2.8 The formation and evolution of elliptical galaxies

Two main types of galaxy inhabit our Universe: those that are supported against gravity primarily by rotation and have a disc-like morphology, and those that are supported by random motions and are spheroidal in shape. Spiral galaxies, with their prominent arms lit up by hot radiating gas and young stars, fall into the former category. The spheroidal, or *elliptical* galaxies have a predominantly old stellar population and are devoid of gas.

Spiral galaxies are believed to form when hot gas cools and collapses into a centrifugally supported disc in which star formation can take place. Spiral formation is believed to be a slow process, with the galaxy producing stars at a roughly constant rate over much of the age of the Universe.

The formation of ellipticals has long been the subject of considerable controversy. One school of thought holds that because ellipticals appear to have remarkably uniform properties and because their stars are very old, they must all have formed at much the same time early in the history of the Universe. In this picture, the structure of an elliptical was "set" when it collapsed monolithically from a single overdense region at high redshift. Stars were created rapidly in a *burst* of less than a billion years in duration. The galaxy was thus initially extremely luminous and its light was dominated by the short-wavelength (blue) radiation from massive young stars. As the most massive stars aged and evolved off the Main Sequence, the galaxy faded and its light came to be dominated by the longer wavelength (red) radiation from Red Giant stars.

Using theoretical models of stellar evolution, one is able to predict the spectral properties of the radiation emitted as the stars produced in a burst evolve (Fig. 2.14). The main uncertainties in this kind of modelling come from assumptions about the distribution of the individual masses of the stars in the burst, and the way in which the elemental composition of the stellar population evolves as the interstellar medium of the galaxy becomes enriched by the ejecta from supernova explosions of the most massive stars. By matching the models to the observed spectra of elliptical galaxies, one is nevertheless able to learn that the stars contained in nearby ellipticals are probably older than about 10 billion years, although some ellipticals, particularly those in low-density environments, appear to contain a substantial fraction of stars that are only a few billion years old.

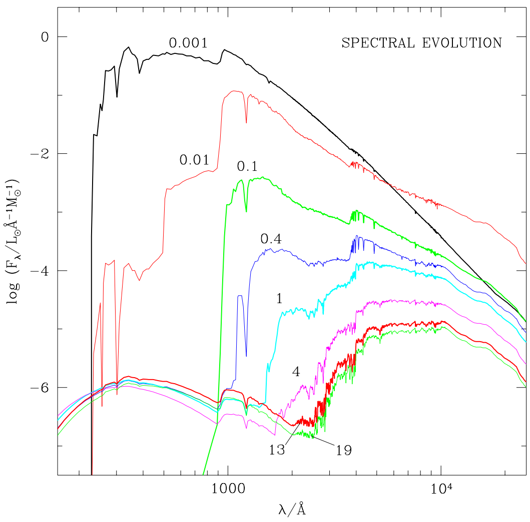

Figure 2.14: The evolution of the spectral energy distribution of an elliptical galaxy in the high-redshift burst model. The spectra are labelled according to the time since the burst in units of a billion (10^9) years. (courtesy of Stéphane Charlot)

It has been known for over a decade that an elliptical-like galaxy can be created if two disc galaxies collide with each other and merge. This scenario has been explored in considerable detail using computer simulations in which the evolution of two orbiting disc galaxies is followed over several billion years by discretizing the system and applying the laws of gravitation and the equations of hydrodynamics repeatedly to each individual simulation "particle". The disc galaxies, which are made up of hundreds of thousands of particles representing both stars and gas in modern computer simulations, are allowed to orbit each other until they merge, and once the remnant galaxy has finally reached equilibrium, its structure is found to be remarkable reminiscent of that of observed ellipticals.

