material that surrounds the central body (red and yellow regions in the lower right panel of Fig. 2.9) has sufficiently large angular momentum that it might remain in a disk around the black hole for some while. This material could therefore be accreted into the black hole on a much longer timescale during which it would copiously radiate neutrinos. Unfortunately, analytical considerations lead to the same conclusion as our numerical simulation of the dynamical merging phase: Even under the most favorable conditions, the energy provided by annihilation of neutrinos and antineutrinos emitted from the disk falls short by nearly two orders of magnitude and thus cannot account for cosmological gamma-ray burst events.

Certainly, this result is rather disappointing. Nevertheless, the described quantitative investigations and simulations have very important implications, because they strongly emphasize that the enigmatic gamma-ray bursts cannot be explained by neutrino annihilation in the vicinity of merging binary neutron stars. The currently most popular idea fails to solve the puzzle. Therefore more complicated models have to be considered, possibly involving effects of amplified and very strong magnetic fields in the merger. Also completely different types of scenarios have to be taken more seriously. (Maximilian Ruffert & H.-Thomas Janka)

2.7 Simulations of relativistic jets

In 1918 H.D. Curtis photographed the giant elliptical galaxy M87 and noticed a "curious straight ray", which was "apparently connected with the nucleus of the galaxy by a thin line of matter". This was the first discovery of a so–called extragalactic jet. Nowadays several hundreds of these extragalactic jets are known. Most of them were discovered by radio observations, because they seem to transport enormous amounts of energy from the nuclei of radio galaxies and quasars (point–like quasi–stellar radio sources emitting enormous amounts of energy) to intergalactic space, thereby powering the extended regions of radio emission (the so–called radio lobes) of these sources. High resolution radio interferometry has shown that the jets are extremely well collimated extending from the very centre of the galaxy all the way out to distances of several hundred thousand light years.

Besides the extragalactic jets, one has also found collimated outflows in some galactic binary systems, most notably in the binary star SS433. The stellar jet of SS433, which was discovered in the late seventies, propagates with a velocity equal to one quarter of the speed of light, i.e., its velocity is near–relativistic. Even larger jet speeds have recently been observed for two galactic X-ray sources, which consist of binaries where one member of the binary is most likely a black hole. The measured apparent (transverse) motion for both sources exceeds the speed of light. This phenomenon, commonly referred to as "superluminal" motion, is also observed for many extragalactic jets at distances of light years up to a few thousand light years. Superluminal motion is widely interpreted as the result of highly relativistic bulk velocities, which are oriented nearly along to the line of sight. For a source of radiation moving near the speed of light the apparent time duration between two events seen by a distant observer is compressed if the motion is close to the line of sight, because the source "chases" its own radiation. Hence, the apparent velocity of the projected motion on the sky can appear to exceed the speed of light.

Recent observations of the quasar 3C31 show that the speed of its jet decreases significantly with increasing distance from the centre. This observed "slow down" of an initially relativistic jet has led some researchers to argue that probably *all* extragalactic jets propagate at relativistic speeds, at least close to the source.

Because of this observational evidence, we have begun to perform simulations of relativistic jets. Such simulations were not feasible until a few years ago when appropriate numerical methods were developed, because the relativistic equations are substantially more complicated and harder to solve than the non–relativistic ones. In our simulations we assumed (as in most other studies) that the gas pressure in the jet is equal to the pressure exerted by the ambient gas (pressure–matched jets), which seems to be roughly the case in astronomical jets.

Our studies revealed that relativistic jets show the same main features as non–relativistic ones (Figs. 2.10 and 2.11). A supersonic *beam* of nearly constant diameter, which periodically slightly expands and converges. This causes a series of internal oblique shock waves, which collimate the flow. The supersonic flow terminates at the head of the advancing beam in a shock wave called a *Mach disk*, which causes an abrupt and strong deceleration of the beam gas to subsonic speed. The kinetic energy of the beam gas is converted into heat, which creates a "hot spot" and increases the pressure of the beam gas by a large amount. The shocked beam gas expands sideways out of the path of the beam and then flows backward along the beam, feeding an enveloping *cocoon* filled with turbulent eddies. Like any airplane flying at supersonic speed, the cocoon is surrounded by a *bow shock*, which compresses and heats the ambient medium. Finally, between bow shock and cocoon there exists a hydrodynamically unstable interface separating shocked ambient gas from jet material.

The dynamical properties of non–relativistic jets, and also some morphological properties, in particular the extent of the cocoon, depend on the jet's Mach number (the beam speed divided by the speed of sound in the beam gas) and its density ratio (the density of the jet gas divided by that of the ambient gas). For relativistic jets an additional quantity is required to completely specify the flow, because the speed of light in vacuum is the maximum speed allowed in relativistic dynamics. Hence, for a relativistic jet the Mach number and the jet speed must be specified separately.

The propagation speed of a jet is the rate at which the head of the beam moves into the surrounding gas. An upper limit for this speed can be obtained by assuming that the jet propagates ballistically (like a bullet). In this approximation the propagation speed of non–relativistic jets depends only on their density ratio. Dilute jets propagate at a small fraction of their beam gas velocity, while very dense jets can propagate at close to the beam gas velocity. Simulations confirm that dense, non–relativistic jets propagate most efficiently. Their speed, however, never exceeds 80% of the ballistic estimate. Low Mach number, dilute jets are less efficient and propagate at roughly 40% of the speed obtained from the ballistic estimate.

For relativistic jets one can also make ballistic estimates. However, it is important to note that the power driving the jet through the ambient gas can be large, not only because the beam gas moves relativistically, but also because it may have a large thermal energy (and so be "hot"). As a result, relativistic ballistic estimates give systematically larger propagation velocities than non–relativistic ones. While in the non–relativistic case only dense jets propagate almost ballistically, in the relativistic case high propagation efficiencies arise for ultrarelativistic beam gas velocities and/or for extremely hot jets.

Large propagation speeds cause the cocoons of relativistic jets to be less prominent than those of non–relativistic jets, the thickness of the cocoon depending upon the beam Mach number. Relativistic beams with a small beam Mach number (i.e. "hot" jets) consist of an almost featureless beam surrounded by a very thin cocoon with at most a tiny backflow. The lack of internal structure in the beam arises because of pressure equilibrium between the beam and its surroundings. A typical "hot" jet is shown in Fig. 2.10. This jet has a beam Mach number of 1.72, a beam gas velocity of 99% of the speed of light and a resulting jet propagation velocity of 86% of the speed of light.

Relativistic jets with a large beam Mach number (i.e. highly supersonic jets) have large backflows and prominent, turbulent cocoons. They also exhibit a complex structure of internal shocks generated by pressure mismatches between the beam and the overpressured cocoon, and by perturbations of the beam boundary by vortices and bulk motions within the cocoon. A typical highly supersonic relativistic jet is shown in Fig. 2.11. It has a beam Mach number of 6.0, a beam gas velocity of 99% of the speed of light and a resulting jet propagation velocity of 37% of the speed of light.

In general these simulations show that relativistic jets propagate remarkably efficiently. As a result they may propagate large distances without being destabilized or disrupted. This is a requirement for a successful model of the observed jets in extragalactic radio sources. However, realistic simulations of jets must be extended to much larger distances if they are to account for the deceleration of observed jets with increasing distance from the source. Simulations must also be carried out in three spatial dimensions to check for stability against non–axisymmetric perturbations. (Ewald Müller & Jose Maria Marti)

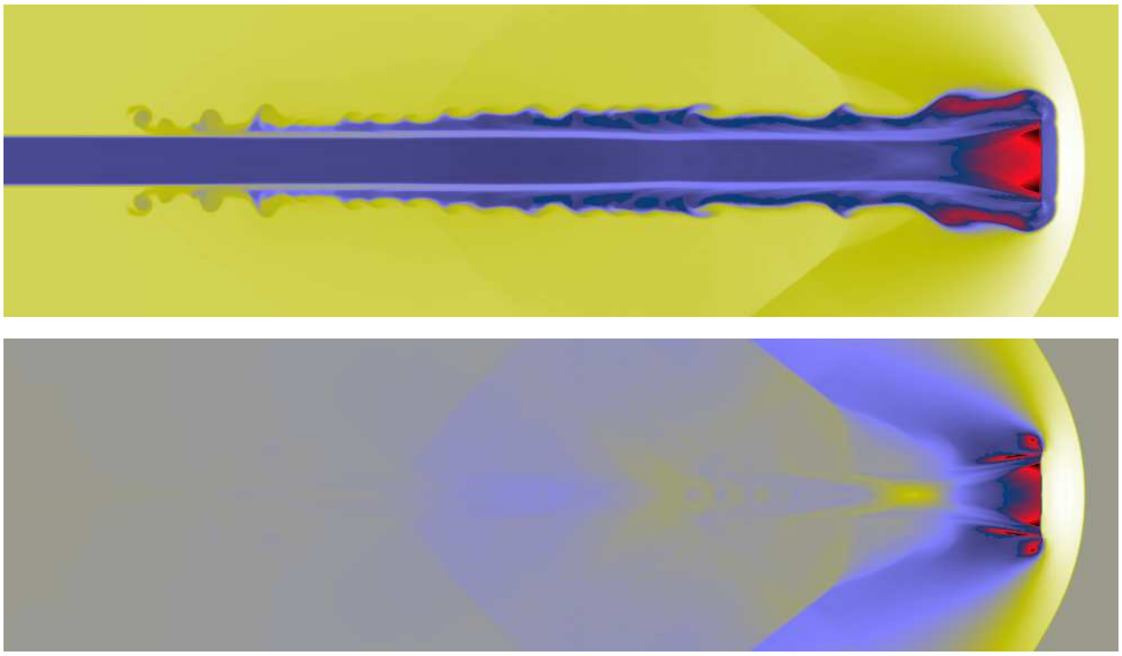

Figure 2.10: Colour coded contour plots of the logarithm of the proper rest-mass density (top) and pressure (bottom) of a "hot" relativistic jet with a featureless, almost "naked" beam. The maximum values are encoded in white and decreasingly smaller values in green, bright blue, dark blue, red and black.

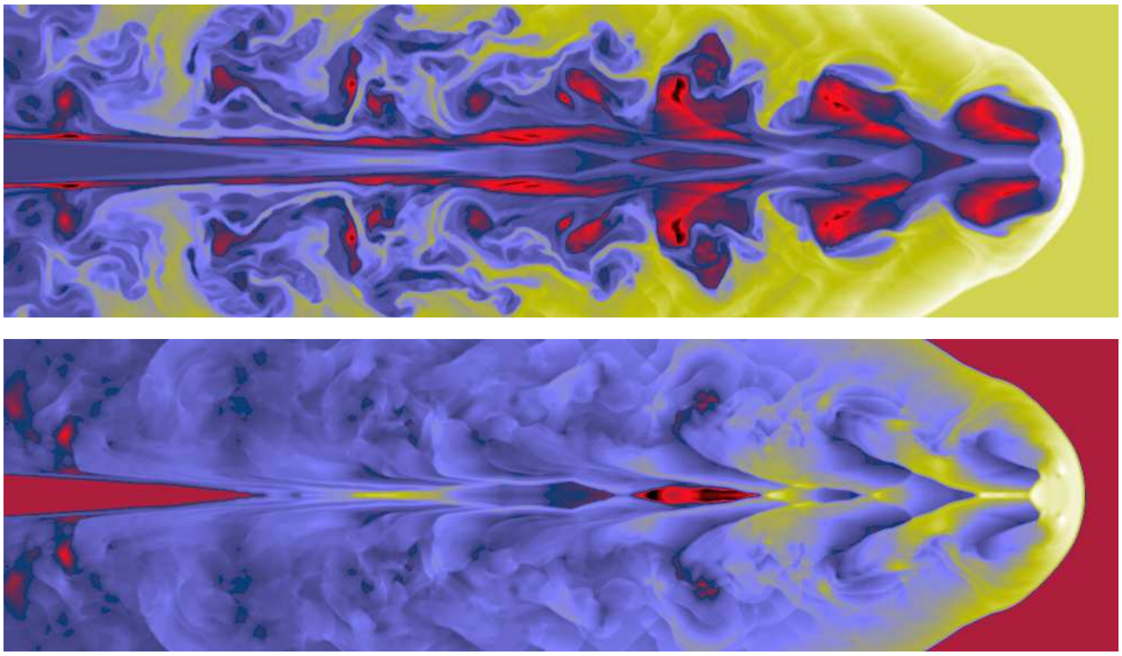

Figure 2.11: Same as Fig. 2.10 but showing the morphology of a highly supersonic, relativistic jet with a prominent, turbulent cocoon.

2.8 Weak gravitational shear-field around bright radio sources

Several investigations have shown that distant quasars are not randomly positioned on the sky relative to foreground objects even though the latter are thought to be much closer to us, and so without any direct physical relation to the quasars themselves. Several explanations have been proposed for this surprising result.
i) Dust associated with foreground galaxies or clusters of galaxies may block part of the quasar light as it traverses them. In this case a set of quasars selected to be brighter than some threshold will appear to avoid foreground objects which dim those quasars which happen to lie behind them so that they fall below threshold. Since dust absorbs ultraviolet light most strongly and hardly affects radio-wavelengths, one would expect the strength of the apparent avoidance to depend on how the set of QSO's is selected. Indeed, there exist indications that bright UV-selected quasars do avoid foreground galaxies and clusters of galaxies, whereas for radio-selected quasars no such effect has been seen so far.
ii) Patchy dust in our own Milky Way affects the apparent brightness of *all* extragalactic objects and could result in quasars and galaxies appearing to be associated, as can be seen by the following argument. In directions with little dust one would see relatively large numbers of both quasars and galaxies, while in "dust" directions the numbers of both kinds of objects would be reduced. Thus distant quasars and foreground galaxies would appear to inhabit the same regions of the sky. In fact, in this case the strength of the association does not actually depend on the quasars being behind the galaxies.
iii) Gravitational lensing can increase the brightness of quasars and so cause apparently bright objects to lie preferentially in the direction of suitably massive foreground "lenses". Massive foreground objects then appear associated with bright background quasars. The angular scale of this correlation should correspond to the angular extent of the intervening mass distribution since, roughly speaking, the magnification of a source by a lens is proportional to the mass of the lens along the line of sight.

Several investigations have shown that the density of nearby galaxies in the direction of bright and distant quasars is larger than the density in typical directions unrelated to quasars. The angular scale of this enhancement appears to be several arcseconds. This can be interpreted as gravitational lensing, if – as commonly assumed – typical galaxies are embedded in dark-matter halos with velocity dispersions of about 220 km/s and sizes several times that of the visible galaxy. However, significant correlations of quasars with foreground galaxies have recently been measured on scales of several arcminutes. The gravitational effects of individual galaxies cannot be responsible for this. MPA scientists studying this problem have therefore argued that these associations may result from gravitational lensing by larger-scale mass distributions which contain the observed galaxies. This hypothesis is supported by the discovery that quasars and foreground clusters of galaxies are associated on angular scales of several arcminutes.

The hypothesis that large-scale mass distributions appear associated with background quasars because of magnification effects can be tested in the following way. If the object which is lensing a quasar extends over several arcminutes, then *all* the sources which lie behind it must be significantly lensed. Generally there are plenty of distant galaxies in such an area; on deep images taken with a 4-meter telescope one can easily detect and measure the light distribution of about 50 galaxies per square arcminute. If a galaxy is behind the lens, then its image becomes brighter, its size increases, and its ellipticity and orientation are changed; the longest axis of the image tends to align at right angles to the direction of the "centre" of the mass distribution. This effect is well understood theoretically, and a full knowledge of it would give a measure of the mass distribution at the position of the galaxy. The problem is that the unlensed properties of an individual galaxy image are unknown, only the lensed image can be observed. However, one can use the fact that distant galaxies should be intrinsically randomly oriented on the sky. This implies that the average shape of a set of unlensed galaxies (imagine stacking all their images on top of one another) would be round. In the presence of a lens this is no longer true since all background galaxies are distorted in a similar way. Stacking their images then produces a "mean galaxy" which is not round, its shape reflecting the properties of the lens. The more elliptical this mean galaxy, the stronger the lens; the orientation of the mean galaxy is again tangential around the centre of the lens. Hence, a lens can be made "visible" by measuring the mean galaxy shape at several points in its vicinity. The resulting field is usually called the "gravitational shear-field" or just the "shear-field". In practice the measurement is difficult because the effect is small. In addition, seeing at ground-based telescopes (i.e. turbulence in the atmosphere) makes galaxy images significantly larger and rounder, reducing the effect one is trying to measure. However, seeing does not affect the mean direction of the distortion, and this allows gravitational shear to be detected unambiguously from the ground.

