikrowellenhintergrund. Sterne und Weltraum, **39/5**, 330–337 (2000).

Bartelmann, M.: Schall aus dem frühen Universum. Physikalische Blätter, **56/6**, 14–15 (2000).

Börner, G.: Ein Zustand wie zehn Mikrosekunden nach dem Urknall. Süddeutsche Zeitung, 15.2.2000.

Börner, G.: Die Statistik der Galaxienverteilung. Astronomie und Raumfahrt **37**(2000)2, p.16–20.

Hillebrandt W. and E. Müller: Proceedings of the 10th Workshop on "Nuclear Astrophysics" Ringberg Castle, Tegernsee. March 20 – 25, 2000 MPA/P12, 141p.

Kercek, A.: Simulation von Novaausbrüchen In: Forschung und wissenschaftliches Rechnen. GWDG-Bericht Nr. 54, Göttingen 1999, 37–44.

Spruit, H.C.: The Photosphere In: Encyclopedia of Astronomy and Astrophysics. Institute of Physics Publishing/MacMillan, Bristol 2000, 2045–2652.

Spruit, H.C.: Accretion Disks In: Encyclopedia of Astronomy and Astrophysics. Institute of Physics Publishing/MacMillan, Bristol 2000, 12–17.

4.4 Invited talks

M.-A. Aloy: “Similarities and Universality in Relativistic Flows” (Mykonos, 1.10.–5.10.)

M. Bartelmann: ESO-Kolloquium (Garching, 22.2.)

M. Bartelmann: Astrophysikalisches Kolloquium: (Bonn, 7.7.)

M. Brüggen: Colloquium at the University of Leicester: “Simulations of Cooling Flows” (Leicester, U.K. 22.11.)

S. Charlot: ITP Workshop on “Galaxy Formation and Evolution” (Santa-Barbara, USA, 14.3.–17.3.)

S. Charlot: TMR Workshop on “Extracting Information from Galaxy Spectra” (Porquerolles, France, 20.5.–21.5.)

S. Charlot: Ringberg Workshop on “Starburst Galaxies: Near and Far” (Ringberg, Germany, 10.9.–15.9.)

E. Churazov: JENAM conference, (Moscow, 27.05.-01.06.)

E. Churazov: Workshop “Plasma Processes in Laboratory and Space”, (Moscow, 18.10.–21.10.)

T.A. Enßlin: 24th meeting of the IAU, Joint Discussion 10, “Particle Acceleration and Diffusion in Fossil Radio Plasma”(Manchester, England, 7.8–18.8.)

M. Gilfanov: IX Marsel Grossmann Meeting on “Recent developments in theoretical and experimental general relativity, gravitation and relativistic field theories” (Rome, Italy, 2.07.–8.07.)

M. Gilfanov: 33rd COSPAR Scientific Assembly, Symposium “X-ray and gamma-ray signatures of black holes and neutron stars” (Warsaw, Poland, 16.07.–23.07.)

M. Gilfanov: Joint European and National Astronomical Meeting for 2000 “European Astronomy at the turn of the Millenium” (Moscow, Russia, 29.05.–3.06.)

M.G. Haehnelt: International conference ”Galaxy Formation and Evolution” (St Barbara, 14.3.–17.3.)

M.G. Haehnelt: Oort worshop “Black Holes: Evidence, Evolution and Future Prospects” (Leiden, 17.4.–20.4.)

M.G. Haehnelt: The Oort Centenary Symposium, “Mapping the dark matter distribution at high redshift”, (Leiden, 25.4.–27.4.)

M.G. Haehnelt: First Harvard-Smithsonian Conference on Theoretical Astrophysics (Boston, 15.5.–18.5)

M.G. Haehnelt: JENAM 2000, (Moskau, 29.5.–3.6.)

M.G. Haehnelt: Tsukuba International Workshop (Tsukuba, 3.7.–7.7.)

M.G. Haehnelt: ESO workshop on ”Deep Fields” (Garching, 9.10.–12.10.)

W. Hillebrandt: “Energy densities in the Universe”, Recontres de Moriond (Les Arcs, 22.1.–29.1.)

W. Hillebrandt: 10th Ringberg Workshop on “Nuclear Astrophysics” (Ringberg Castle, 20.3.–25.3.)

W. Hillebrandt: Int. Workshop on “Type Ia Supernovae” (Trento, 9.7.– 5.8.)

W. Hillebrandt: Int. Conference “Cosmic Evolution” (Paris 13.11.–17.11.)

H.-Th. Janka: International Conference “Stellar Collisions, Mergers, and their Consequences” (New York, 30.5.–2.6.)