Considerable impetus for this *merger picture* of elliptical formation also comes from a rather different direction, namely that of cosmology. In the popular *hierarchical* or bottom-up theories (see preceding article), structure in the Universe is built up through the continuous merging of subunits. This is the reason why theorists working in this field have tended to favour the merger picture of elliptical formation even though the evidence in support of it has, up to recently, been rather unimpressive. Although some nearby ellipticals show signs of a recent disturbance, such as shells or dust lanes, most form a remarkably homogeneous family of objects and it has been a puzzle how mergers occurring continously over the whole age of the Universe could account for this.

The latest generation of large telescopes and high-sensitivity detectors has brought astronomers several steps closer to unravelling the mysteries of elliptical galaxy formation. Surveys of faint galaxies now reach out as far as a redshift of one, a time when the Universe was only a third of its present age. The long-cherished dream of seeing galaxies in the process of formation has now become reality.

One such survey is the Canada-France Redshift Survey (CFRS), carried out by a team of astronomers from Toronto and Paris using a 4 metre telescope on Mauna Kea in Hawaii. Using a multi-slit spectrograph, these scientists obtained redshifts for nearly 700 faint galaxies with an average redshift of 0.5. The most striking result from the survey emerged when the sample of galaxies was divided into two parts according to colour: *blue* galaxies typical of nearby spirals and *red* galaxies typical of local ellipticals. It was found that the total light produced by blue galaxies had increased by almost a factor 10 at redshift one, whereas that emitted from red galaxies had changed very little.

Astronomers at the MPA realized that this result had important implications for theories of elliptical formation. In particular, if ellipticals formed in a high-redshift burst and then faded until the present, the total light in red galaxies should be substantially *greater* in the past, not the same as today. With a more careful analysis of the data, the MPA scientists were able to show that the abundance of galaxies with the colours expected for evolving ellipticals was three times smaller at redshift one than it is today. This implies that two-thirds of present-day ellipticals were either experiencing strong star formation at that epoch (and thus were blue rather than red in colour) or were in much smaller pieces and hence too faint to be included in the survey. A statistical test showed that the simple high-redshift burst model could be ruled out with 99.9 percent confidence. A similar result was obtained for an independent smaller but deeper survey carried out by University of Hawaii astronomers using the 10 meter Keck telescope.

With the present data, it is not possible to tell whether it is merging, star formation, or both, that has been responsible for the lack of bright red galaxies at redshift one. Images of the CFRS galaxies taken with the refurbished Hubble Space Telescope will soon be available and it should then be possible to answer this question. Future surveys carried out with the new generation of 8 and 10-metre class telescopes will probe to even fainter limits and higher redshifts where, if the merger models are correct, no bright ellipticals at all should remain. In the meantime scientists at the MPA are constructing models for the formation of galaxies by merging that can be compared directly with the observations as they become available. For a given set of cosmological initial conditions, these so-called "semi-analytic" models follow gas-cooling, star formation, and the merging of galactic subunits in a hierarchy of merging dark matter halos. The results indicate that most of the observed properties of present-day ellipticals can easily be explained in such a picture and that the evolution of ellipticals at high redshift is strongly dependent on the cosmological model and may thus provide an important discriminatory tool. (Guinevere Kauffmann)

2.9 How to measure what cannot be seen: statistical descriptions of the galaxy distribution

It is one of the great aims of cosmologists to understand in detail the distribution and evolution of cosmic matter. The astronomers produce high precision maps of the spatial distribution of galaxies — the basic building blocks of luminous matter in the Universe. The observations determine the angular position on the sky and the redshift of each galaxy in a sample. For a galaxy following precisely the uniform cosmic expansion the redshift is proportional to the distance, and thus a 3-dimensional map of the galaxy distribution can be constructed. Figure 2.15 shows a redshift map of the most recent data set, the Las Campanas Redshift Survey (LCRS). The figure clearly demonstrates the highly structured galaxy distribution with large clusters, and a network of sheets and filaments surrounding large underdense regions. The texture seen here is reminiscent of earlier surveys — like the Center for Astrophysics (CfA) survey — but the structures are replicated many times across the bigger volume of the LCRS. Although the analysis of this data set has not been completed — among others a group at the MPA is also working on it — preliminary results show that the average clustering properties in different large volumes in this sample agree quite accurately indicating that it is large enough to faithfully exhibit a typical picture of the Universe.