B. Fort and his collaborators in Paris and Toulouse were the first to try this test. They mapped the field around several bright, high-redshift radio quasars using the New-Technology-Telescope (NTT) and the Canadian-French-Hawaii-Telescope (CFHT). In most cases they do indeed find a significant shear-field, and are able to identify groups of galaxies associated with the dark matter lens. In the case of the quasar 1622+238 the shear-field derived from the faint, distant background galaxies is nearly centred on the quasar and coincides well with the position of a group of foreground galaxies. Thus it seems that the enhanced population of relatively bright galaxies around the quasar traces the dark matter concentration; the observed lensing could be due to the dark halo of the group.

Another example of weak gravitational shear towards a quasar is BR1202−0725. The apparent magnitude of this quasar is $R = 18.7$ and it has a redshift of $z = 4.694$, which makes it the brightest known quasar with $z \geq 4.5$. Deep exposures of this field are now being analysed by a French-German collaboration. The gravitational shear-field can be seen in Fig. 2.12. The observed field covers a region of 4 square arcminutes and contains 147 galaxies for which a shape measurement was possible; for the evaluation of the shear-field we use only those 113 galaxies which are fainter than 23.5 mag. There appear to be three mass concentrations in this field. The northern one, centred at ($1\overset{\prime}{.}1$,$1\overset{\prime}{.}6$), is sufficiently strong to be identified by eye from the shear-field, the southern one at ($1\overset{\prime}{.}2$,$0\overset{\prime}{.}6$) is elliptically elongated, and the eastern one is centered nearly on the boundary ($0\overset{\prime}{.}2$,$1\overset{\prime}{.}8$). The collaboration has developed methods for evaluating the statistical significance of such features, and

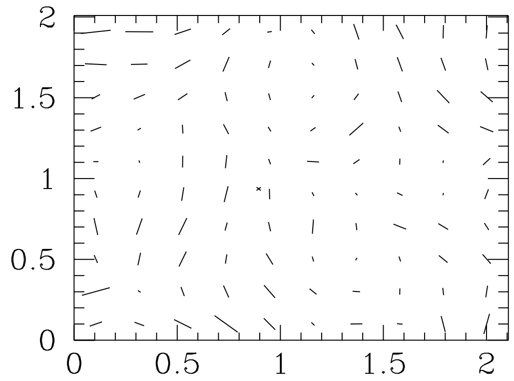

Figure 2.12: Shear-field of galaxies fainter than 23.5 magnitudes in the field of the quasar 1202-0725. The length of each line is proportional to the mean ellipticity of the galaxies at its position, the direction is equal to their mean direction. The quasar, at ($0\overset{\prime}{.}91$,$0\overset{\prime}{.}96$), is indicated by a cross. The size of this field is approximately $2' \times 2'$, North is up and East is left.

we are convinced that we have discovered real dark matter concentrations in the direction of this bright high-redshift quasar.

Using theoretical tools developed at the MPA, one can, in principle, straightforwardly transform the gravitational shear-field into a map of the intervening dark matter distribution. In practice one has to account for the effects of seeing, which has so far been done only in a crude way. In addition, to calculate the magnification of the quasar we have to know the redshift of the lens(es) and the mean redshift of the lensed galaxies. If the lens is at small redshift and the lensed galaxies have a typical redshift near unity, then the magnification of BR1202−0725 is about 0.7 magnitudes. This value could be significantly increased if the lenses are at redshifts of 0.5 or higher. As a result it will be important to measure redshifts for them by identifying associated galaxies.

With this kind of work, the magnification of individual quasars can be estimated case by case. Such studies should therefore provide a quantitative test of the hypothesis that gravitational lensing causes the apparent association of high-redshift quasars with foreground objects. (Stella Seitz)

2.9 Clusters of galaxies: arcs, arclets, and X-ray emission

Clusters of galaxies are the largest and most massive gravitationally bound structures in the Universe. In the era of optical astronomy, they were defined as objects in the sky where the number density of galaxies exceeds a certain threshold, or by similar criteria. Zwicky recognized as early as in 1933 that the typical velocity dispersion of galaxies in clusters is so large that clusters can only be gravitationally bound by masses much in excess of the sum of the individual galaxy masses. This result was the earliest indication that galaxy clusters must contain something else than galaxies, and that this 'something else' must dominate the matter content of the clusters. Galaxies, by which clusters were originally defined, contain only about 10% of the total cluster mass, which is typically on the order of 10^{14} to 10^{15} solar masses.

An additional constituent of galaxy clusters was discovered after the first X-ray telescopes were launched. They detected diffuse X-ray emission spread over the central parts of the clusters, which is evidently not due to individual galaxies. When spectral information about this X-ray emission became available, it turned out that the emission mechanism is thermal bremsstrahlung, i.e., radiation emitted by thermal electrons accelerated by ions. This intracluster gas also amounts to typically about 10% of the total cluster mass. The X-ray emission provides additional information about the entire (dark and luminous) cluster mass and its spatial distribution.

Both these methods to determine cluster masses, the kinematics of cluster galaxies and the X-ray emission of the intracluster gas, require assumptions which are difficult to justify. Galaxy kinematics yields reliable mass estimates only if the galaxies are in virial equilibrium with the cluster potential. For mass estimates from X-ray emission to be correct, the intracluster gas must be in thermal equilibrium and in hydrostatic equilibrium with the cluster potential. The applicability of such assumptions is doubtful, because simple time-scale estimates reveal that the time required to establish the assumed equilibria is comparable to the time clusters needed to form. It turns out, however, that the two methods to determine cluster masses yield results which differ by typically only a factor of two, thus providing support for the equilibrium assumptions made.

A third powerful method to determine cluster masses is based on the fact that masses deflect light. For this 'gravitational lens' effect, the dynamical state of the deflecting matter and its composition is entirely unimportant. While the interpretation of galaxy kinematics and X-ray emission requires the presence of light-emitting, or baryonic, matter, the light deflection is determined by the total amount of mass whatever it may consist of. Gravitational lensing, however, is only sensitive to the projected mass distribution, hence an ambiguity as to the distribution of mass along the line of sight remains. Again, gravitational lensing-based mass estimates of galaxy clusters agree with the previous two ways to estimate masses within a factor of two. This by itself is a remarkable fact.

Uncertainties of a factor of two are, however, no longer satisfactory in view of the continuously improving quality of observational data. In fact, it is likely that the discrepancies between the different mass estimates contain important information about galaxy clusters. In other words, if the methods based on galaxy kinematics and on X-ray emission of the intracluster gas rely on equilibrium assumptions, discrepant results should allow to infer the degree to which these assumptions are satisfied, and thus to find out about the actual dynamical state of the cluster constituents.

For several reasons, this is not only important for our understanding of the structure of individual galaxy clusters. It has been argued in recent years that the cosmic time by which clusters form depends on cosmological parameters. If clusters are 'old', i.e., if they formed long ago, they had time to relax to an equilibrium state, while this cannot be expected if they are 'young'. Hence the dynamical state of cluster components depends on their age, and since their age depends on cosmological parameters, the information about the dynamical state should open a way to constrain cosmological parameters, for example the mean matter density of the Universe. In addition, it is possible and likely that clusters contain magnetic fields. If these fields are dynamically important, their influence can be quantified once the dynamical state of the cluster can be inferred by independent methods.

The gravitational lens effect of clusters can

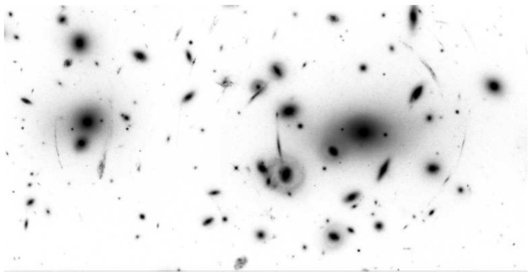

Figure 2.13: One example for weak and strong lensing by a galaxy cluster. In this *Hubble Space Telescope* image of the cluster Abell 2218, a large number of arcs and arclets can be seen around the two centers of the cluster. (NASA HST Archive)

naturally be divided into strong and weak lensing. Strong lensing by clusters gives rise to a spectacular phenomenon, viz. the formation of so-called arcs. Arcs are strongly deformed images of background sources which occur in the central regions of some massive clusters (see Fig. 2.13). They are usually tangentially oriented relative to the cluster center and can be used to probe the mass distribution in the innermost parts of galaxy clusters. Weak lensing leads to small deformations of background sources. Being based on a weak effect, this approach must be statistical, but the spatial number density of suitable sources is sufficiently large to allow averaging over a large number of them. Weak gravitational lensing is therefore the primary tool to obtain the morphology of cluster mass distributions, and these can directly be compared with the morphology of the X-ray emission.

It has been claimed that the gravitational lens effect of some observed clusters is stronger than expected from their X-ray emission. In particular, the intracluster gas in some clusters should be hotter than observed to reconcile the two. In these particular cases, the mass required to explain the lens effect is significantly larger than that obtained from the X-ray gas temperature. This is a very intriguing result because if the cluster gas is indeed cooler than expected from equilibrium assumptions, part of the pressure required to maintain hydrostatic stability must be of non-thermal origin. Bulk flows in the intracluster gas are a very likely explanation, because in their presence the gas is incompletely thermalized. If, however, bulk flows turn out to be unlikely, there must be another source of pressure, which could well be provided by magnetic fields.

Groups at MPA are actively involved in quantifying these effects. Weak lensing by clusters is a major issue and is investigated in detail. A method has recently been developed to employ weak gravitational lensing to reconstruct the projected two-dimensional gravitational cluster potential. This method is sufficiently general as to allow cluster analyses which directly combine data from gravitationally lensed objects and from the X-ray emitting cluster gas.

Strong lensing is studied in detail with cluster models obtained from elaborate and computer-intensive gas-dynamical simulations. Several surprising results have already been derived in the course of this project. Most importantly, clusters were found to produce significantly more large arcs if they are substructured rather than symmetric, because the gravitational tidal field of a cluster is much increased by subclumps in the cluster mass distribution. This establishes a relation between the frequency of large arcs and the age of galaxy clusters, and thus a connection between arc statistics and cosmological parameters. The gas-dynamical cluster simulations allow to investigate the X-ray emission of the intracluster gas simultaneously with the gravitational lens effect of the clusters, and also to quantify uncertainties of X-ray based mass determinations. A variety of mass determination techniques were applied to synthetic cluster data. It was confirmed that there is a relation between the dynamical state of a cluster and its ability to form arcs, and it was specified how this relation is established.

Additionally, projects have been started to study the dependence of arc statistics on cosmological parameters, with the final aim to significantly constrain, e.g., the mean density of the Universe. Collaborations with observers at Toulouse (France), Cambridge (England), and at ESO have also begun and promise to yield significant results in the near future. Once our methods to combine X-ray and lensing observations of clusters are completely developed, their application to optical and X-ray data can be expected to offer insights into the state of galaxy clusters which are impossible to obtain otherwise. (Matthias Bartelmann)

2.10 Quasar absorption lines, the intergalactic medium, and galaxy formation

Among the most exotic classes of astronomical objects in the universe is a population of extremely bright light sources, first discovered about thirty-five years ago and commonly referred to as quasars or QSOs. The quasar phenomenon is now known to originate in the very centers of distant galaxies, and is believed by most to be caused by the accretion of mass onto a very massive, highly condensed central object. On account of their enormous luminosities many quasars can be seen out to very large distances. On its way to us the light from a quasar has penetrated all gaseous matter along the line-of-sight, so its spectrum contains a continuous record of the absorption imprinted by intervening gas clouds and galaxies. Any quasar spectrum exhibits hundreds of discrete absorption features, predominantly from the Lyman alpha (Lyα) absorption line of neutral hydrogen, redshifted by the cosmological expansion such that these features occur distributed over a wide wavelength range in the optical spectrum of the quasar. From the observed wavelength of each line we can measure the redshift and thus the distance of the absorbing gas; width, depth and detailed structure of the line contain information about the temperature, kinematics, the content of heavy elements and the ionization state of the corresponding gas cloud.

The physical nature of Lyman alpha absorbers has long remained unclear. This is mainly due to the fact that most basic properties like size, density and mass of the absorbers are quite difficult to constrain observationally. Since these absorbers are much more numerous than known types of galaxies they were originally classified as "intergalactic clouds". However, there has been discussed a variety of alternative explanations: huge disks of a previously unknown class of faded galaxies; "faint blue galaxies"; gigantic galactic halos; tidal debris from galaxy interactions; gas accumulating in shallow pre-collapsed dark matter potential wells; and galactic winds.

The last year or two have seen much progress in our understanding of what these absorbers actually are. This is mainly due to new observations and to progress in numerical simulations. The fact that pairs of quasars with rather small angular separation on the sky (up to a few arcmin) show very similar absorption features in their spectra puts strong constraints on the size of the absorbers. This considerably improves estimates of other physical properties like the mean density or the mass. One of the main characteristic properties of an absorption system is its column density of neutral hydrogen, i.e. the number of neutral hydrogen atoms per unit volume integrated along the line-of-sight. Observed absorption systems span a wide range of at least twelve orders of magnitude in neutral hydrogen column density. Numerical simulations indicate that this sequence in column density mainly reflects the range of mean density of the absorbing gas. At the lowest column densities the absorption systems are due to long-range (of order a few million light years) fluctuations of small amplitude in the intergalactic medium, while towards higher column densities denser and denser regions are probed corresponding to dynamically more evolved systems. The highest column density systems occur in lines-of-sight passing the dense central regions of fully collapsed objects.

Quasar absorption lines are therefore an excellent tool to test the effects of the gravitational clustering of dark matter — the standard paradigm for the formation of structure — on the gas content of the universe. Low-column density absorbers probe the growth of density fluctuations of the dark matter when they are still small while absorption systems with larger column density test these fluctuations when they have grown large enough to trigger the gravitational collapse of a region of the universe in which eventually one or a few galaxies will form.

The different stages of this process are investigated at MPA with a variety of methods. Analytical methods are used to extract information about the dynamical state of low-column density absorbers from the spectra of pairs of quasars with small angular separation. The details of the dynamical evolution depend on global geometrical properties of the universe, and so one can hope to obtain information about fundamental cosmological parameters like the mean mass density or the cosmological constant.

Numerical simulations are used to model the gravitational collapse of small regions of the universe in order to investigate the process of galaxy formation. During the collapse stars form and transform a fraction of the gas (which consists mainly of hydrogen and helium) into heavy elements. These heavy elements are expelled from the stars and are mixed into the surrounding gas as the stars reach the end of their lives. This process is generally believed to be responsible for the absorption features of elements heavier than hydrogen or helium which are seen in most quasar spectra. The details of these features depend on the density and temperature of the absorbing gas and the ultraviolet radiation in its neighborhood. One common and prominent absorption feature is due to triply ionized carbon (CIV). Figure 2.14 shows such absorption features in artificial spectra which were produced for various lines-of-sight through a simulated "galaxy forming" region. A comparison with observed spectra makes possible a detailed investigation of the physical conditions in the gas from which galaxies form. Different ionic species probe the conditions in different parts of a protogalaxy. As a result, putting together all the available information should give new insights into how galaxies form, and should help us to learn more about the star formation history of the universe. (Martin Haehnelt)

2.11 Dark matter, galaxy filaments, and the density of the universe

One of the major embarrassments of present-day astrophysics is that more than 90% of the material in the universe remains unseen. Large amounts of "dark matter" appear to be present around galaxies like our own, and even more seems to lie between the galaxies in galaxy clusters. In both cases the unseen material must be there if the motions of the observed stars and the gas are to be consistent with Newton's (or Einstein's) law of gravity. Confirming evidence comes from the images of distant objects seen behind galaxy clusters; these are distorted by gravitational lensing effects exactly as expected if the clusters are indeed made mostly of dark matter. Unfortunately this dark matter has yet to be detected in any more direct way, and as a result we still have no observational clue as to its nature.