H.-Th. Janka: ECT* Programme “Physics of Neutron Star Interiors” (Trento, 18.6.–7.7.)

H.-Th. Janka: Physikalisches Kolloquium (Dresden, 19.12.)

G. Kauffmann: 195th Meeting of the American Astronomical Society, “The Formation and Evolution of galaxies” (Atlanta, Georgia, 12.1–15.1.)

G. Kauffmann: “Galaxy Formation and Evolution”, Santa Barbara, California (14.3.–17.3.)

G. Kauffmann: “Victoria Computational Cosmology Conference”, Victoria, Canada (21.8.–25.8.)

G. Kauffmann: “Starbursts Near and Far”, Ringberg Castle, Germany (10.9.–15.9.)

K. Kifonidis: Tours Symposium on ”Nuclear Physics IV” (Tours, 4.9.–7.9.)

E. Müller: 6th International Computational Accelerator Physics Conference ”ICAP 2000” (Darmstadt, 11.9.–14.9.)

E. Müller: Nuclei in the Cosmos ”NiC 2000” (Aarhus, 26.6.–1.7.)

P. Schneider: “Symposium für Professor Jürgen Ehlers”, (AEI Golm, 18.2.–19.2.)

P. Schneider: “Fundamental Physics in Space and related topics”, (CERN, Geneva 5.4.–7.4.)

P. Schneider: “DARK 2000”, (Heidelberg, 11.7.–14.7.)

P. Schneider: “New Cosmological Data and the Values of the Fundamental Parameters”, IAU Symposium 201, (Manchster, UK 7.8.–11.8.)

H.C. Spruit: Joint European and National Astronomy Meeting 2000 (Moscow 29.5–2.6.)

H.C. Spruit: Workshop in Honor of P.P. Eggleton’s 60^{th} birthday (Bormio 25.6.–1.7.)

R. Sunyaev: JENAM 2000 (Moscow, Russia, 29.5.–3.6.)

R. Sunyaev: IX Marsel Grossmann meeting (Rome, Italy, 2.7.–8.7.)

R. Sunyaev: “Black Hole: evidence, evolution and future prospects” (Leiden, The Netherlands, 17.4.–20.4.)

R. Sunyaev: The 2nd Chicago Conference on Thermonuclear Astrophysical Explosions, (Chicago, USA 8.6.–10.6.)

R. Sunyaev: 33rd. COSPAR Scientific Assembly, (Warsaw, Poland 16.7.–23.7.)

R. Sunyaev: Workshop Dedicated to the Sunyaev-Zel’dovich Effect, (Toulouse, France 29.6.–30.6.)

R. Sunyaev: Summer Space Science School, (Alpbach, Austria 28.7.)

R. Sunyaev: National Meeting in Astronomy and Astrophysics (Lisboa, Portugal, 26.7.–28.7.)

R. Sunyaev: “X-Ray astronomy 2000” (Palermo, Italy, 4.9.–8.9.)

R. Sunyaev: 4th. INTEGRAL Workshop “Exploring the gamma-ray universe”, (Alicante, Spain 4.9.–8.9.)

R. Sunyaev: “Plasma Processes in Laboratory and Space”, conference devoted to the 60th birthday of academician Albert Galeev, (Moscow, Russia 19.10.–20.10.)

S.D.M. White: Dark Matter 2000 (Marina del Rey, California, 23.2–25.2)

S.D.M. White: Workshop on “The Formation of Galaxies” (Santa Barbara, California, 14.3.–17.3.)

S.D.M. White: “The First Generation of Cosmic Structures”

S.D.M. White: TMR Network workshop ”Stellar Populations” (Porquerolles, 20.5.–21.5.)

S.D.M. White: “Disk Galaxies and Galaxy Disks” (Rome, 12.6.–16.6) (Cambridge, Mass., 15.5.–18.5.)

S.D.M. White: “Clusters of Galaxies” (Paris, 4.7.–7.7.)

S.D.M. White: ESA Summer School in Astrophysics (Alpbach, Austria 17.7.–28.7.)

S.D.M. White: “Victoria Computational Cosmology Conference” (B.C., Canada, 21.8.–25.8.)

S.D.M. White: Herbstschule in Hochenergiephysik (Maria Laach, Germany, 5.9.–15.9.)

S.D.M. White: ESO/ECF/STScI Workshop on “Deep Fields” (Garching, 9.10–11.10.)

S.D.M. White: “Cosmic Evolution” (Paris, 13.11.–18.11.)

S.D.M. White: “100 Years of Quantum Theory” (Berlin, 11.12.–13.12.)