Theoretical attempts to understand how the clustering pattern of galaxies is behaving now and how it got that way must take into consideration a basic uncertainty about the composition of the cosmic matter. There is growing evidence of the existence of a nonluminous, ,,dark" component of the cosmic matter which may account for a large fraction, perhaps 90%, or even 99%, of the total. The nature of this dark matter is still unknown — there is a wide range of exotic particles which might serve as theoretical candidates, but unfortunately no experimental confirmation up to now. Cosmologists have learnt to live with the embarrassing fact that the type of particle making up the dominating matter component in the Universe is not known. The lack of knowledge can be nicely compensated by allowing several hypothetical cases and investigating their consequences for cosmic structure formation. The construction of theoretical models for dark matter has the advantage that these particles interact only by gravity, and do not dissipate their energy. The task is then to find a scenario that leads from reasonable initial conditions through the dynamics of the gravitational interaction to a final state that matches significant features of what is observed. In the expanding Universe the action of gravity is such that small density contrasts grow. Volumes which contain slightly more mass than average will lag behind, and eventually form collapsed lumps or halos, but the catastrophic collapse of the whole system is prevented by the general expansion. In general a highly structured clustering pattern emerges. The model parameters consist of the quantities characterizing the background cosmological model (mean density, mean expansion rate, age) and the initial conditions for the distribution of the dark matter, especially the amplitudes of the density perturbations, on different scales.

Figure 2.16 displays the result of such a model calculation plotted in the same way as the LCRS data of Fig. 2.15. The two figures look similar, although the ,,galaxies" in the theoretical model are "pseudo-galaxies", appropriately identified dark matter density concentrations. Just looking at the picture is not enough, however. Different people might see different things. A quantitative statistical description must be given. A simple characterization of the clustering pattern can be achieved by counting the neighbours a galaxy has at a given separation r. This count is averaged over all the members of the sample, then compared to the count for a randomly distributed sample. The same procedure is applied for different separations r, and thus a so-called ,,two-point correlation function" is calculated. It has turned out that these correlation functions have a rather simple form, close to a power law. They also are important functions for the theory to reproduce.

A quantitative comparison shows that the two-point correlation functions at small separations are different, i.e. the real galaxies are not clustered in the same way as the dark matter models. This fact, that light does not trace matter perfectly, was incorporated into the model building by allowing for a "bias" — an ad hoc prescription how to identify specific dark matter concentrations with galaxies, such that the two-point correlation functions agree. The bias will, of course, be determined by the physics of galaxy formation, but as long as there is no well-established theory for this process, it is an additional freedom in the construction of models. More information can be obtained from other statistics, such as the correlations of triplets of galaxies. This might constrain the models more strongly.

Besides the clustering, the pattern of motion of the luminous galaxies also reflects the structure of the dark matter. The galaxies follow on average the uniform Hubble expansion, but superimposed are velocities caused by the gravitational action of mass concentrations, luminous and dark. These peculiar velocities therefore map out the total mass distribution. They are manifest in redshift maps, such as Fig. 2.15, as slight distortions: Compact groupings of galaxies are elongated along the line of sight. This "finger of God" effect is produced by the random velocities in a gravitationally bound cluster. In a redshift map a galaxy moving toward the observer is placed closer than corresponds