In the absence of observation the imagination of theorists can flower unchecked. Early suggestions for the composition of the dark matter included the dead remnants of an early population of stars, jupiter-like objects individually too small to burn nuclear fuel like a normal star, or small black holes formed at the time of the Big Bang. In recent years, most cosmologists have focussed on an even more exotic possibility, namely that the unseen material is an entirely new form of matter, quite distinct from the "ordinary" matter which makes up all the objects that we can see (including stars, planets and people). The first such suggestions supposed that the dark matter might be made of neutrinos, very weakly interacting elementary particles which are produced in radioactive decays, but which have not yet been demonstrated to have a finite mass. Nowadays a number of technical arguments make this possibility seem unlikely and the preferred candidates are elementary particles such as axions or neutralinos, which are so far known to exist only in the heads of high energy physicists.

The only convincing way to demonstrate that the dark matter is made of axions, would, of course, be to detect these axions with an Earth-bound experiment. There is, however, another way to investigate whether the dark matter is made of elementary particles of this general type (generically referred to as "Cold Dark Matter" or CDM). If most of the matter in the universe is indeed CDM, then the structure of this dominant component grows only as a result of gravity: no other forces act on it. This is a great simplification in comparison with ordinary matter, which also feels electric, magnetic, atomic and radiation forces. As a result it is feasible to simulate the evolution of the CDM distribution directly on a computer. The idea is to represent the distribution of CDM at some early epoch by a nearly uniform distribution of computer "particles" (each of which has to represent as many as 10^{80} axions!) and then to let the machine follow the growth of structure by integrating the relevant equations directly. One can then check whether the resulting distribution of CDM in the computer is consistent with what we know about the dark matter distribution in the real universe.

There are two tricky points in carrying this programme through. The first is that you have to decide how to distribute the computer particles at the beginning of the calculation since this obviously determines what happens to them later. Luckily, there are theoretical models for the origin of structure which make quite specific

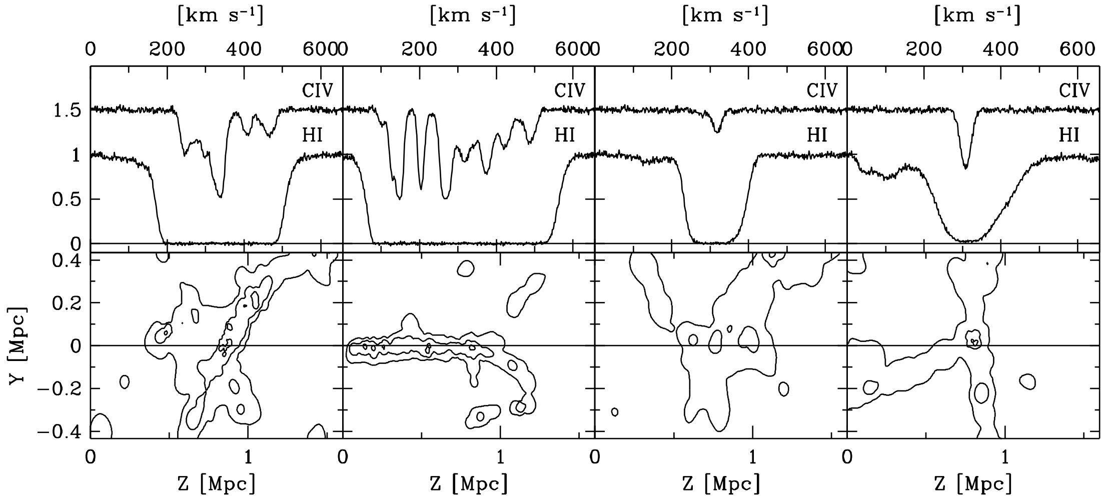

Figure 2.14: The top panels show the CIV and Lyα absorption in artificial spectra calculated for different lines-of-sight through a region of ongoing galaxy formation simulated with a Smoothed-Particle-Hydrodynamics code. The bottom panels show density contours of the corresponding spatial distribution of CIV (the solid line indicates the line-of-sight).

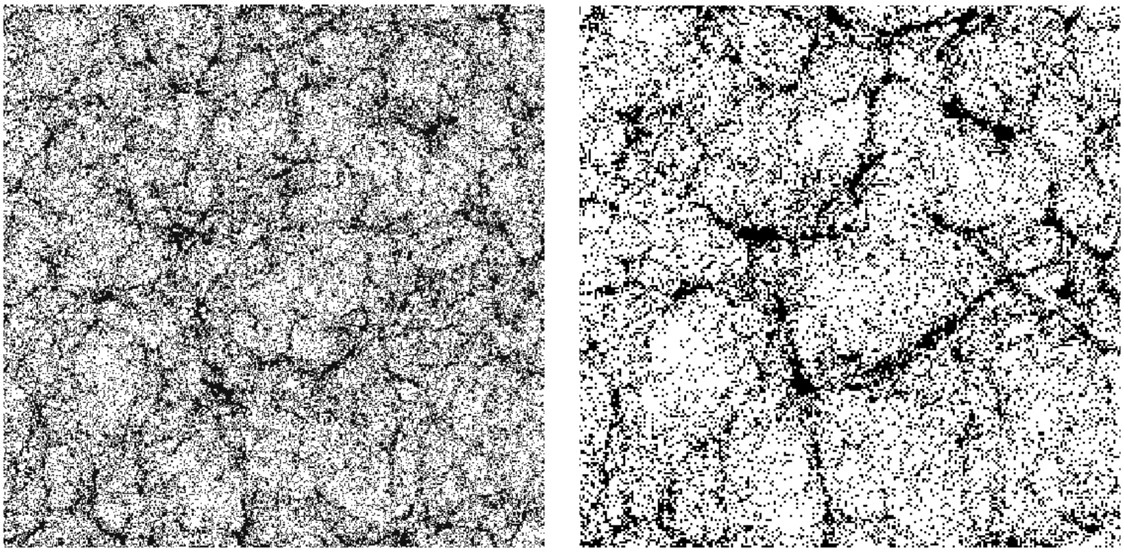

Figure 2.15: The present-day distribution of CDM predicted by a model where the dark matter provides the full critical density (left picture) and by a model where it provides one third of the critical density (right picture).

predictions for how this distribution should be laid down. (These theories suppose that structure in the universe is a result of quantum fluctuations present a very small fraction of a second after the Big Bang.) The second tricky point is that the computer predicts the distribution of dark matter in the present Universe, and this is just what we cannot see. What we do see is the distribution of galaxies, and so we need to understand how this is related to the dark matter distribution. The two are expected to be qualitatively similar, but there are likely to be significant quantitative differences.

The arrival of a new parallel supercomputer (a CRAY T3D) at the Garching Computer Centre has allowed the MPA galaxy formation group to carry out simulations of the evolution of the dark matter distribution in unprecedented detail. This work is carried out as part of an international collaboration, the Virgo Consortium, based primarily in the UK. The present-day distribution of CDM predicted by two of these simulations is illustrated in Fig. 2.15 (A density plot of one of them is shown on the cover of this report). This shows a thin slice through the full calculation. Its width is about 16 times its thickness and is about 10,000 times greater than the smallest structures resolved by the calculation; the latter are about the same size as the Sun's orbit around our Milky Way galaxy. This picture shows quite dramatically the richness of the structure predicted in a CDM universe. One sees small lumps, which correspond to individual isolated galaxies like our own, and large lumps which correspond to rich galaxy clusters. Moreover all these lumps are arranged in large-scale coherent structures which appear as filaments in these pictures but turn out to be sheets when the full three-dimensional distribution is examined.

The qualitative appearance of the structure in Fig. 2.15 is quite similar to that found in observational surveys of the galaxy distribution. In order to make this comparison precise the MPA group is currently trying to understand how galaxies would form under the gravitational influence of their simulated CDM distribution. This will allow them to predict where galaxies of different types and brightnesses should be located in pictures like Fig. 2.15, and so to make quantitative comparisons with observational data. Such work will test whether the CDM hypothesis is consistent with the structure of the universe we live in. Preliminary results are quite promising, and if the hypothesis does indeed turn out to be viable, simulations of this kind will not only provide evidence that we have correctly identified the nature of the dark matter, but will also allow other properties of of our universe to be measured. For example, the dark matter distribution in the right picture of Fig. 2.15 is a prediction for a universe where CDM provides only one third of the critical density required to halt the cosmic expansion and lead, eventually, to a Big Crunch. The pattern predicted if there is enough CDM to provide the full critical density is significantly different (Fig. 2.15, left picture). It might therefore be possible to use the observed galaxy distribution to distinguish between these two possibilities. (Simon White and Jörg Colberg)

3 Research Activities

3.1 Sun and interplanetary matter

In collaboration with B. Freytag (University of Kiel), M. Steffen (Astrophysikalisches Institut Potsdam), and J. Wagenhuber (MPA), H.-G. Ludwig investigated the variation of the mixing-length parameter α during the solar evolution from the ZAMS to the RGB. Independent of evolutionary calculations α was derived from a grid of hydrodynamical models. α was found to increase significantly towards the RGB. — Together with M. Steffen hydrodynamical model atmospheres were used to study the influence of lateral temperature inhomogeneities on the emergent solar spectrum. Effects on the formation of the continuum and the Balmer lines were derived.

U. Anzer investigated new magnetic field data on solar prominences. From the model for magnetic equilibrium he derived values for central densities and column densities of these prominences. These values were systematically higher than those obtained from spectroscopic analyses. — K. Jahn (University of Warzawa), R. Schlichenmaier (MPE), and H.U. Schmidt started a numerical study of the convective motion and internal flow of thin magnetic flux tubes imbedded into the stratified background model of a deep penumbra provided earlier by Jahn and Schmidt.

O. Terekhov (Space Research Institute, Moscow) and R. Sunyaev investigated nuclear lines in the spectra of solar flares at the maximum of cycle 22 of solar activity as observed by the Granat/Phebus instrument at 100 keV–100 MeV. They estimated the mass of the Deuterium produced in solar flares. The contribution of stellar flares to the Deuterium and Lithium abundance observed in the Universe was studied.

N. Inogamov (Landau Institute of Theoretical Physics, Chernogolovka) applied their analytical theory of star oscillations (see Sect. 3.4) to explain the p-oscillations of the Sun.

R. Wegmann and H.U. Schmidt in collaboration with T. Bonev (Sofia, Bulgaria) determined the structure of the plasma tail of comet Austin 1990 from a series of four CCD images. The tail turns out to be a flat ribbon with bar or even dumb-bell shaped cross-sections.

3.2 Stellar structure and evolution

J. Fliegner's thesis, which is guided by N. Langer, investigates the evolution and appearance of rotating massive stars. They determined the photospheric shape of rotating mass-losing Wolf-Rayet stars and its time evolution. In collaboration with G. Garcia-Segura (UNAM, Mexico) and M.-M Mac Low (MPIA, Heidelberg), they investigated the effect of rotation on giant eruptions of Luminous Blue Variable stars like η Carinae. Together with K. Venn, they examined the rate of boron destruction in the surface layers of rotating main sequence B stars, which is compared with observations. — A. Heger, as part of his diploma thesis with N. Langer, showed how the internal structure and the observable properties of Wolf-Rayet stars are affected by optically thick winds, and determined a mass-luminosity relation for these stars including the effect of wind darkening. — Together with G. Garcia-Segura (UNAM, Mexico) and M.-M. Mac Low (MPIA, Heidelberg), N. Langer has determined the evolution of circumstellar bubbles surrounding Wolf-Rayet stars following a red supergiant evolution, and derived conditions for clump formation in interacting stellar winds and a detailed model for the clumpy structure of the supernova remnant Cas A. — Together with A. Pasquali, C. Leitherer, A. Nota (STScI Baltimore), W. Schmutz (ETH Zürich), and L.

Drissen and C. Robert (Montreal), N. Langer has studied the evolutionary status of so-called slash-stars in the LMC, and thereby obtained important constraints on the mass loss and angular momentum evolution of massive stars in general. — In an effort to determine the upper stellar mass limit in the Large Magellanic Cloud, N. Langer has, with R.P. Kudritzki and collaborators (University Observatory, Munich), investigated the evolution of stars up to 250 $M_{\odot}$.

Achim Weiss and P. Denissenkov (St. Petersburg, Russia) showed that anomalies in the CNO-, NeNA-, and MgAl-cycles isotopes as observed in many globular cluster red giants can be explained by mixing between the bottom of the convective envelope and the upper edge of the hydrogen burning shell. This mixing, which is not included in standard stellar structure theory, was described by a parametrized diffusion approach with mixing depth and speed motivated by the assumption that differential rotation could be the reason for it. They also showed that the same mixing can help to explain oxygen isotope anomalies both observed in S- and C-stars on the AGB and measured in meteoritic grains. — Furthermore, the results for the globular cluster red giants were used to study the effect on ^{3}He in low-mass stars. It is found that contrary to standard stellar evolution, ^{3}He is severely destroyed. This may solve the problem of the observed ^{3}He properties of the interstellar medium and allows for a much higher primordial deuterium abundance than previously thought. The standard calculations were done by J. Wagenhuber, who investigated the fate of ^{3}He including thermal pulses on the AGB. He also continued with his thesis about AGB star properties, which is completed by now. — Apart from the main subject of his thesis, J. Wagenhuber collaborated with Y. Tuchman (Jerusalem, Israel) about pulsational and mass loss properties of Mira variable stars. They investigated the impact of the actual evolution of the luminosity during the quiescent phase of the thermal pulse cycle on pulsational properties of Mirae and LPVs in the LMC and compared the results with observations. They showed that the results are different from those derived simply by applying the core mass–luminosity relation and help to resolve some discrepancies.

H.-G. Ludwig continued his studies of the atmospheric and envelope structure of DAV white dwarfs based on hydrodynamical models. Together with A. Gautschy (University of Basel) and B. Freytag (University of Kiel), the role of the surface convection zone for the excitation of pulsations was investigated. It was demonstrated that the usually neglected effects of the small-scale convective motions influence the pulsational stability. — In collaboration with B. Freytag and M. Steffen (both University of Kiel) convective overshooting was studied in white dwarfs, A-type stars, and the Sun. From the numerical models a common description was derived for the mixing of material in the overshooting layers. Strong effects were predicted for A-type stars and white dwarfs. The solar lithium abundance might be affected.

M. Groenewegen finished some projects started at his previous post-doc position. The circumstellar shell of IRC +10 216 was investigated with a dust radiative transfer code. From the near-infrared visibility curves it was derived that the grain size is about 0.16 μm. — A simple model to calculate free-free emission was developed to analyse the cm observations of this star. It was derived that in the cm region dust emission is not important and that free-free emission is optically thin. This implies that the cm emission comes predominantly from the central star. The observations reveal that the 2 cm region is aspherical, and hence the interpretation is that the central star around IRC +10 216 is aspherical. The size of the emission region equals the stellar radius predicted from the model. This discovery may have implications for the interpretation of the transition of mostly spherical AGB shells to mostly aspherical planetary nebulae.

The analysis of R CrB lightcurves obtained by E. Olson (Urbana, USA) and R. Fried (Tucson, USA) was completed by Achim Weiss. In all four objects observed, small amplitude variations as predicted by theory could be observed, their periods lying between about 35 and about 65 days. However, a correlation between amplitude and the presence or frequency of R CrB-type fadings seems to exist that deserves further observations.

S. Degl'Innocenti, Achim Weiss, and G. Raffelt (MPI Physik, Munich) tested the effect of a varying gravitational constant G on globular cluster isochrones (in collaboration with G. Fiorentini and B. Ricci (Ferrara, Italy)). Within observed limits on $\mathrm{d}G/\mathrm{d}t$ globular cluster isochrones would appear as those of 16 Gyr old clusters (evolved under constant G), but could be as young as 12 or as old as 20 Gyr.