5 Personnel

5.1 Scientific staff members

Directors

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

Scientific Member

R.-P. Kudritzki (on leave of absence since Oct. 1)

Staff

M. A. Aloy-Torás (Febr. 1–Dec., 31), U. Anzer, P.J. Armitage (till Sept. 30), A. Banday, M. Bartelmann, S. Bianchi (since Sept. 1) G. Börner, M. Brüggen (on leave of absence since Nov. 1), E. Churazov, D. Clowe (till March 31), C. Cress (till Sept. 14), F. Daigne, G.H.F. Diercksen, K. Dolag (since May 1), T. Enßlin, J.A. Font–Roda, M. Gilfanov, M. Groenewegen (till Sept. 30), M. Haehnelt (till Oct. 31), S. Heinz (since Oct. 15), H.–T. Janka, K. Jedamzik, C. Kaiser (till Sept. 30), G. Kauffmann, A. Kercek (till Dec. 31), L. King, W.P. Kraemer, R.–P. Kudritzki, F. Miniati (since Nov. 1) H.J. Mo, E. Müller, J.C. Niemeyer (since Oct. 1), R. Popham (till Aug. 31), H. Ritter, H. Schlattl, P. Schneider (till Febr. 29), H.C. Spruit, H.–C. Thomas, F. van den Bosch (since Aug. 1) R. Wegmann (till Sept. 30), A. Weiß, S. Zaroubi.

Emeriti

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

Scientists associate:

H. Arp, E. Meyer–Hofmeister, J. Schäfer, R. Wegmann (since Oct. 1).

Ph.D. Students

R. Banerjee, J. Braithwaite (since Nov. 1), A. Büning (since June 1), R. Casas, G. Contardo (till March 31), C. Cramphorn, B. Deufel, H. Dimmelmeier, K. Dolag (till April 30), G. Drenkhahn, T. Erben (till Dec. 31), M. Flaskamp (since Febr. 1), H.-J. Grimm, H. Hämmerle, F. Hansen, K. Kifonidis (till Dec. 31), G. Kruse (till March 31), W. Lin (till Aug. 6), M. Lisewski (till May 31), S. Marri, H. Mathis, B. Menard (since Sept. 15), A. Nickel, N. Przybilla (till May 31), M. Rampp, K. Reblinsky (till July 31), J. Rehm (till May 31), M. Reinecke, F. Röpke (since July 1), H. Schlattl (till Sept. 30), J. Schmalzing (till Sept. 30), F. Siebel (since Nov. 1), V. Springel (till Sept. 30), F. Stöhr (since Febr. 1), C.F. Vollmer (till June 30), N. Yoshida.

Diploma students

C. Brauner (till Oct. 1), T. Leismann (till July 1), F. Linke (till Dec. 4), R. Pfrogner (till March 1), D. Sauer (till Dec. 1), L. Scheck (till July 1).

Alexander von Humboldt fellowships

D. Munshi (Triest, Italy), till Feb. 29; D. Bielinska–Waz (Torun, Poland), till Oct. 30.

DAAD–fellowships

C. Morales–Merino (Tlaxcala, Mexico) till Feb. 28; N. Yoshida (Tokyo, Japan).

EC–fellowships

C.P. Dullemond, S. Hardy (till Febr. 29), L. King (till March 1), T. Theuns (till March 15).

5.1.1 Staff news

M. Bartelmann: Erteilung der Lehrbefugnis für Astronomie an der Ludwig–Maximilians-Universität, München (Ernennung zum Privatdozenten).

M. Brüggen: awarded the Blackwell Prize by the Royal Astronomical Society in London for the best astrophysical thesis in the U.K.

G.H.F. Diercksen: Alexander von Humboldt Foundation Honorary Research Fellowship of the Foundation for Polish Science.

G.H.F. Diercksen: Gold Medal of the Faculty of Natural Sciences, Comenius University, Bratislava.

G.H.F. Diercksen: Japanese-German Research Award of the Japan Society for the Promotion of Science.

E. Müller: Erteilung der Lehrbefugnis für theoretische Astrophysik an der Technischen Universität München (Ernennung zum Privatdozenten).

H.C. Spruit: Extraordinary Professorship, University of Amsterdam.

R. Sunyaev: The Catherine Wolfe Bruce Gold Medal for 2000 from the Astronomical Society of Pacific.

R. Sunyaev: State Prize of Russia for 2000 (for scientific results of the GRANAT astrophysical space mission)

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

S.D.M. White: Honorary Professorship, Shanghai Astronomical Observatory, Chinese Academy of Sciences.