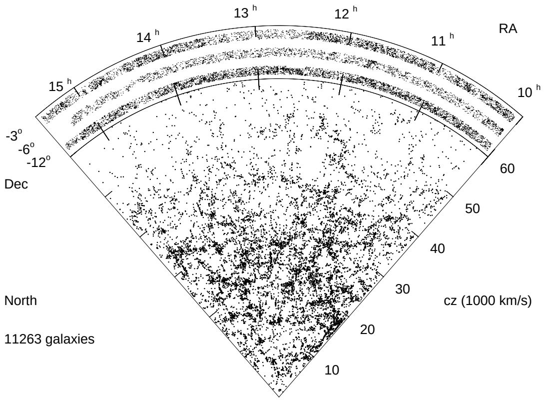

Figure 2.15: The distribution of galaxies in the North galactic cap from the LCRS survey. Galaxies were observed in three different slices of declination which are all projected onto each other. The coordinates plotted are the "right ascension" (a longitude coordinate on the celestial sphere) and the redshift, here given as a recession velocity obtained by multiplying the redshift by the velocity of light (300000 km s^{-1}).

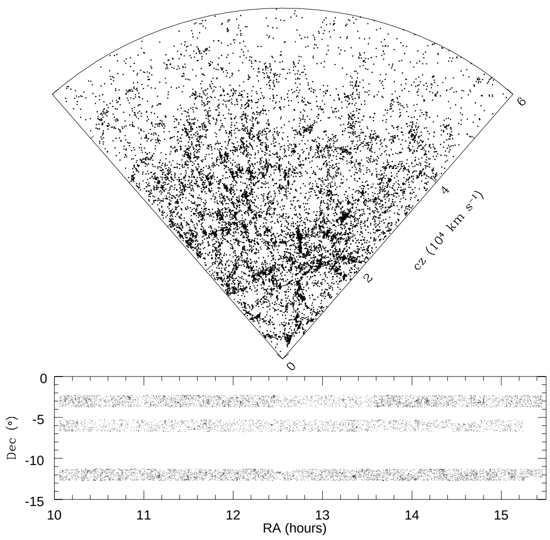

Figure 2.16: Selected dark matter particles from a numerical simulation are plotted in the same way as the LCRS observations of Fig. 2.15.

to its real distance; analogously a galaxy moving away appears at a greater redshift-distance.

The direct analysis of the pattern of motion around a mass concentration is only possible, if the real distances to the galaxies are measured in addition to the redshifts of their spectral lines. To obtain distances, the astronomers use semi-empirical relations between photometric properties, like the width of a particular spectral line, and the luminosity of a galaxy. This time-consuming observational program has been completed only for several hundred galaxies. The result is, nevertheless, spectacular: it seems that a big system of galaxies and clusters around us is moving towards an, as yet unknown, mass which was appropriately named "The Great Attractor".

The effect of peculiar motions in general, however, can only be estimated in an average, statistical sense: Since peculiar motions distort positions along the line of sight, the two-point correlation function in redshift space is a function of two variables, the separations parallel and perpendicular to the line of sight. The measurement of this anisotropy leads to a value for the average of the squared velocity differences of galaxy pairs.

This quantity depends on the separation of the two galaxies, and on small scales, where the relative motion is only caused by the local gravitational field, it contains information on the average clustering of the matter. Thus it is important for probing cosmological models as well as for understanding how galaxies trace the underlying mass distribution. In 1983 Peebles and Davis estimated this quantity from the first CfA survey. They obtained a value that was much lower than the results of numerical simulations. For more than 10 years this unsatisfactory situation was unchanged, but then it could be shown that the pair velocity varied enormously in different astronomical data sets, and much larger values could be obtained.

Such effects can now be studied in great detail, because it has turned out that the two-point correlation function and the peculiar velocities in the late nonlinear stage of gravitational clustering can both be expressed as analytic functions of the initial state of the system. These functions depend only on the parameters of the cosmological models, and on the initial distribution of the dark matter particles. A detailed study of a wide range of different clustering models is now possible. Such a study would not be feasible just using time-consuming numerical simulations.