F. Caputo (Rome, Italy), V. Castellani (Pisa, Italy), and S. Degl'Innocenti compared the observed luminosity function of the dwarf spheroidal galaxy Leo I with theoretical expectations for three selected ages – 1, 1.5, and 2 billion years – deriving an age of about 1.5 Gyr. This result does not appear to be critically affected by assumptions about the cluster distance modulus or the Initial Mass Function.

H. Spruit (in collaboration with J. van Paradijs, R. Waters (both University of Amsterdam), and H.J. van Langevelde (University of Leiden)) studied the observability of Thorne-Żytkow objects and concluded that ^{29}SiO and ^{30}SiO observed at 4μ and in the mm range may offer the best chance of identifying such objects.

3.3 Supernovae and nucleosynthesis

Hydrodynamic instabilities on all scales in Type Ia supernovae were studied by means of multi-dimensional numerical simulations by J.C. Niemeyer in a thesis, supervised by W. Hillebrandt, and in collaboration with S.E. Woosley (UCSC/Lick Observatory, Santa Cruz) and S.I. Blinnikov (ITEP, Moscow). It was shown that turbulence is likely to be the main mechanism for accelerating the thermonuclear deflagration front to a fraction of the sound velocity. Since turbulence will be created mainly by the shear instability which, in turn, develops after the buoyancy instability has grown nonlinear, it can be expected (and was confirmed by numerical simulations) that the amount of ^{56}Ni produced in the explosion depends on the initial conditions and, consequently, on the way the flame is ignited. J.C. Niemeyer an S.E. Woosley also investigated to possibility of delayed detonations or detonations driven by pulsations in Chandrasekhar-mass white dwarfs.

Together with S.E. Woosley (UCSC/Lick Observatory, Santa Cruz, California), T.A. Weaver (LLNL, Livermore), and M. Herant (Los Alamos Natl. Lab.), N. Langer has studied models of Type I supernovae resulting from massive mass-losing stars, and derived their nucleosynthetic yields and supernova light curves.

P. Ruiz-Lapuente (with R. Canal (University of Barcelona) and A. Burkert) explored scenarios for Type Ia supernovae (SNe Ia) as related to galaxy type. Both Chandrasekhar–mass and sub-Chandrasekhar explosions were considered in double degenerate systems, symbiotic systems, and cataclysmic-like systems. Statistics and evolution of SNe Ia characteristics along the Hubble sequence (going from early to late–type galaxies) and redshift were predicted. They found that Chandrasekhar–mass Type Ia SNe from the candidate systems explored seem statistically disfavored in early-type galaxies. — P. Ruiz-Lapuente calculated the spectra of sub-Chandrasekhar explosions for the phase about 7–8 months after the explosion. In collaboration with E. Livne (Racah Institute of Physics, Hebrew University, Jerusalem) hydrodynamic models from 2-D calculations of these explosions have been evaluated in comparison with observations. Those models confront problems related to their forbidden emission at late phases as compared to the bulk of the observations of SNe Ia. Hydrodynamic calculations are still in progress, and new models are being examined. — P. Ruiz-Lapuente also examined the value of the Hubble constant as related to the mass of the exploding WD in SNe Ia. A value of $H_0 = 68 \pm 6$ (stat) ± 7 (syst) was derived from the density signatures on the late emission of SNe Ia (^{56}Co-Powered Nebular Candles Method).

Ph. Podsiadlowski has continued his work on the production of Type Ib/Ic supernova progenitors in massive binaries by testing the theoretical predictions with the small number of known observational counterparts (in particular, Φ Per and υ Sgr). The comparisons confirm many of the theoretical predictions, but also pose new problems and questions, for example, concerning the stability of early case B mass transfer. — With W.N. Brandt and S. Sigurdsson (Cambridge), he has investigated the implications of the observed space velocities of binaries containing black-hole candidates and low-mass secondaries on the kick velocities the putative black holes received during their formation process. They found that unlike the case of neutron stars, black holes do not typically receive large kicks at birth. One notable exception is the black hole candidate in X-ray Nova Sco 1994, where the black hole may only have formed after an intermediate neutron-star stage.

In a common project H.-Th. Janka and E. Müller investigated the delayed explosion mechanism of Type II supernovae via neutrino heating by performing one-, two-, and three-dimensional hydrodynamical simulations from core bounce to about one second after the formation of the supernova shock. Convective mixing inside the protoneutron star was found to affect the size of the neutrino luminosities and to cause angular variations. Convective overturn in the neutrino-heated region proved to be helpful for the explosion. In both the spherically symmetric and the multidimensional cases, however, the timescale and energy of the explosion turned out to depend very sensitively on the neutrino luminosity from the collapsed stellar core. The models were evaluated for the implications of the large-scale asymmetries for neutron star recoils and gravitational wave emission. — Supervised by H.-Th. Janka, W. Keil continued to perform general relativistic simulations of the neutrino cooling phase of newly-formed neutron stars in order to study the dependence of the neutrino emission and of the detectable neutrino signal on the neutron star mass, on the supranuclear equation of state, on the neutrino opacities (in collaboration with G. Raffelt (MPI für Physik, Freimann)), and on additional elementary processes like the production of axions in the dense core of the protoneutron star (in collaboration with M.S. Turner and G. Sigl (Enrico Fermi Institute, Chicago)). — In a joint work with T. Baumgarte (Cornell University, Ithaca), S.A. Teukolsky (Cornell University, Ithaca), and S.L. Shapiro (Center for Astrophysics and Relativity, Ithaca), W. Keil and H.-Th. Janka have extended their investigations of hadronic phase transitions during the protoneutron star evolution to the stage where the gravitational instability of the newly-formed, hot neutron star sets in. The final collapse into a black hole was followed to its completion.

T. Plewa in collaboration with R. Cid-Fernandes (Instituto de Fisica, UFRGS, Brasil), M. Rozyczka (Nicolaus Copernicus Centre, Warsaw), R. Terlevich (RGO), G. Tenorio-Tagle (IAC), J. Franco (UNAM), and W. Miller (UNAM) studied the evolution of ejecta fragments in compact supernova remnants. High-resolution hydrodynamical simulations have been performed using adaptive mesh refinement (AMR) techniques which for the first time allowed one to observe the thin shell instability in the supernova remnant evolving in high-density medium. It has been shown that the fragments are prone to fragmentation inside the shocked region of the remnant. The low-density ($\delta\rho/\rho <$ 30) fragments are likely to be completely disrupted before they reach the thin shell. More massive fragments may, however, approach the shell as well defined entities. The shocked fragments eventually collide with the outer shell at velocities reaching several thousand km/s. The outcome of such a collision is an X-ray flare. Fragment–shell collisions occurring randomly in space and time are in principle capable of generating light curves and power spectra similar to those observed in some AGNs.

M.M. Sharma and W. Hillebrandt (in collaboration with G.A. Lalazissis, J. König, and P. Ring (all Technical University, Munich)) have investigated the isospin dependence of the spin-orbit potential and properties of nuclei close to and far from the valley of β-stability using the relativistic mean-field theory (RMF) in comparison with certain effective nucleon-nucleon interactions. The results gave indications for strong shell effects even away from stability which has considerable consequences for the synthesis of neutron-rich heavy isotopes in the r-process. In the framework of the RMF-theory a compilation of properties of rare-earth nuclei and of some exotic $Z = 40$ nuclei was also performed.

3.4 Close binaries and accretion

With Z. Han, P.P. Eggleton, C.A. Tout (Cambridge), Ph. Podsiadlowski has applied the binary population synthesis code, developed previously mainly by Z. Han, to various classes of binaries, initially to barium stars and CH stars and more recently to RCrB and OB subdwarfs. Detailed comparisons with the observational data base reveal surprisingly good agreement in many important parameters (e.g., orbital periods, masses), thereby supporting the standard theory. — M. de Kool has continued his work on binary population synthesis. With P.J. Green (Harvard) he investigated to what extent the properties of dwarf carbon stars can be explained by accretion of carbon enriched material from an AGB companion star in a binary. He also investigated what constraints on uncertain parameters in binary population synthesis are implied by the observed orbital properties of some recently discovered close but detached white dwarf plus main sequence star binaries.

For the PhD thesis of H. Braun, which is guided by N. Langer, simultaneous calculations of the components of massive close binary systems, under detailed consideration of mixing processes triggered by the accretion process, have been performed, and the fate of the stellar components and their nucleosynthetic yields have been determined.

Ph. Podsiadlowski has systematically investigated the effects of tidal heating on a typical low-mass globular-cluster star during a tidal-capture and subsequent circularization process. He found that, if the tidal energy is thermalized either very close to the surface or very deep inside the capturing star, the star will only swell up moderately and the system is likely to survive as a binary (a low-mass X-ray binary progenitor if the captured object is a neutron star). On the other hand, when the energy is deposited in an intermediate region, the star may swell up to giant dimensions, which will lead to a complete merger of the star with the captured object. — N. Inogamov (Landau Institute of Theoretical Physics, Chernogolovka) and R. Sunyaev investigated oscillations of stars in binary systems due to tidal interaction. An analytical model for the calculation of the eigenmodes of acoustic and gravity oscillations of stars was developed.

H. Ritter, in collaboration with J. Frank (Louisiana State University), A. King (University of Leicester) and U. Kolb (Lick Observatory), have carried out a global analysis of mass transfer cycles in cataclysmic variables. Necessary and sufficient conditions for the occurrence of intermediate time scale mass transfer cycles could be derived. These conditions essentially prove that such mass transfer cycles can only result from irradiation of the low-mass donor star by accretion luminosity generated as a consequence of mass transfer in the first place. However, it is also found that irradiation alone is not sufficient to drive sustained and large-amplitude mass transfer cycles in most systems of interest. Rather, loss of orbital angular momentum in response to mass transfer seems to be necessary as a supporting mechanism to drive such cycles. These conclusions hold irrespective of details of the assumed irradiation model or the irradiation efficiency. — Z.-Y. Zhang, in collaboration with H. Ritter, finished work for his PhD thesis on the reaction of low-mass stars and its implications for the secular evolution of cataclysmic variables. The main result of this investigation is that even under the most favorable conditions and within the most realistic irradiation model considered (the point source model), mass transfer cycles in cataclysmic variables cannot be driven by irradiation alone if the donor star is outside the mass range $0.7M_{\odot} \lesssim M \lesssim 1.0M_{\odot}$. — H. Ritter and J.-M. Hameury (Observatoire de Strasbourg), using full stellar models, examined the response of low-mass stars to external irradiation. By and large their results confirm those of simple analytical calculations by Zhang and Ritter, and, applied to the global analysis of mass transfer cycles, show that in cataclysmic variables irradiation alone can lead to mass transfer cycles only if the mass of the donor star is in the range $0.7M_{\odot} \lesssim M \lesssim 1.0M_{\odot}$. — R. Stehle, U. Kolb, and H. Ritter studied Population II cataclysmic variables (PopII CVs). Based on a differential comparison between model populations it was shown that previous observationally selected samples do not represent PopII CVs. The CV period distribution of a visual magnitude limited sample with proper treatment of incompleteness towards fainter magnitudes was derived. — H.C. Spruit made observations of the cataclysmic variable WZ Sge at La Palma, temporally resolving the changes in the H_{α} line profile during the eclipse. He developed a maximum-entropy Doppler mapping code for interpreting these observations.

F. Meyer and E. Meyer-Hofmeister investigated the accretion onto the compact star in dwarf nova systems ongoing during quiescence. X-rays and UV radiation originate from the accretion disk corona and the white dwarf boundary layer. A comparison with ROSAT spectra was started together with F.K. Liu (International School for Advanced Studies, Trieste). Together with C. la Dous (VILSPA and Sonneberg Observatory), UV observations of dwarf novae were used to test theoretical predictions of the accretion flow. — S. Schandl developed a numerical code to calculate the optical lightcurve of close binaries including illumination effects of disk and secondary by the compact primary, the geometrical and thermal modifications by the hot spot, and the energy transport on the secondary. For Her X-1 she reproduced the long-period variation in the lightcurve with the effect of the hot spot in that case when the stream hits the warped disk at its rim. To explain the mean optical lightcurve she found that energy transport on the secondary is necessary. — The numerical code developed by S. Schandl was also used to study, together with E. Meyer-Hofmeister and F. Meyer, the optical lightcurve of the supersoft X-ray source CAL 87. Following the model of van den Heuvel et al., in which mass transfer from the secondary of about 10^{-7} $M_\odot$/yr leads to stationary hydrogen burning on the primary white dwarf, the investigation shows that the stream–disk interaction is very important and produces a cold, clumpy spray embedded in a hot coronal plasma. — B. Warner studied the nature of instabilities in truncated accretion discs of the kind found in intermediate polars. Evidence was found for thermal instabilities (as in dwarf novae) and inner edge instabilities caused by interaction with the magnetosphere. — D. Syer and C.J. Clarke (IoA) demonstrated, using a simple analytic model, that the presence of a massive satellite can globally modify the structure and emission properties of an accretion disc to which it is tidally coupled. In the case of a T Tauri accretion disc, a model was developed for short-rise time FU Orionis outbursts. Such a model requires the prompt formation ($< 10^5$ years) of satellites in the mass range 10^{-4} to $10^{-1} M_\odot$ around a T Tauri star.

U. Anzer and G. Börner analysed the random variations of the pulse period of Vela X-1. They developed a model for wind-fed X-ray sources which can produce pulse period fluctuations of sufficiently large amplitude. — U. Anzer and G. Börner in collaboration with A. Feldmeier (University Observatory, Munich) and F. Nagase (ISAS, Kanagawa, Japan) started a project to model radiatively driven stellar winds which are exposed to ionisation effects from an orbiting X-ray source. Such a model is required to explain the observed asymmetric eclipse light curve of Vela X-1.

M. Ruffert continued simulations of Bondi-Hoyle accretion. The reduction of the adiabatic index to values close to unity (e.g., 4/3, radiation dominated case, and 1.01, isothermal gas case) yields more stable flows than previously obtained with higher values of gamma, and the flip-flop flow prominent in 2D simulations does not appear at all. Other features of the flow, like mass accretion rate, drag forces, etc., differ only qualitatively from the models done using a larger index (e.g., 5/3). — Together with U. Anzer the investigation of non-axisymmetric boundary conditions was started by including a velocity gradient in the incoming flow. The angular momentum accreted was found to be a substantial fraction of the angular momentum contained in the accretion cylinder. — N. Inogamov (Landau Institute of Theoretical Physics, Chernogolovka) and R. Sunyaev studied phenomena connected with unsteady accretion on relativistic stars immersed into interstellar gas medium. It was found that a variance appears as quasi-periodically repeated flashes of radiation from these stars.

The coalescence of binary neutron stars was investigated in a collaboration between M. Ruffert, H.-Th. Janka, and G. Schäfer (MPG-AG, University of Jena). The three-dimensional, hydrodynamical simulations of the merging of the neutron stars were evaluated for the structure of the gravitational wave signal with respect to the possibility of detection by the new gravitational wave interferometers LIGO, VIRGO, and GEO600. Overall qualitative agreement with the analytic point-mass approximation at large distances and with the hydrodynamical simulations of other groups at small separation was found. Quantitatively, the results depend sensitively on the assumed neutron star spins and on the properties of the nuclear equation of state. The models also provided detailed information about the neutrino emission. Neutrino-antineutrino annihilation in the surroundings of the merging neutron stars was found to yield an energy that fails to explain the energetics of gamma-ray bursts at cosmological distances by more than two orders of magnitude. Analytical considerations showed that even under the most favorable circumstances the neutrino emission from the disk that possibly forms around a cental black hole after the merging is not sufficiently luminous, and the annihilation energy remains too low by at least a factor of 20.

E. Müller and W. Brinkmann (MPE) have begun a numerical study of the precessing twin jets of SS433. Using a parallelized three-dimensional version of the PPM based hydrodynamical code PROMETHEUS, they have simulated the propagation of (one of) the precessing jet(s) starting at a distance of 0.01 light years from the source and covering the evolution of several 162-day precession periods. The interstellar matter is modeled by means of a relativistic variant of the ideal gas equation of state (Jüttner or Synge gas). Because of the large propagation speed of the jet (0.26 c), extremely strong shock waves (Mach number about 10^4) are encountered which heat the interstellar gas to very high temperatures (several 10^{10} K). It is the aim of this investigation to try to explain the observed X-ray emission of the jets of SS433. — H.C. Spruit, T. Foglizzo, and R. Stehle studied the collimation of jets by the poloidal fields of disks and showed that there is a maximum degree of collimation which increases with the ratio of outer to inner radius of the disk.