5.1.2 Diploma and Ph.D. theses 2000

Diploma theses:

C. Brauner: “The Role of Molecular Hydrogen in Galaxy Formation”, University Regensburg.

T. Leismann: “Decelerating Extragalactic Relativistic Jets”, Technical University; Munich.

F. Linke: “General Relativistic Simulation of Collapsing supermassive Stars”, Technical University; Munich.

R. Pfrogner: “Simulation des Gravitationslinseneffektes bei Spiralgalaxien”, Ludwig–Maximilians–University, Munich.

D. Sauer: “Uncertainties in the Determination of the Primordial ^{4}He Abundance”, Technical University; Munich.

L. Scheck: “Untersuchungen zur Langzeitentwicklung relativistischer, extragalaktischer Jets”, Technical University; Munich.

Ph.D. theses:

T.G. Abel: "The First Structures in the Universe. A theoretical study of their Formation, Evolution and Impact on Subsequent Structure Formation". Ludwig–Maximilians–University; Munich (1999).

K. Dolag: "SPH-Simulationen der Entwicklung von Magnetfeldern in Galaxienhaufen", Ludwig–Maximilians–University; Munich.

T. Erben: "Applications of the weak gravitational lens effect", Ludwig–Maximilians–University; Munich.

G. Kruse: "Statistische Untersuchungen zum schwachen kosmologischen Gravitationslinseneffekt", Ludwig–Maximilians–University; Munich (1999).

M. Rampp: "Radiation Hydrodynamics with Neutrinos: Stellar Core Collapse and the Explosion Mechanism of Type II Supernovae", Technical University; Munich.

K. Reblinsky: "Projection effects in clusters of galaxies" Ludwig–Maximilians–University, Munich.

J. Rehm: "The Influence of Matter-Antimatter Domains on Big Bang Nucleosynthesis", Ludwig–Maximilians–University, Munich.

V. Springel: "On the Formation and Evolution of Galaxies", Ludwig–Maximilians–University; Munich (1999).

Habilitation thesis:

A. Weiss: "Calculation and application of low-mass stellar models" Ludwig–Maximilians–University, Munich (19.7.00).

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
T. Abel	(Cambridge, U.S.A.)	14.8.–11.9.
R. Adamczak	(Torun, Poland)	20.10.–20.12.
H. Asada	(Hirosaki, Japan)	10.7.–31.8.
I. Baraffe	(Lyon, France)	1.10.–31.12.
D. Bielinska-Waz	(Torun, Poland)	till 30.10.
S. Blinnikov	(Moscow, Russia)	3.7.–11.8.
G. Bruzual	(Merida, Venezuela)	1.9.–30.9.
P.R. Bunker	(Ottawa, Canada)	11.9.–24.9.
X.-W. Cao	(Shanghai)	18.2.–18.8.
I. Cernusak	(Bratislava, Slovak Republic)	4.6.–4.7.
S. Charlot	(Paris, France)	1.1.–30.6.
		since 1.10.
P.A. Denissenkov	(St. Petersburg, Russia)	31.1–2.4.
W. Duch	(Torun, Poland)	3.7.–15.8.
S.A. Ehgamberdiev	(Tashkent, Uzbekistan)	29.02.–3.4.
W. Duch	(Torun, Poland)	3.7.–15.8.
J. Faulkner	(Santa Cruz, U.S.A.)	till 15.9.
C. Fryer	(Los Alamos, U.S.A.)	26.8.–8.9.
B.A. Fryxell	(Chicago, U.S.A.)	28.2.–27.3.
		22.6.–22.7.
S.A. Grebenev	(Moskau, Russia)	23.08.–23.09.
		20.11.–21.12.
P. Heinzel	(Ondrejov, Czech Rep.)	22.5.–22.6.
		12.11.–12.12.
J.M. Ibáñez	(Valencia, Spain)	22.6.–6.7.
V. Imshennik	(ITEP, Russia)	29.10.–29.11.
N.A. Inogamov	(Moskau, Russia)	21.08.–30.09.
L. Ixaru	(Bukarest, Romania)	5.6.– 5.7.
P. Jensen	(Wuppertal, Germany)	15.3.–25.3.
		16.7.–28.7.
M. Karelson	(Tartu, Estland)	8.5.–21.5.
		11.12.–22.12.
J. Karwowski	(Torun, Poland)	8.6.–6.7.
V. Kellö	(Bratislava, Slovak Republic)	1.10.–11.11
P. Kilpatrick	(Belfast, Northern Ireland)	1.7.–4.8.
M. Klobukowski	(Edmonton, Canada)	16.6.–16.7.
O. Kotov	(Moskau, Russia)	19.2.–2.4.
		17.11.–25.12.
A. Kritsuk	(St. Petersburg, Russia)	12.4.–10.5.
		5.7.–6.8.
I. Kryukov	(Moscow, Russia)	5.3.–5.4.
		1.12.–15.12.
Q.B Li	(Beijing, China)	28.7.–28.8.
G. Lodato	(Pisa, Italy)	15.11.–23.12.
M. Longhetti	(Milan, Italy)	6.4.–21.4.
		16.7.–28.7.