For small separations — corresponding to the extent of a galaxy halo — each galaxy pair is very likely contained within one cluster, or completely outside. Since the peculiar velocities are largest in rich clusters, their contribution dominates the average pair velocity. Therefore this quantity is only well estimated, if the sample contains many rich galaxy clusters. All galaxy redshift samples used up to now do not fulfill this condition but the LCRS may be the first data set of sufficient size. Its analysis is in progress. The analytic models show that the average small scale pair velocity strongly discriminates between different models of structure formation. Thus the high-quality data from future surveys, perhaps already the Las Campanas Survey, will lead to better determinations of these statistical quantities, and thus to strong constraints on the clustering properties of the dark matter. (Gerhard Börner)

2.10 Weak lensing and cosmology

Large-scale structure in the Universe magnifies and distorts the images of distant galaxies. Observations of this outcome of the gravitational deflection of light can provide valuable insights on our cosmological surroundings. Theoretical efforts at MPA have focussed on computing the gravitational lensing effect for a variety of viable cosmological models.

Galaxy surveys are the traditional method of mapping the distribution of matter on scales of millions of light years. Interpretation of any observation of the galaxy distribution requires an understanding of how the light of galaxies is related to the distribution of the dark, non-luminous matter, which is believed to be the dominant component of the mass in the Universe. This has proved a rather difficult problem — it is the principal obstacle to mapping large-scale structure and understanding the cosmological parameters of our Universe. Gravitational lensing however is a direct probe of the dark matter, as the deflection of light rays is caused by all mass concentrations, visible as well as dark. This is the main advantage of using lensing to map the dark matter.

Consider a distribution of intrinsically circular, distant galaxies on the sky. Gravitational lensing enlarges the image of each such galaxy and distorts its shape into an ellipse. These two effects, the enlargement and distortion, are the simplest outcomes of the deflection of the photons as they pass through massive structures between the source galaxy and us. Clusters of galaxies are the most prominent collapsed structures, and therefore lensing by clusters has been studied extensively through both these effects. "Large-scale structure" includes the full range of structure formed by the dark matter, ranging from individual galaxies or clusters to much weaker, non-luminous perturbations of the matter distribution which have not yet collapsed into isolated objects. In a typical, randomly chosen patch of the sky photons would traverse structures mostly of the second kind — the weak, diffuse perturbations. The cumulative effect of these perturbations is to magnify and distort galaxy images by a few percent or even less.

In 1991 three independent calculations of weak lensing effects by large-scale structure concluded that theoretical cosmological models predict a 1-2% distortion in the shapes of faint galaxies. The angular size over which this effect is coherent and detectable ranges from about an arcminute to a degree on the sky. Observationally it has proven a challenge to detect such a small effect. The source galaxies are at redshifts of about 1, i.e. at a distance that is a significant fraction of the size of the observable Universe (Note: redshift is a measure of distance, since in an expanding Universe model more distant galaxies are moving away from us faster, and therefore their light is shifted towards the red side of the spectrum more strongly). To detect distortions in the shapes of such distant galaxies requires excellent observing conditions. Even more important is to control systematic errors, e.g. distortions in the CCD (charge coupled device) cameras used to image the galaxies, that could artificially produce elliptical images from circular sources.

In recent years better cameras installed on 4 meter class or bigger telescopes have provided images with sufficient resolution to carry out searches for such distortions. Planned observations in the coming one or two years should yield definitive measurements. So far there are only preliminary detections of coherent image distortions in small fields of view (2 arcminutes on a side) which are probably due to weak lensing by large-scale structure. The magnitude of this detected ellipticity is in line with theoretical expectations. It is clearly important to quantify the implications of a measured signal for theoretical cosmological models.

The image distortions caused by lensing arise because photons are deflected as they climb in and out of the gravitational potential wells created by dark matter perturbations. These perturbations have grown from small ripples in the fluid which constituted the very early Universe.

Hence they are closely connected to the cosmological model for the initial conditions of the Universe. By averaging the induced image distortions over regions of varying size on the sky, the cosmological perturbations can be probed on different length scales.