H.-C. Thomas and collaborators (A. Schwope (Potsdam), K. Beuermann and V. Burwitz (Göttingen), S. Jordan (Kiel), and R. Haefner (University Observatory, Munich) demonstrated the non-dipolar field structure of the polar QS Tel (= RX J1938.6-4612) by comparing models of cyclotron line emission from the accretion area on the white dwarf to low-resolution spectra. H.-C. Thomas and K. Reinsch (Göttingen) spectroscopically identified the X-ray source AX J2315-592 (detected serendipitously with ASCA) as a new AM Herculis binary. — H.-C. Thomas and collaborators from 7 other institutes reported the discovery of a galactic 'supersoft' X-ray source (RX J0019.8+2156) and discuss the implications for stable nuclear burning of accreted material on the surface of the white dwarf. — H.-C. Thomas and collaborators (K. Reinsch, K. Beuermann, and H. Hanusch, (Göttingen)) studied the orbital modulation of two intermediate polars (AE Aqr and YY Dra) in the soft X-ray regime.

S. Dieters completed a comprehensive study of the X-ray timing properties of Sco X-1 in collaboration with M. van der Klis (University of Amsterdam). Together with M. van der Klis (University of Amsterdam), E. Kuulkers (ESTEC, Noordwijk, Netherlands), B. Vaughan (Caltech), F.K. Lamb (University of Illinois, Urbana-Champaign), he also studied the time-lags in the QPO of Sco X-1. No time-lags were found in contrast to other similar systems. The difference is suggested to be due to differences in the magnetic field strength of the neutron star. — In collaboration with K. Borozdin and S. Sazonov (both Space Research Institute, Moscow), the X-ray properties of two Galactic superluminal radio-jet sources GRS 1915+105 and GRO 1655−40 were investigated by R. Sunyaev. It was shown that both sources experience transitions between different spectral states. Joint analysis of long-term X-ray, radio, and IR observations is continuing.

S. Dieters extended a program of photometry of old novae selected because their outbursts were similar to those of black hole X-ray transients. A spectroscopy of the old nova CP Pup was performed in an attempt to refine the white dwarf mass by detecting the spectral features of the secondary. — S. Dieters also performed optical observations of GRO1655-40, an eclipsing black hole candidate. Reduction of the data is underway. This work is done in collaboration with H.C. Spruit, F. van der Hoof (University of Amsterdam), J. Greenhill (University of Tasmania, Australia), J. van Paradijs (University of Amsterdam), and the BATSE team at the Marshall Space Flight Center. — The properties of the well-known Galactic black hole candidate GX 339-4 were investigated by S. Trudolyubov (Institute of Physics and Technology, Moscow) under the supervision of R. Sunyaev using GRANAT/SIGMA data. Explanation of the results obtained is in progress.

3.5 The Galaxy, external galaxies, and Active Galactic Nuclei

With M.J. Rees, Ph. Podsiadlowski has continued to work on Galactic halo models for classical gamma-ray bursts (GRBs). They showed that it is relatively easy to construct Galactic halo models, in which the bursters are ejected from the Galactic disk, that fit all observational constraints (the isotropic sky distribution and the non-uniform $\log N - \log S$ distribution), provided that the potential of the Galactic halo has some small anisotropies (as predicted, e.g., by popular CDM galaxy formation models) and that the population of bursters receives very large kicks at birth (much larger than 'normal' radio pulsars). They have also worked on a new variant of an asteroid model for GRBs, where the bursting neutron star is surrounded by planets and asteroids and where the bursts are indirectly caused by the impacts of asteroids which have been perturbed into destructive orbits by planet interactions.

Constructing self-consistent dynamical models for barred galaxies is a critical problem which stellar dynamicists have been struggling with for years without a satisfactory solution. H.S. Zhao extended his thesis work on this subject and made the first stable bar model which can fit the kinematics of the bulge stars and the DIRBE/COBE observed boxy and asymmetrical light distribution of the Galactic bulge in detail. — H.S. Zhao also found many families of analytical models for galactic nuclei which have a power-law density profile in their core region as found by the Hubble Space Telescope.

Together with J. Gunn (Princeton), J.V. Villumsen works on the dynamical evolution of the disk of our Galaxy in a model with continuous infall of gas. The study uses a fully self-consistent 3-D N-body code using FFTs specially designed for this problem.

In collaboration with Y.-N. Chin and C. Henkel (MPIfR, Bonn), J.B. Whiteoak (ATNF, Australia), and E.B. Churchwell (Madison, Wisconsin), N. Langer has studied the Galactic interstellar sulfur isotopic ratios and their interpretation in terms of stellar oxygen burning.

Based on the ASCA PV phase observations of 1E1740.7-2942, R. Sunyaev, M. Gilfanov (Space Research Institute, Moscow), and E. Churazov (Space Research Institute, Moscow) showed that the absence of a sufficiently strong fluorescent K-line of iron together with the strong low-energy and iron K-edge absorption indicate that the molecular cloud discovered in the direction towards the source is located in front of the compact source, rather than the source being imbedded in the cloud. — The HII regions around bright Galactic X-ray sources were the subject of a study by S. Grebenev (MPA visitor and Space Research Institute, Moscow). — S. Grebenev also investigated the evolution of the X-ray emission of M87 using GRANAT/ART-P data.

J. Schäfer introduced a dust and gas model for explaining the residual radiation intensities (after subtracting the CMBR) of the FIRAS-COBE spectra observed at $2 < \nu < 95$ cm^{-1} frequency. A one-component dust model explains the dominant dust radiation as being due to an empirical temperature-dependent dust absorption coefficient and a reasonable dust density distribution. Each dust spectrum was then fitted by a temperature curve along the line of sight. The small remaining intensities of all spectra could be accurately fitted by using the collision induced emission spectrum of normal hydrogen of 11 K multiplied by a factor. It is assumed that the hydrogen sources occur at the corresponding condensation density of about $4.5{\cdot}10^{18}$ cm^{-3} in small inhomogeneities of the gas clouds. Unusual requirements must be accepted in order for these gas clouds to reach the high densities: the clouds must be fractally structured, with gravitationally bound elementary fragments, and the gas in the elementary fragments must be turbulent in order to develop huge density gradients. Another crucial requirement is missing condensation sites in order to avoid continuing condensation and immediate star formation. Under these conditions the hydrogen sources are certainly close to regions of star formation. Many FIRAS-COBE spectra have been fitted in order to obtain maps of H_2 in Galactic longitude ($\Delta l \approx 15^o$) and all relevant Galactic latitudes ($|b| < 50^o$). Up to now there are three examples showing correlation with measured HI maps.

In collaboration with F. Prada (MPE, now at Instituto de Astrofisica de Canarias), H.S. Zhao worked on deriving the line-of-sight velocity distribution from a galaxy spectrum. They found a robust five-parameter fitting formula which can reliably recover the line-of-sight stellar velocity distributions of external galaxies.

D. Syer and S. Tremaine (CITA) studied non-axisymmetric configurations of a razor-thin, scale-free, barotropic fluid. Even such an idealised problem was found to have a rich structure. The relevance to lop-sided distributions of HI and stars in many disk galaxies was indicated. — D. Syer showed how to develop an expansion of nearly oblate systems in terms of a set of potential-density pairs. A harmonic (multipole) structure was imposed on the potential set at infinity, and the density could be made regular everywhere.

M. de Kool has worked with M.C. Begelman (JILA) on an analytical model for radiation pressure driven disk winds containing magnetic fields. It was shown that such winds have properties that make them an attractive explanation for the origin of the broad blue-shifted absorption lines observed in the spectra of some quasars.

H.-C. Thomas and collaborators (D. Grupe, K. Beuermann, and K. Mannheim (Göttingen), N. Bade (Hamburg), D. de Martino (VILSPA), A. Schwope (Potsdam), and H. Fink (MPE, Garching)) discussed possible mechanisms (accretion disk instability, tidal disruption of a star, supernova outburst) for the outburst of the Seyfert galaxy IC 3599 and the likely explanation (thermal radiation from an accretion disk) for the X-ray spectrum and variability of the Seyfert galaxy WPVS 007.

The propagation of supersonic relativistic jets was simulated in two spatial dimensions by J.M. Marti (University of Valencia, Spain), E. Müller, J.A. Font, and J.M. Ibanez (both University of Valencia, Spain) covering a wide range of jet parameters. The simulations were performed with a newly developed two-dimensional hydrodynamical code which is based on an explicit conservative differencing of the special relativistic hydrodynamics equations and on the use of an approximate Riemann solver. The simulations show that relativistic jets have the same gross morphological features as non-relativistic ones: a bow shock, a well collimated beam with internal oblique shocks terminating in a Mach disk and a cocoon. The prominence of the internal shocks and of the cocoon, however, depends on whether the internal energy of the jet is large (hot jet) or small (cold jet) compared to its rest mass energy. Hot jets have no cocoon at all, but their beam is surrounded by lobes near the jet head. They also almost completely lack internal structure and their beam/cocoon is very stable against the growth of pinch instabilities. The structural appearance of cold jets is quite similar to that of Newtonian ones. In addition, relativistics jets show a high propagation efficiency.

3.6 Gravitational lensing

Work on the reconstruction of the surface mass density in clusters of galaxies from weak lensing of background galaxies was continued.

In his Diploma thesis, supervised by P. Schneider, N. Deiser has shown that the local reduced shear can be derived just from the orientation statistics of the lensed images; since the orientation is less affected by seeing than the magnitude of the ellipticity, this finding provides a valuable means for the reconstruction of the surface mass density from ground-based data.

M. Bartelmann studied methods for inferring the projected mass distribution of clusters which are currently being developed and quantified their accuracy. The derived cluster mass estimates are lower bounds to the actual cluster masses which reach about 80% accuracy or more when applied to cluster fields with about $5'$ side length or larger. — M. Bartelmann, R. Narayan (CfA), S. Seitz, and P. Schneider suggested a novel technique to infer cluster mass distributions and their two-dimensional gravitational potential from the systematic distortions and magnifications of background images. The combination of both these effects allows one to determine cluster masses to about 5% accuracy. The proposed technique is readily extended to incorporate further information on the galaxy clusters from, e.g., X-ray observations. — With R. Narayan (CfA), M. Bartelmann suggested a method to determine redshifts of faint galaxies based on gravitational lensing and demonstrated the feasibility of this approach. With about 10 cluster fields and an equal number of empty control fields, the proposed algorithm allows to simultaneously infer faint-galaxy redshifts to about 10% and cluster masses to about 5% accuracy.

S. Seitz and P. Schneider have derived a reconstruction technique which is free of boundary artifacts and which is particularly designed to filter out a noise component which is readily identified as such from observational data; it has been demonstrated that this new technique is superior to other known unbiassed finite-field reconstruction methods. — C. Seitz and P. Schneider have investigated cluster mass reconstruction by accounting for a broad redshift distribution of the faint galaxy population; whereas in the weak lensing case this does not provide an additional difficulty, the nonlinear reconstruction gets modified. In addition, they showed that the “global invariance transformation” which leads to ambiguities in the total mass of the cluster is broken – though weakly – for a realistic redshift distribution of the galaxies. — Using the unbiassed reconstruction method for a redshift distribution of galaxies, C. Seitz, J.-P. Kneib (IoA, Cambridge), P. Schneider, and S. Seitz have analysed Hubble Space Telescope images of the cluster 0939+4713 (Abell 851) and reconstructed its surface mass density. Significant substructure was found which also closely resembles the light distribution in this cluster, as well as the X-ray emission. Strict upper and lower bounds on the total mass of the cluster inside the WFPC2 aperture have been derived.

M. Steinmetz and M. Bartelmann used gas-dynamical cluster simulations to investigate the accuracy of cluster mass estimates based on their X-ray emission, and to study X-ray properties of clusters selected for their lensing effect. They found that lensing-selected clusters are dynamically more active than average clusters, and in particular that clusters with intermediate rather than extreme X-ray luminosities contribute most to the lensing effect.

With S.N. Dutta (Oxford), M. Bartelmann studied the implications of arc statistics for the cosmological density and found that arcs in galaxy clusters are significantly suppressed if the density is low. They proposed that arc statistics provide a sensitive new tool to constrain cosmological parameters.

M. Bartelmann and A. Loeb (CfA) considered how estimates of the neutral-hydrogen density in damped Lyman-α absorbers in QSO spectra are changed by gravitational lensing of the systems hosting the hydrogen disks. Gravitational lensing can cause the inferred neutral-hydrogen density in the universe to be overestimated by factors between about 2 and about 5 depending on cosmology and QSO brightness, and it can mimic spurious evolution in the absorber systems. — With T. Kolatt (CfA), M. Bartelmann proposed a lensing based measurement to determine the distance of the cosmic structure which causes the dipolar motion of the solar system relative to the cosmic microwave background. They showed that the experiment is feasible with currently available QSO data.

In his Diploma thesis, supervised by P. Schneider and M. Bartelmann, A. Bartsch has developed a new and sensitive statistical method for investigating the associations of (foreground) galaxies with luminous high-redshift galaxies. This method is optimized for distinguishing between a theoretically predicted angular cross-correlation function between QSOs and galaxies and a random distribution. Application to the 1-Jansky sample of high-redshift QSOs and the IRAS Faint Source Catalog has verified a statistically significant association. — In his Diploma thesis, supervised by P. Schneider, B. Geiger has developed a novel method for determining the time delay in gravitationally lensed QSO systems. With particular emphasis on the close-separation radio system 0218+35.7 which is particularly well suited for the determination of the Hubble constant from lensing, this "lightcurve reconstruction" method can be applied to the total lightcurve of the images obtainable from single-dish observations, supported by a few interferometric measurements of the flux ratio. — G.-H. Lescow has analysed in his Diploma thesis (supervised by P. Schneider) a large number of QSO lightcurves, supplied by M.R.S. Hawkins, to derive constraints on the number density of sub-stellar mass objects in the universe from the scarcity of microlensing events. The upper bounds on the cosmological density of compact objects were improved considerably relative to earlier similar work.

P. Schneider and H.-W. Rix have developed a maximum-likelihood technique for analysing deep images with respect to galaxy-galaxy lensing. They have demonstrated that with currently possible observations, either from the ground or with HST, the characteristic mass parameters (velocity dispersion, cut-off radius) of galaxies could be determined very accurately. Observational proposals for carrying out such observations have been accepted at the CFHT and at NTT.

In collaboration with R.M. Rich (Columbia University) and D.N. Spergel (Princeton University), H.S. Zhao applied a self-consistent Galactic bar model to the microlensing event counts towards the Galactic bulge/bar by MACHO and OGLE collaborations. They showed that the microlensing rate already rules out many brown dwarf stars in the Galactic bulge/bar, and that most lenses need to be faint stars at the near end of the Galactic bar. Their model is also constrained to fit the non-circular motions of the Galactic center gas and the light and kinematics of the stars.

J.V. Villumsen has worked on the theory of gravitational lensing by large scale structure in Friedmann models with arbitrary values of Ω_0 and Λ. The density fluctuations in the universe induce a shear field on the sky whose properties can be predicted for a given cosmological model and the power spectrum of density fluctuations. The amplitude of the shear field is proportional to the amplitude of density fluctuations σ_8, nearly proportional to Ω_0 and only weakly dependent on Λ. The statistical properties of the shear field, i.e., power spectrum, two-point correlation function $C_{pp}(\theta)$, and variance $\sigma_p^2(\theta)$ can be calculated. Observations made at the 5-m telescope at Palomar indicate a variance of $\sigma_p = 0.027 \pm 0.005$ which would imply that $\Omega_0\sigma_8 \approx 1$. Measuring the amplitude of lensing at widely separated redshifts would allow a determination of Ω_0 independent of σ_8 and Λ.