Name	home institution	Duration of stay at MPA
P.A. Malmqvist	(Lund, Sweden)	10.10.–10.11.
S. Mandal	(Santinikitan, India)	1.9.–31.10.
S. Mao	(Manchester, U.K.)	since 5.12.
L. Mashonkina	(Kacan State Univ., Russia)	3.7.–2.10.
F. Masset	(London, U.K.)	1.10.–31.12.
S. Matarrese	(Padova, Italy)	till 31.7.
M. Meneghetti	(Padova, Italy)	6.6.–31.7.
		16.11.–22.12.
J. Myers	(Clemson, U.S.A.)	14.5.–28.6.
L. Moscardini	(Padova, Italy)	5.07.–20.07.
P.K. Mukherjee	(Calcutta, India)	11.9.–9.11.
D. Nadyozhin	(Moscow, Russia)	24.2.–31.3.
S. Nuritdinov	(Univ. of Uzbekistan)	24.10.–23.11.
A. Nusser	(Haifa, Israel)	25.8.–5.9.
		10.9.–3.10.
B. Paczynski	(Princeton, U.S.A)	2.7.–9.8.
A.R. Prasanna	(Ahmedabad, India)	1.5.–2.6.
P. Papadopoulos	(Portsmouth, U.K.)	24.9.–14.10.
H. Papathanassiou	(Portsmouth, U.K.)	24.9–14.10.
T. Plewa	(Warschau, Poland)	1.3.–30.4.
		1.6.–31.10.
N. Pogorelov	(Moscow, Russia)	4.3.–5.4.
		1.12.–15.12.
K. Postnov	(Moscow, Russia)	20.11.–24.12.
M.G. Revnivtsev	(Moskau, Russia)	20.02–19.05.
		20.9.–20.12.
B. Rosner	(Chicago, U.S.A.)	24.6.–23.7.
M. Ruffert	(Edinburgh, Scotland)	3.4.–20.4.
P. Ruiz-Lapuente	(Barcelona, Spain)	till 28.2.
		4.7–25.8.
M. Salaris	(Liverpool, U.K.)	2.6.–21.7.
S.Y. Sazonov	(Moskau, Russia)	9.1.–2.4.
		21.8.–10.10.
		11.11.–23.12.
W. Schaap	(Groningen, Netherlands)	12.11.–26.11.
N.I. Shakura	(Moskau, Russia)	20.11.–23.12.
R. Sheth	(Fermilab, U.S.A.)	13.11.–26.11.
C. Shu	(Shanghai, China)	since 1.12.
N.R. Sibgatoulline	(Moskau, Russia)	10.1.–15.2.
		26.7.–4.9.
		24.11.–24.12.
S. Sild	(Tartu, Estland)	2.5.–31.5.
		1.10.–31.10.
M. Sindelka	(Prague, Czech Rep.)	22.5.–22.7.
E. Sorokina	(Moscow, Russia)	19.3.–2.4.
		3.7.–11.8.

Name	home institution	Duration of stay at MPA
V. Spirko	(Prague, Czech Rep.)	22.5.– 8.7.
V. Springel	(Harvard Univ.)	1.10.–31.10.
N. Sugiyama	(Kyoto, Japan)	26.9.–10.10.
R.. Taam	(Evanston, U.S.A.)	15.8.–15.9.
M. Takami	(Tokyo, Japan)	25.5.–25.6.
M. Urban	(Bratislava, Slovak Republic)	4.6.–14.7.
		10.12.–22.12.
R. van den Weygaert	(Groningen, Netherlands)	13.11.–28.11
E. Vanzella	(Padova, Italy)	7.3.–7.6.
M. Viel	(Padova, Italy)	till 31.3.
		16.7–6.8
A. Voevodkine	(Moskau, Russia)	19.2.–2.4.
		17.11.–25.12.
S.E. Woosley	(Santa Cruz, U.S.A.)	26.7.–31.8.
X.-B. Wu	(Beijing, VR China)	till 17.12.
B. Wybourne	(Torun, Poland)	1.6.–17.6.
S. Yamamoto	(Nagoya, Japan)	20.7.–12.8.
V. Zheleznyakov	(Nizhnij Novgorod, Russia)	2.7.–31.07.