J.V. Villumsen has shown that the magnification bias induced by lensing by large scale structure has a significant influence on the angular two-point correlation function of faint galaxies. The amplitude of the observed correlation will decrease differently with limiting magnitude than expected from Limber's equation. For a red sample the amplitude will decrease faster than expected, hit a minimum, and then increase with increasing magnitude. For a blue sample the amplitude will decrease slower than expected, hit a minimum, and then increase with increasing magnitude. Together with T. Broadhurst, J.V. Villumsen is working on measuring this effect from observations. Correlating color selected galaxy samples should show this effect clearly.

3.7 Galaxy formation, clusters of galaxies, and large scale structure

The formation of high redshift objects in a cosmic string and hot dark matter model was studied by R. Moessner in collaboration with R. Brandenberger (Brown University, Providence, USA). It was found that the number density of high redshift objects massive enough to be capable of hosting quasars is large enough to account for the observed abundance of high redshift quasars.

M. Haehnelt and M. Steinmetz in collaboration with M. Rauch (Caltech) investigated heavy-element QSO absorption systems caused by gas condensations at high redshift which evolve into normal galaxies at the present epoch. Artificial QSO spectra were generated for a variety of lines-of-sight through regions of the universe simulated with an SPH code. CIV and HI absorption features were found which closely resemble observed CIV and HI absorption systems. The model suggests that both high-ionization multi-component heavy-element absorbers and damped Lyα systems result from groups of small protogalactic clumps of about $10^9 M_\odot$. — H.J. Mo, with J. Miralda-Escudé (Institute for Advanced Study, Princeton), studied the properties of gaseous galactic haloes and their implications for the QSO absorption line systems. They found that current observational results on QSO metal line systems can be understood in the framework of our general idea of galaxy formation in hierarchical clustering models.

The influence of a photoionizing background on the formation of galaxies was studied by M. Steinmetz in collaboration with J. Navarro (Tucson, Arizona and MPA). Gas dynamical simulations without a UV background field exhibit an excessive angular momentum transport which results in the formation of very dense cores of gas at the center of galaxies. Late infalling diffuse gas settles into a disk. However, most of the mass is accumulated in the dense cores. This is in contrast to the more extended gas distribution of observed galaxies. It turns out that the presence of a UV background field only marginally affects the formation of the dense cores of gas, but cooling of the late infalling diffuse gas is strongly suppressed. No gaseous disk is formed then and the disagreement between simulated and observed galaxies is even worse.

G. Kauffmann (MPA and MPE), A. Nusser (Cambridge), and M. Steinmetz investigated the physical origin of biasing in the distribution of galaxies relative to dark matter by means of semianalytical galaxy formation models and N-body simulations. It turns out that linear bias is a good assumption on large scales for galaxies of all types and luminosities. Typical values for the bias parameter range from 1 to 2.5. Galaxies of different morphology or luminosity have different bias factors.

J.V. Villumsen, together with T. Brainerd and D. Goldberg (both University of Boston) has run a series of high-resolution N-body simulations of the formation of clusters using the Hierarchical Particle Mesh (HPM) code written by J.V. Villumsen. The HPM code allows the investigator to nest smaller simulations self-consistently within large simulations resulting in a "power zoom" effect. Two 2-level simulations have been run with a top grid size of 200 h^{-1} Mpc and a subgrid of size 33.3 h^{-1} Mpc in order to investigate the amount of late-time infall of mass in clusters of galaxies in a standard CDM universe. The grid used is a 256^3 mesh with 128^3 particles in the top grid. It is apparent from these simulations that the masses of the clusters increase by 1 to 2 orders of magnitude from redshifts of 2 to the present day and that mass located as far away as 15 h^{-1} Mpc at the start of the simulation ends up in the central Abell radius of the cluster at the end of the simulation (i.e. the present epoch).

In collaboration with C. Frenk (Durham), A. Evrard (Michigan), and F. Summers (Princeton), S.D.M. White carried out large simulations of the formation of a galaxy cluster which included both a dark matter component and a dissipative gas component which could cool and condense to make galaxy-like objects. The goal was to investigate whether evolution from small Gaussian fluctuations in a nearly uniform universe could produce a cluster containing a hot intergalactic medium and many distinct galaxies. The results suggest that this standard picture can indeed lead to clusters with structure and galaxy populations similar to those observed, but that present simulation techniques have at best only marginally sufficient resolution to follow the relevant processes.

The density structure of dark haloes is the subject of an ongoing study by S.D.M. White in collaboration with J. Navarro (Tucson, Arizona and MPA) and C. Frenk (Durham). The haloes which form in a Cold Dark Matter universe were found to be well fitted by a simple formula in which the density decreases as the inverse of the radius near the halo center and as the inverse cube of the radius at large radii. The characteristic density appearing in this formula is proportional to the density of the universe at the typical formation time of haloes of the mass considered, and so is larger for low mass haloes (e.g. the haloes of small galaxies) than for massive haloes (e.g. galaxy clusters). This kind of structure resolves several apparent contradictions between the structure of clusters inferred from X-ray and from gravitational lensing observations. Follow-up work suggests that this universal dark halo structure is expected in any hierarchical clustering model for structure formation. — The structure and dynamical evolution of dark matter haloes in clusters of galaxies were studied by G. Tormen (Cambridge, UK) in collaboration with S.D.M. White and F. Bouchet (IAP, Paris). The analysis was performed using high resolution N-body simulations of an $\Omega = 1$ universe with scale free fluctuations. It was found that the haloes are not isothermal; their density profile in the range from $0.01\,r_V$ to r_V (with r_V the virial radius) is well approximated by a fitting curve: $\rho(r) \propto 1/r(r_0 + r)^2$, where r_0 depends on the halo mass. The effect of the dynamical evolution of the halo on the density and velocity field was studied, and the dynamical equilibrium was tested with the Jeans equation. The dark matter distribution of the simulated halo was found to agree with recent estimations of dark matter in galaxy clusters coming from gravitational lensing observations.

H.J. Mo and S.D.M. White constructed a purely analytic theory which allows the gravitational clustering properties of dark haloes to be calculated directly in hierarchical models for structure formation. They tested their formalism extensively against N-body simulations and then used it to analyse how the distribution of galaxies may be biassed relative to that of the mass in the real universe. — With Y.P. Jing, they used this model to understand how the large scale clustering of clusters of galaxies is related to the fundamental parameters of cosmology and the initial density fluctuation spectrum.

Y.P. Jing and G. Börner investigated the velocity dispersion profiles of clusters of galaxies for seven models with differing cosmological parameters. After simulating the currently ongoing largest redshift survey for rich clusters, they concluded that this observation cannot put a stringent constraint on the cosmological parameters. — With G. Börner and R. Valdarnini (SISSA, Trieste), Y.P. Jing studied the three-point correlation function of clusters of galaxies for two plausible cosmological models. Using N-body simulations, they found a strong dependence on the triangle shapes for the three-point function normalized by the classic hierarchical form.

B. Jain, H.J. Mo and S.D.M. White showed that autocorrelation functions and power spectra for the dark matter in hierarchical clustering theories can be estimated simply and accurately from the linear power spectrum of the initial fluctuations from which structure grows. They provided fitting formulae calibrated with a set of N-body simulations. The formulae they give remain accurate into the highly nonlinear regime and are useful for a wide variety of applications in the analytic study of large-scale structure, for example the estimation of the statistics of weak lensing. — With R. Sheth (Berkeley), B. Jain used a relation between density profiles of dark matter haloes and the correlation function of the matter to predict the amplitude of the small-scale correlation function. — B. Jain also studied the evolution of gravitational clustering, as reflected in statistical measures like the correlation function as well as in the structure of dark matter haloes. With E. Bertschinger (MIT) he completed a study of the self-similar evolution of scale-free initial spectra $P(k) \propto k^n$ with particular emphasis on the $n = -2$ case.

Together with Xia X.-Y. (Tianjin) and Deng Z.-G. (Beijing), G. Börner studied the occurrence of typical scales in the distribution of infrared galaxies. High-luminosity infrared galaxies were identified with interacting galaxies and with ROSAT sources (with T. Boller (Potsdam)).

R. van de Weygaert, with F. Bernardeau (Saclay, Paris), studied two new numerical methods to estimate the statistics of velocity fields in structure formation scenarios from a given set of velocities at discrete points, based on the Voronoi and the Delaunay tessellation generated by this point set. Preliminary results have indicated that these methods would be useful for determining Ω. — R. van de Weygaert addressed the issue of the influence of tidal fields on the formation of structure. Special focus was put on the evolution of voids in external tidal fields, both by looking at the evolution of underdense homogeneous ellipsoids and by looking at the evolution of voids in specially sculpted initial Gaussian density fields. The void work is coauthored by A. Babul (NYU, New York). — Also, the role of tidal fields in the formation of filaments in the matter distribution has been addressed and is the topic of current research by R. van de Weygaert. For this, R. van de Weygaert in collaboration with E. Bertschinger (MIT, Boston) developed a method based on the Hoffman-Ribak algorithm to set up Gaussian initial density and velocity fluctuation fields, characterized by an arbitrary power spectrum, that is constrained to contain one or more peaks/dips on a certain scale. Each peak can be constrained to have a certain height, shape, and density profile steepness, while the matter distribution is sculpted in a selfconsistent way such that the values of the peculiar gravity and tidal field components at the position of the peak are the specified ones. A computer code for this is available upon request.

In collaboration with D. Goldwirth (Tel Aviv, Israel) and L. da Costa (IAP, Paris and ESO, Munich), R. van de Weygaert studied in how far the two-point correlation function is sensitive to the presence of voids. For this purpose they performed numerous calculations on galaxy distributions in the walls of Voronoi tessellations. They concluded that in particular the zero-length is a sensitive measure. — Finally, R. van de Weygaert proved the mathematical theorem, together with S. Chiu and D. Stoyan (Freiberg), that 2-dimensional sections through 3-D Voronoi tessellations are not themselves Voronoi tessellations. This had been a long-standing problem in stochastic geometry.

3.8 Physical cosmology

Together with M. Kasai (Hirosaki, Japan) and H. Russ (Tübingen) G. Börner derived a relativistic version of the Zel'dovich approximation. This can be used to study the effects of cosmological inhomogeneities.

The prospects for measuring cluster peculiar velocities using the kinematic Sunyaev-Zeldovich effect were studied by M. Haehnelt in collaboration with M. Tegmark (MPI Physik, Munich). It was found that the peculiar velocities of as many as 30 individual clusters can be determined accurately and that the bulk motion of an ensemble of 200 X-ray luminous clusters at redshifts of more than 10000 $\mathrm{km\,s^{-1}}$ can be measured with an accuracy of the order of 200 $\mathrm{km\,s^{-1}}$. The work was carried out as part of a joint effort of the Theory Working Group led by G. Efsthathiou (Oxford) and F. Bouchet (IAP, Paris) which prepares the scientific case for the proposed ESA cosmic-microwave-background mission COBRAS/SAMBA.

In collaboration with M. Rauch (Caltech), M. Haehnelt studied the properties of Lyα forest absorbers. Recent measurements of the size of these absorbers were used to show that the overall baryonic mass contained by them exceeds the nucleosynthesis limit unless the absorbers have a flat geometry. M. Haehnelt further showed that if the structure in the universe originates from initially Gaussian random fluctuations, the typical absorber responsible for coincident absorption in close quasar pairs will be a pancake embedded in an underdense region of the universe which expands faster than the Hubble flow.

In collaboration with L.Z. Fang (Univ. of Arizona, Tucson), Y.P. Jing analysed the COBE data of the cosmic background radiation anisotropies and found that a primordial power spectrum with an infrared cutoff can fit the COBE data better than a spectrum without any infrared cutoff.

3.9 Gravitation theory

The members of the relativity group have been mainly concerned with preparing the move to the new institute in Potsdam.

J. Ehlers (with T. Buchert) has worked out a Lagrangian perturbation theory and applications to structure formation in Newtonian cosmology. — H. Friedrich analysed space-like infinity using the framework of the conformal field equations. — H. Beyer (with B.G. Schmidt) pursued further properties of quasinormal modes of relativistic stellar oscillation, in particular concerning questions of completeness. — J. Frauendiener began to prepare Einstein's conformal field equations for numerical work. — J. Kannar showed that smooth solutions exist for the local characteristic initial value problem for Einstein's vacuum field equations with data at null infinity.

3.10 Physical processes

H.-Th. Janka studied the "paradox" that different kinds of neutrinos (electron neutrinos, electron antineutrinos, and muon and tau neutrinos) are predicted in theoretical models to be emitted from the supernova core with very similar luminosities but mean energies that differ by more than a factor of two. This fact is compatible with the Stefan-Boltzmann Law if the latter is generalized to include the effect that muon and tau neutrinos are much more isotropized by nucleon scatterings at their neutrinosphere.

In collaboration with G. Raffelt (MPI für Physik, Freimann) and D. Seckel (Bartol Research Institute, Newark), W. Keil and H.-Th. Janka investigated the effects of a reduction of the axial-vector neutral and charged current neutrino interactions in the dense supernova medium by rapid nucleon-spin fluctuations. Such spin fluctuation effects influence the cooling of protoneutron stars by neutrino emission. Limits on the possible spin fluctuation rate could be obtained by using the neutrino data measured in connection with supernova SN 1987A. The studies have implications for the understanding of a possible axion emission from supernova cores and affect the axion mass limit that can be deduced from the SN 1987A neutrino signal. Moreover, they suggest that there exists an additional mode of substantial energy transfer by neutrino-nucleon collisions with potential importance for the formation of the emitted neutrino spectra.

R. Sunyaev and E. Churazov investigated the recoil profile of X-ray emission lines due to scattering by the electrons bounded in neutral atoms and molecules. The effects predicted (Raman satellite lines, etc.) open the possibility of a direct determination of the helium abundance in the atmospheres of the Sun, flaring stars, giant molecular clouds, and accretion disks in AGNs.

3.11 Numerical methods

R. Wegmann extended his own fast method for numerical conformal mapping to ellipses as canonical regions. He proved that the method converges if a certain smoothing procedure is applied. This extends the range of applicability of the method appreciably.

R. Wegmann developed an upwind differencing method for the double adiabatic equations which describe a plasma with anisotropic pressure. He applied it to the plasma flow in the comet solar wind interaction. — Under the guidance of H.U. Schmidt and R. Wegmann, T. Gan-Baruch (PhD student from the University of Tel-Aviv) developed a computer program for the treatment of a two-component plasma with anisotropic pressure. Until now she has obtained results for cometary plasma flow with a two dimensional version of this program.

In a collaboration with R. Dgani (California Institute of Technology, Pasadena), W.F. van Thor (University of Amsterdam), and L.J. van den Horn (University of Amsterdam), H.-Th. Janka has worked on the inclusion of the concepts of a static and dynamic artificial opacity into a spectral, flux-limited neutrino diffusion scheme for moving media in order to achieve momentum conservation. The code was tested at exemplary stellar background models with focus on the effects of the dynamical terms like Doppler shifts.

T. Plewa in collaboration with E. Mueller continued the development of the new multidimensional code suited for high resolution simulations of hydrodynamical flows. The code exploits adaptive mesh refinement (AMR) techniques to automatically increase numerical resolution in the regions occupied by flow discontinuities. AMR offers substantial savings in usage of computer resources. In some 1D simulations speedup by a factor of 700 was observed and in the majority of the studied 2D cases the code used one tenth of the CPU time needed to obtain the same results on a single computational mesh. Further work in this field will concentrate on a three-dimensional version of the code and on porting the code to massively parallel machines (Cray T3D).

In his thesis work K. Ludwig developed a program that incorporates time-dependent thermal relaxation together with radial diffusion in the evolution of accretion disks. The program includes a number of physical interactions that have previously been neglected and allows one to follow the propagation of transition waves between the two stable states of the disk in detail. — R. Stehle developed a 2-D hydrodynamic code for accretion disks, in which the vertical motions in the disk are included in a 'one-zone' approximation. He also completed a 2-D MHD code for the evolution of poloidal magnetic fields in accretion disks.

D. Syer and S. Tremaine (CITA) developed an algorithm for constructing N-body realisations of equilibrium stellar systems. The algorithm complements existing orbit-based modelling techniques using linear programming or other optimization algorithms. — D. Syer and S. Tremaine (CITA) also described a technique for solving the combined collisionless Boltzmann and Poisson equations in a discretised, or lattice, phase space. The time and the positions and velocities of 'particles' take on integer values, and the forces are rounded to the nearest integer.

Together with J.M. Owen (Ohio State University), P. Shapiro, and H. Martel (both University of Austin, Texas), J.V. Villumsen has been developing a new version of SPH (Smooth Particle Hydrodynamics) for use in cosmological simulations. The code utilizes triaxial kernels which allow a better resolution of shocks. Due to the higher resolution the code has significantly less preheating than standard SPH codes. The code also requires less artificial viscosity. The downside to the code is that it does not rigorously conserve angular momentum, however this problem can be greatly reduced by forcing the kernel field to be smooth. Tests in rotating systems show that the angular momentum non-conservation is minimal. This code can also be applied to non-cosmological simulations.

3.12 Quantum mechanics of atoms and molecules; astrochemistry

Theoretical studies are in progress in order to investigate the stability, structure, spectra, and dynamics of Rydberg molecules as function of their size, their central atom (such as H, Li, Na, K), and their rare-gas ligands. Preliminary results for molecules of the formula RgH (Rg = He, Ne, Ar, and Kr) show that they form stable Rydberg molecules, that for molecules involving the rare gases He and Ne the electronic excitation is localized at the hydrogen atom, and that the distribution of the excited electron completely encloses the molecule (DFG Schwerpunktprogramm: Molekulare Cluster, E.W. Schreiner).

The theoretical studies of excited electronic states have been extended to classical and quantum mechanical studies of highly excited Rydberg electrons in crossed electric and magnetic fields. Guided by an approximate Hamiltonian, the structure of the phase space has been explained in terms of invariant tori, periodic orbits, chaotic motion, chaos/order transitions, and Arnol'd diffusion (J.-R. von Milczewski, T. Uzer (Atlanta, USA)).

The photodynamic therapy (PDT) of cancer is based on the use of light sensitive molecules, called photosensitizers. Clinical tests of the photodynamic therapy of cancer using 5-aminolevulinic acid-induced (ALA) photosensitizers have been very successful and encouraging. While there are different speculations about the (re)action of photosensitizers in biochemical environments leading to the damage and death of cells, little is known in detail about the physical and chemical process(es) involved in it. A concerted experimental, theoretical, and clinical effort is being started to understand the photodynamic therapy of cancer (NSERC Canada Strategic Project (in preparation): R. Pottier and V.H. Smith (Kingston, Canada)).

Recently, for the first time, excited states have been characterized experimentally in molecular crystals by X-ray crystallography. At low temperatures these states have practically infinite lifetimes. Very little is known about the formation, stability, and electronic structure of these states. Theoretical studies have been started in order to explain the processes of formation and depletion and the structure of these states (NSERC Canada Cooperative Project: P. Coppens (Buffalo, USA), V.H. Smith, and Jiahu Wang (both Kingston, Canada)).

For the studies of the properties and processes of atoms and molecules in excited electronic states outlined above, the development and implementation of new quantum mechanical methods was found to be necessary. The symmetric group approach (SGA) configuration interaction (CI) method has been chosen as the standard tool. Among others, an approximation has been developed that takes into account relativistic effects due to two-electron terms in the Breit-Pauli Hamiltonian in the internal (reference) CI space but electron correlation effects, as usual, in both the internal and external CI space. At present this approximation is being implemented (N. Flocke, J. Karwowski (Torun, Poland)).

For theoretical studies of chemical processes in the condensed phase, among others, combined quantum mechanical/classical models have been developed which treat the solute quantum mechanically and the solvent as a classical dielectric continuum. The combination of the recently developed multi-cavity self-consistent reaction field method with the supermolecule representation of the first coordination shell of inorganic ions in aqueous solution has enabled one to predict their bulk solvation energies with reliable accuracy (M. Karelson (Tartu, Estonia)). Also, work is in progress to replace the continuum approach by a model in which the solvent is described with a classical dynamic simulation (P. Graf, A. Nitzan (Tel Aviv, Israel)).

The concept of a knowledge-based, stepwise evolutionary, open software environment has been developed: the OpenMol program. The development of appropriate knowledge structures and rules has been continued. Numerical software has been designed and implemented for the closed- and open-shell self-consistent field (SCF) method (T. Jürimäe (Tartu, Estonia)), for the CI method (N. Flocke, E.W. Schreiner), for the coupled cluster (CC) method (V. Kellö (Bratislava, Slovak Republic)), and for relativistic corrections due to the one-electron terms in the Breit-Pauli and no-pair Hamiltonians to the SCF and CC methods (M. Barysz (Katowice, Poland)). The design and implementation of the graphical input to the application programs and for the graphical representation and animation of the results has been continued (gOpenMol) (L. Laaksonen (Espoo, Finland)). Particular emphasis has been put on the development of the OpenMol a-Release of the numerical software and of the associated documentation (K. Grudzinski (Torun, Poland), E.W. Schreiner).

As a new research project rigorous quantum mechanical studies of the radiative association reaction were taken up. This is one of the basic processes of molecular formation in various interstellar environments. Unbiassed experimental information is difficult to obtain. Theoretical predictions put very high demands on the accuracy of the electronic structure calculations of several low-lying electronic states and their coupling or dipole transition features (W.P. Kraemer) and require the development of new techniques for determining all bound rotation-vibration levels together with the lower quasi-bound resonance states (V. Špirko, M. Jurek, P. Soldán (all Academy of Sciences, Prague)).

At the same time previous studies of the coupling between electronic and nuclear motions (vibronic coupling) in the case of Renner–Teller coupled electronic states of triatomic molecules were extended to allow the calculation of transition intensities. Predictions of the line patterns of yet unknown spectra of the molecular dihydrides CH_2^+ and NH_2^+ are made (W.P. Kraemer together with P. Jensen (Wuppertal) and P.R. Bunker (Ottawa, Canada)).

4 Publications

4.1 Publications in journals

4.1.1 Publications that appeared in 1995:

Aksenov, A.G., and S.I. Blinnikov: A Newton iteration method for obtaining equilibria of rapidly rotating stars. A&A **290**, 674-681.

Anzer, U.: Parameters of quiescent prominences derived from magnetic field measurements. Solar Phys. **161**, 49-55.

Anzer, U., and G. Börner: Random variations of the pulse period of X-ray binaries with wind accretion. A&A **299**, 62-68.

Arp, H.: Ultraviolet extensions measured with ROSAT HRI around active galaxies. A&A **294**, L45-L48.

Arp, H.: Alignment of radio and X-ray sources across PG1211+143. A&A **296**, L5-L8.

Arp, H.: Observational cosmology impacts physics. Physics Essays **8**, 350–365.

Arp, H.: X-ray evidence that 3C273 is in the Virgo Cluster. Physics Letters A **203**, 161-164.

Arp, H.: Naked quasars. Mercury **24**, 35.

Bartelmann, M.: Cosmological parameters from angular correlations between QSOs and galaxies. A&A **298**, 661–671.

Bartelmann, M.: Arc statistics with realistic cluster potentials. III. A systematic effect on cluster mass estimates. A&A **299**, 11–16.

Bartelmann, M.: Cluster mass estimates from weak lensing. A&A **303**, 643–655.

Bartelmann, M., and R. Narayan: The Lens Parallax Method: determining redshifts of faint blue galaxies through gravitational lensing. ApJ **451**, 60–75.

Bartelmann, M., M. Steinmetz and A. Weiss: Arc statistics with realistic cluster potentials. II. Influence of cluster asymmetry and substructure. A&A **297**, 1–12.

Beuermann, K., K. Reinsch, H. Barwig, V. Burwitz, D. de Martino, K.-H. Mantel, M.W. Pakull, E.L. Robinson, A.D. Schwope, H.-C. Thomas, J. Trümper, A. van Teeseling and E. Zhang: Discovery of a galactic supersoft binary X-ray source. A&A **294**, L1–L4.

Beyer, H.R., and B.G. Schmidt: Newtonian stellar oscillations. A&A **296**, 722–726.

Brandt, W.N., Ph. Podsiadlowski and S. Sigurdsson: On the high space velocity of X-ray Nova Sco 1994: implications for the formation of its Black Hole. MNRAS **277**, L35–L40.

Braun, H., and N. Langer: Effects of accretion onto massive main sequence stars. A&A **297**, 483–493.

Canal, R., P. Ruiz-Lapuente and A. Burkert: The single-degenerate scenario for Type Ia SNe in cosmic perspective. ApJ 456, L101–L105.

de Kool, M., and P.J. Green: A model for the space density of dwarf carbon stars. ApJ **449**, 236–245.

de Kool, M., and M. C. Begelman: Radiation pressure driven magnetic disk winds in Broad Absorption Line QSOs. ApJ **455**, 448–455.

Dow, K.L., and S.D.M. White: ROSAT observations of Coma cluster galaxies. ApJ **439**, 113–120.

Duch, W., and G.H.F. Diercksen: Feature space mapping as a universal adaptive system. Comput. Phys. Commun. **87**, 341-371.

Foglizzo, T., and M. Tagger: The Parker-shearing instability in azimuthally magnetized discs. A&A **301**, 293–308.

Garcia-Segura, G., M.-M. Mac Low and N. Langer: The evolution of circumstellar rings formed by massive star winds. Ap&SS **224**, 459–460.

Goldwirth, D.S., L.N. da Costa and R. van de Weygaert: The two–point correlation function and the size of voids. MNRAS **275**, 1185–1194.

Groenewegen, M.A.T.: Are a-spherical AGB shells due to a-spherical central stars. A&A **305**, L61–L64.

Grupe, D., K. Beuermann, K. Mannheim, N. Bade, H.-C. Thomas, D. de Martino and A.D. Schwope: X-ray outburst of the peculiar Seyfert galaxy IC3599. A&A **299**, L5–L8.

Grupe, D., K. Beuermann, K. Mannheim, H.-C. Thomas, H.H. Fink and D. de Martino: Discovery of an ultrasoft transient ROSAT AGN: WPVS007. A&A **300**, L21–L25.

Haehnelt, M.G.: Momentum transfer by an internal source of ionizing radiation an important feedback during galaxy formation? MNRAS, **273**, 249–256.

Han, Z., P.P. Eggleton, Ph. Podsiadlowski and C.A. Tout: The formation of Barium and CH stars and related objects. MNRAS **277**, 1443–1462.

Haser, S.M., D.J. Lennon, R.-P. Kudritzki, J. Puls, A.W.A. Pauldrach, L. Bianchi and J.B. Hutchings: The stellar wind of an 08.5l(f) star in M31. A determination of mass loss rate and metallicity. A&A **297**, 136–146.

Hashimoto, M., Y. Eriguchi and E. Müller: Equilibrium Structure of Self-gravitating Keplerian Disks. A&A **297**, 135–140.

Herrero, A., R.P. Kudritzki, R. Gabler, J.M. Bichez and A. Gabler: Fundamental parameters of galactic luminous OB stars. II. A spectroscopic analysis of HDE 226 868 and mass of Cygnus X–1. A&A **297**, 556–566.

Jain, B., H.J. Mo and S.D.M. White: The evolution of correlation functions and power spectra in gravitational clustering. MNRAS **276**, L25–L29.

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Janka, H.-Th., and E. Müller: The first second of a Type-II supernova: convection, accretion, and shock propagation. ApJ **448**, L109–L113.

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Jensen, P., M. Brumm, W.P. Kraemer and P.R. Bunker: An *ab initio* calculation of the Rovibronic energies of the CH_2^+ molecule. J. Mol. Spectrosc. **172**, 194–204.

Jing, Y.P., and G. Börner: The velocity dispersion profiles of clusters of galaxies: a cosmological test and the sampling effect. MNRAS **278**, 321–325.

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Jing, Y.P., H.J. Mo, G. Börner and L.Z. Fang: Substructures and density profiles of clusters in models of galaxy formation. MNRAS **276**, 417–431.

Jurek, M., V. Špirko and W.P. Kraemer: Ab initio determination of the rate coefficient for radiative association of $He(^1S) + H^+$. Chem. Phys. **193**, 287–296.

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Keil, W., H.-Th. Janka and G. Raffelt: Reduced neutrino opacities and the SN 1987A signal. Physical Review D **51**, 6635–6646.

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Kraemer, W.P., V. Špirko and M. Jurek: Formation of HeH^+ by radiative association of $He^+ +$ H. An advanced *ab initio* study. Chem. Phys. Lett. **236**, 177–183.

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Liu, F.K., F. Meyer and E. Meyer-Hofmeister: Dwarf novae in quiescence: the relationship between disk evaporation and accretion onto a white dwarf. A&A **300**, 823–833.

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Müller, E., and M. Steinmetz: Simulating self-gravitating hydrodynamic flows. Comp. Phys. Comm. **89**, 45–58.

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Niemeyer, J.C., and W. Hillebrandt: Turbulent nuclear flames in Type Ia supernovae. ApJ **452**, 769–778.

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Ruffert, M., and U. Anzer: Bondi-Hoyle accretion simulations including velocity gradients. A&A **295**, 108–112.

Ruffert, M., H.-Th. Janka and G. Schäfer: Coalescing neutron stars as gamma-ray bursters? Ap&SS **231**, 423–426.

Ruiz-Lapuente, P., A. Burkert and R. Canal: Type Ia supernova scenarios and the Hubble sequence. ApJ **447**, L69–72 .

Schindler, S., L. Guzzo, H. Ebeling, H. Böhringer, G. Chincarini, C.A. Collins, S. De Grandi, D.M. Neumann, U.G. Briel, P. Shaver and G. Vettolani: Discovery of an arc system in the brightest ROSAT cluster of galaxies, A&A **299**, L9–L12.

Schneider, P.: Cluster lens reconstruction using only observed local data. A&A **302**, 639–648.

Schneider, P., and M. Bartelmann: The power spectrum of density fluctuations in the Zel'dovich approximation. MNRAS **273**, 475–483.

Schneider, P., and C. Seitz: Steps towards nonlinear cluster inversion through gravitational distortions. I. Basic considerations and circular clusters. A&A **294**, 411–431.

Schwope, A.D., H.-C. Thomas, K. Beuermann, V. Burwitz, S. Jordan and R. Haefner: Two-pole accretion in the high-field polar RX J1938.6-4612. A&A **293**, 764–776.

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Spruit, H.C., R. Stehle and J.C.B. Papaloizou: Interchange instability in an accretion disc with a poloidal magnetic field. MNRAS **275**, 1223–1231.

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Steinmetz M., and M. Bartelmann: On the spin parameter of dark matter haloes. MNRAS **272**, 570–578.

Steinmetz, M., and E. Müller: The formation of galaxies in a cosmological context: structure and kinematics of disk galaxies. MNRAS **276**, 549–562.

Thomas, H.-C., and K. Reinsch: AX J2315-592. IAU Circ. No. 6261 (1995 November 14)

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Velazquez, H., and S.D.M. White: Dynamical models for the Sagittarius dwarf galaxy. MNRAS **275**, L23–L26.

Wegmann, R.: MHD model calculations for the effect of interplanetary shocks on the plasma tail of a comet. A&A **294**, 601–614.

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Woosley, S.E., N. Langer and T.A. Weaver: Mass loosing helium stars: presupernova evolution and explosion. ApJ **448**, 315–338.

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Bernardeau, F., and R. van de Weygaert: A new method for accurate estimation of velocity field statistics. MNRAS.

Blinnikov, S.I., P.V. Sasorov and S.E. Woosley: Self-acceleration of nuclear flames in supernovae. Space Science Reviews.

Böhringer, H., D.M. Neumann, S. Schindler and R.C. Kraan-Korteweg: A3627: a nearby, X-ray bright, and massive galaxy cluster. ApJ.

Chiu, S.N., R. van de Weygaert and D. Stoyan: The sectional Poisson Voronoi tessellation is not a Voronoi tessellation. Jnl. Appl. Prob.

Degl'Innocenti, S., G. Fiorentini, G.G. Raffelt, B. Ricci and A. Weiss: Time-variation of newton's constant and the age of globular clusters. A&A.

Denissenkov, P.A., and A. Weiss: Deep diffusive mixing in globular cluster red giants. A&A.

Feldmeier, A., U. Anzer, G. Boerner and F. Nagase: Vela X-1:how to produce asymmetric eclipses. A&A.

Flocke, N., M. Barysz, J. Karwowski and G.H.F. Diercksen: Symmetric group approach to relativistic CI. I. General formalism. Intern. J. Quantum Chem.

Flocke, N., M. Barysz, J. Karwowski and G.H.F. Diercksen: Symmetric group approach to relativistic CI. II. Reduction of matrices in the spin space. Intern. J. Quantum Chem.

Flocke, N., M. Barysz, J. Karwowski and G.H.F. Diercksen: Symmetric group approach to relativistic CI. III. Matrix elements for spin-dependent operators. Intern. J. Quantum Chem.

Frenk, C.S., Evrard, A., White, S.D.M and Summers, F.J.: Galaxy dynamics in clusters. ApJ.

Haehnelt, M.G., and M. Tegmark: Using the kinematic SZ effect to determine the peculiar velocities of clusters of galaxies. MNRAS.

Inogamov N.A.: An analytical description of the five-minute oscillations of Sun. Pis'ma v Astronomicheskii Zhurnal (Astronomy Letters).

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Janka, H.-Th., and E. Müller: Neutrino heating, convection, and the mechanism of Type-II supernova explosions. A&A.

Klessen, R.S., and A. Burkert: Constraints on massive black holes as dark matter candidates using Galactic globular clusters. MNRAS.

Maley, D., P.L. Kilpatrick, E.W. Schreiner, N.S. Scott and G.H.F. Diercksen: The formal specification of abstract data types and their implementation in Fortran 90: implementation issues concerning the use of pointers. Comput. Phys. Commun.

Martí, J.M[a]., and E. Müller: Extension of the Piecewise Parabolic Method to one-dimensional relativistic hydrodynamics. J. Comp. Phys.

Martin, I., C. Lavin, M. Velasco, M.O. Martin, J. Karwowski and G.H.F. Diercksen: Quantum defect orbital study of electronic transitions in Rydberg molecules. Ammonium and Fluoronion radicals. Chem. Phys.

Meyer-Hofmeister, E., N. Vogt and F. Meyer: The influence of a magnetic field of the secondary star on dwarf nova outbursts. A&A.

Minniti, D., W. Liebert, E.W. Olszewski, E.W. and S.D.M. White: Background giants in the field of the globular cluster M22: kinematics of the galactic bulge. Astron. J..

Mo, H.J., and S.D.M. White: An analytic model for the clustering of dark matter haloes. MNRAS.

Moessner, R., and R. Brandenberger: Formation of high redshift objects in a cosmic string theory with hot dark matter. MNRAS.

Pauldrach, A.W.A., M. Duschinger, P.A. Mazzali, J. Puls, M. Lennon and D.L. Miller: NLTE models for synthetic spectra of type Ia supernovae. A&A.

Podsiadlowski, Ph.: The response of tidally heated stars. MNRAS.

Ruffert, M.: Three-dimensional hydrodynamic Bondi-Hoyle accretion V. Specific heat ratio 1.01, nearly isothermal flow. A&A.

Ruffert, M., H.-Th. Janka and G. Schäfer: Coalescing neutron stars — a step towards physical models. I. Hydrodynamic evolution and gravitational wave emission. A&A.

Schandl, S.: Her X-1: Modelling the anomalous and preeclipse dips with the coronal wind model. A&A.

Schindler, S.: The accuracy of mass determination in galaxy clusters by X-ray observations. A&A.

Schindler, S.: Interaction in the bimodal galaxy cluster A3528. MNRAS.

Schindler, S.: ROSAT results on groups and clusters of galaxies. Astrophysical Letters and Communications.

Schindler, S.: The accuracy of mass determination in galaxy clusters by X-ray observations. Astrophysical Letters and Communications.

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Steinmetz, M.: GRAPESPH: Cosmological smoothed particle hydrodynamics simulations with the special purpose hardware GRAPE. MNRAS.

Sunyaev, R., and E. Churazov: Scattering of X-ray emission lines by neutral and molecular hydrogen in the vicinity of galactic nuclei and compact sources. Pis'ma v Astronomicheskii Zhurnal (Astronomy Letters).

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4.2 Proceedings and publications in monographs

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4.3 Popular articles and books

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4.4 Preprints ("Green Reports")

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Janka, H.-Th., E. Müller: Neutrino heating, convection, and the mechanism of type–II supernova explosions. MPA 863

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5 Personnel

5.1 Scientific staff members

U. Anzer, M. Bartelmann (on leave of absence till July 31), H. Beyer (till March 31), G. Börner, T. Buchert (till March 31), S. Degl'Innocenti (since April 1), M. de Kool (till Dec. 31), G.H.F. Diercksen (on leave of absence till March 19), S. Dieters (since July 1), J. Ehlers (till March 31), T. Foglizzo, J. Frauendiener (till March 31), H. Friedrich (till March 31), A. Gautschy (till Sept. 30), M. Groenewegen (since Oct. 1), M. Haehnelt, W. Hillebrandt (on leave of absence till June 30), B. Jain, H.–Th. Janka (on leave of absence till Sept. 30), P. Kafka, U. Kolb (on leave of absence till Oct. 31), W.P. Kraemer, R.–P. Kudritzki, H.–G. Ludwig, S. Mao (since Sept. 1), R. Mendez (Jan. 1 – June 30), E. Meyer–Hofmeister, F. Meyer, H. Mo, R. Mößner (since Oct. 1), E. Müller, J. Niemeyer (since Dec. 1), H.–D. Radecke (May 1 – Oct. 31), H. Ritter, H.–W. Rix (till Aug. 31), M. Ruffert, J. Schäfer, S. Schandl, B.G. Schmidt (till Dec. 31, delegated April 1 – Dec. 31), P. Schneider, H.C. Spruit (on leave of absence till April 30), M. Steinmetz, D. Syer (since Oct. 1), R. Sunyaev (since Oct. 1), K. Takahashi (till Aug. 14), H.–C. Thomas, J. Villumsen, R. Wegmann, A. Weiß, R. van de Weygaert (till July 31), S.D.M. White, H.S. Zhao, Th. Zwerger (April 1 – Sept. 30).

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

Heisenberg–grant: N. Langer (Göttingen).

Ph.D. students: R.–P. Andersen, J. Beuing (May 1 – Sept. 30), U. Brauer (till March 31), H. Braun (till Dec. 31), J.M. Colberg (since Sept. 1), M. Duschinger (since July 1), P. Englmaier (till Aug. 31), J. Fliegner, B. Geiger (since Nov. 1), P. Graf (till Aug. 23), A. Heger (since Sept. 1), A. Huss, G. Karakatsanis (till Dec. 11), W. Keil, R. Klessen (till April 30), R. Kneissl, K. Ludwig, J.–R. von Milczewski (till Dec. 18), J. Niemeyer (till Dec. 5, on leave of absence till Sept. 30), K. Schenker (April 1 – Sept. 30), C. Seitz, S. Seitz, E. Schreiner, T. Soffner (till March 31), R. Stehle (on leave of absence till Feb. 28), O. Ullmann, J. Wagenhuber, A.G. Weiß (till Dec. 14), Th. Zwerger (till March 3).

Diploma students: K. Achatz (till Aug. 31), A. Bartsch (till April 30), G. Contardo (since March 1), N. Deiser (till Aug. 31), M. Gaudlitz (since Feb. 1), B. Geiger (till Aug. 31), A. Heger (till June 30), G.–H. Lescow (till Sept. 30), B. Perkens–Golomb (since Aug. 16), M. Platzöder (till July 31), J. Rehm (since March 1), K. Schenker (till May 31), H. Schlattl (since May 1), M. Vanselow (till July 31).

5.2 Staff news

On April 1, H. Beyer, J. Ehlers (as managing director), J. Frauendiener, H. Friedrich, and B.G. Schmidt began their scientific research work at the newly founded Max–Planck–Institut für Gravitationsphysik in Potsdam.

R. Sunyaev was appointed Scientific Member at the Max–Planck–Institut für Astrophysik and will become one of the Board of Directors once the structure of the institute administration is changed. He accepted the offer on Oct. 1. R. Sunyaev was also awarded the Gold Medal of the Royal Astronomical Society, London, and the Robinson Prize of the University of Newcastle.

5.3 Visiting scientists

Name (home institution) duration of stay at MPA

MPG fellowships:
M. Barysz (Katowice, Polen) Aug. 1 – Nov. 26; S. Blinnikov (Moscow, Russia) Oct. 1 – Dec. 31; K.N. Borozdin (Moscow, Russia) Nov. 21 – Dec. 21; E.M. Churazov (Moscow, Russia) June 20 – July 20; P. Denissenkov (St. Petersburg, Russia) Jan. 8 – March 5; I. Forcada (Cambridge, UK) till Dec. 31; J. Frank (Louisiana, USA) June 6 – July 6; Z. Frei (Budapest, Hungary) Sept. 20 – Dec. 20; A. Fullerton (Newark, USA); M.R. Gilfanov (Moscow, Russia) July 20 – Aug. 20; S.A. Grebenev (Moscow, Russia) June 20 – July 20; W. Groom (Cambridge, UK) till Dec. 31; V.S. Imshennik (Moscow, Russia) Nov. 8 – Dec. 14; N.A. Inogamov (Moscow, Russia) July 30 – Aug. 30 and Nov. 21 – Dec. 20; K. Jahn (Warsaw, Poland) June 1 – Aug. 31; J. Karwowski (Torun, Poland) June 1 – June 30 and Sept. 24 – Oct. 24; M. Kasai (Hirosaki, Japan) July 22 – Sept. 16; V. Kellö (Bratislava, Slovak Republic) Aug. 1 – Sept. 30; A. Kritsuk (St. Petersburg, Russia) Aug. 6 – Oct. 15; G. Lake (Seattle, USA) July 16 – Aug. 31; J.P. Morris (Clayton, Australia) Nov. 7 – Dec. 6; J. Navarro (Tucson, USA) June 26 – Aug. 12; J.M. Owen (Columbus, USA) Nov. 11 – Dec. 15; T. Plewa (Warsaw, Poland); M. Rozyczka (Warsaw, Poland) Oct. 1 – Oct. 31; P. Ruiz–Lapuente (Barcelona, Spain) since Aug. 1; M. Salaris (Teramo, Italy) since Oct. 1; S.Y. Sazonov (Moscow, Russia) July 20 – Aug. 19 and Nov. 21 – Dec. 21; P. Soldan (Prague, Czech Republic) Nov. 13 – Dec. 12; V. Spirko (Prague, Czech Republic) May 1 – July 31 and Nov. 13 – Dec. 13; R. Sunyaev (Moscow, Russia) June 11 – Sept. 2; O.V. Terekhov (Moscow, Russia) June 15 – July 29; S.P. Trudolyubov (Moscow, Russia) Nov. 21 – Dec. 21; Y. Tuchman (Jerusalem, Israel) July 16 – Aug. 15; V. Utrobin (Moscow, Russia) Nov. 1 – Dec. 31; H. Velasquez (Cambridge, UK) till Dec. 31; K. Venn (Austin, USA); J. Vojtik (Prague, Czech Republic) Nov. 1 – Nov. 30; B. Warner (Cape Town, South Africa) Oct. 1 – Dec. 31; Z. Zhang (Beijing, China) till Sept. 30.

Alexander von Humboldt–research awards and fellowships:

Alexander von Humboldt–awards: W. Kolos (Warsaw, Poland) till March 31; A. Nitzan (Tel Aviv, Israel) April 2 – May 5 and Aug. 1 – Aug. 31; S.E. Woosley (Santa Cruz, USA) Nov. 11 – Dec. 12.

Alexander von Humboldt–fellowships: Y. Jing (Triest, Italy); O. Ventura (Montevideo, Uruguay) May 8 – Sept. 1.

DAAD–fellowship:
F. Mrugala (Torun, Poland) Oct. 9 – Dec. 9.

DFG–fellowships:
Z. Deng (Beijing, China) March 27 – July 26; P. Podsiadlowski (Cambridge, UK) since April 1; V. Urpin (St. Petersburg, Russia) Oct. 1 – Dec. 31; X. Xia (Tianjin, China) April 12 – July 11.

EC–fellowships:
K. Grudzinski (Torun, Poland) Aug. 2 – Oct. 31; M. Marti (Valencia, Spain) till May 31.

ESF–fellowships:
M. Barysz (Katowice, Poland) May 6 – July 1.

Other visitors:
G. Carraro (Padova, Italy) March 3 – April 4 and Aug. 31 – Oct. 8; I. Cernusak (Bratislava, Slovak Republic) Aug. 1 – Sept. 30; R. Durrer (Zürich/Genève, Switzerland) March 13 – April 1; T. Gan–Baruch (Tel Aviv, Israel) July 1 – Dec. 31; M. Groenewegen (Paris, France) July 17 – July 31; G. Hensler (Kiel, Germany) since Oct. 1; P. Jensen (Wuppertal, Germany) Sept. 11 – Sept. 24; B. Jeziorski (Warsaw, Poland) Sept. 24 – Dec. 23; A. King (Leicester, UK) July 15 – Aug. 11; L. Laaksonen (Espoo, Finland) June 8 – July 2; V. Luridiana (Mexico City) July 17 – Aug. 12; P.–Å. Malmqvist (Lund, Sweden) May 8 – May 31 and Oct. 9 – Oct. 31; C.F. McCain (Mt. Stromlo, Australia) June 5 – June 25; M. Rauch (Pasadena, USA) Sept. 7 – Sept. 23; E. Skillman (Minneapolis, USA) since Sept. 1; G. Tormen (Cambridge, UK) since June 6; R. van de Weygaert (Groningen, The Netherlands) Aug. 8 – Aug. 31; B. Wybourne (Torun, Poland) Aug. 2 – Aug. 30; S. Yamada (Tokyo, Japan) since Sept. 1.

5.4 Diploma and Ph.D. theses

Diploma theses:

K. Achatz: "Dynamik thermonuklearer Verbrennungsvorgänge im 'core helium flash'", Technical University Munich;

A. Bartsch: "Statistische Untersuchung zur Assoziation von Quasaren mit Vordergrund–Galaxien", Technical University Munich;

N. Deiser: "Statistische Methoden zur Bestimmung des Linsenparameters", Technical University Munich;

B. Geiger: "Bestimmung der Lichtlaufzeitdifferenz in Gravitationslinsensystemen", Ludwig-Maximilians-University Munich;

A. Heger: "Stationäre Modelle für Wolf–Rayet–Sterne mit optisch dicken Winden", Technical University Munich;

G.–H. Lescow: "Bestimmung einer oberen Grenze der kosmologischen Dichte in kompakten Objekten geringer Masse aus der Variabilität von Quasarlichtkurven", University Hamburg;

M. Platzöder: "Statistische Analyse der Galaxienverteilung mit Hilfe von Minkowski–Funktionalen", Ludwig-Maximilians-University Munich;

K. Schenker: "Novaausbrüche und die Langzeitentwicklung von kataklysmischen Doppelsternen", Technical University Munich;

M. Vanselow: "Verallgemeinerungen von kosmologischen Lösungen im Rahmen der Lagrange'schen Störungstheorie", Ludwig-Maximilians-University Munich.

Ph.D. theses:

P. Graf: "Ansätze zur Modellierung quantisierter Prozesse in Lösungen", Technical University Munich;

G. Karakatsanis: "Optimierung der Lagrange'schen Störungstheorie für die analytische Simulation kosmologischer Strukturen", Ludwig-Maximilians-University Munich;

J.–R. von Milczewski: "Rydbergelektronen in senkrechten elektrischen und magnetischen Feldern", Technical University Munich;

J. Niemeyer: "On the Propagation of Thermonuclear Flames in Type Ia Supernovae", Technical University Munich;

A.G. Weiß: "Numerische und statistische Verfahren zur kosmologischen Simulation der großräumigen Galaxienverteilung unter Verwendung der Lagrangeschen Störungsrechnung", Ludwig-Maximilians-University Munich;

Th. Zwerger: "Der Gravitationskollaps rotierender Polytrope – Eine systematische Studie", Technical University Munich.