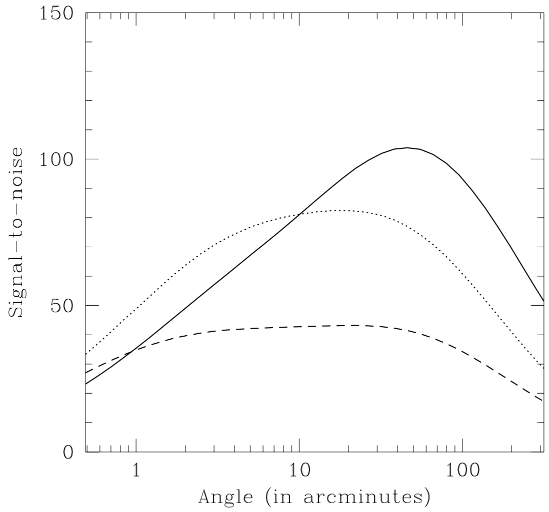

Figure 2.17: The expected distortion signal in galaxy images induced by lensing is obtained by measuring the mean ellipticity of several galaxies. The y-axis shows the ratio of the signal, to the noise expected due to the non-circular shapes of the galaxies before they are lensed. If this signal-to-noise ratio is sufficiently larger than 1 then it is feasible to detect the signal with high quality observations. The estimate shown is based on a hypothetical observation of 200000 faint galaxies in random patches of the sky of total size one square degree. The three curves show cosmological models with $\Omega = 1$ (solid), $\Omega = 0.3, \Lambda = 0$ (dashed), and $\Omega = 0.3, \Lambda = 0.7$ (dotted).

The depth of the potential wells that photons encounter is proportional to the mean density of the Universe. Hence weak lensing is sensitive not only to how large the perturbations are, but to the absolute value of the mean density as well. The mean density relative to the critical density required to close the Universe (called the parameter Ω) is a key, and so far undetermined, cosmological parameter. The larger the value of Ω, the deeper the potential wells and the stronger the lensing effect. Thus lensing can be used to probe the value of Ω. Variations in Ω and the cosmological constant Λ (an exotic form of energy density which does not dilute as the Universe expands), lead to different rates of expansion of the Universe. This changes the actual distance of a galaxy at a given observed redshift from us. There is greater path length available for lensing if the galaxies are at larger distances, thus leading to a stronger cumulative lensing effect. These two effects, the depth and growth rate of potential wells, and the distance relation, allow lensing to probe the value of Ω and Λ. Figure 2.17 shows the value of the image distortion signal due to lensing predicted by different cosmological models.

It is a theoretical challenge to use weak lensing observations to separately measure different cosmological parameters. A detailed investigation revealed that a measurement of the distortion in images of galaxies at different redshifts would provide the ideal test for the presence of Λ, because the distortion signal should increase more rapidly with redshift if Λ dominates the energy density of the Universe. Variation of the distortion signal with angular size probes both the mean density Ω and the density perturbations (see Fig. 2.17. Therefore constraints from other kinds of observations would need to be combined with the measured distortion signal to measure Ω and the density perturbations on different spatial scales separately.

The second of the two effects of lensing described above provides one such independent probe of cosmology: it is the increase in size due to deflection of photon trajectories, known as "magnification bias". This bias leads to a given area of the sky becoming larger, thus diluting the measured number density of galaxies. On the other hand galaxies too faint to be detected in the absence of lensing are brightened and therefore observed. The net effect can be either to increase or decrease the observed number of galaxies, depending on whether the ratio of the numbers of faint and bright galaxies exceeds a critical value.

Magnification bias has already been detected in association with rich clusters. The cosmological application involves using it in a typical, random patch of the sky — again to probe the full range of large-scale structure. Work done at MPA has led to the suggestion of measuring correlations between distant quasars and foreground galaxies; between different types of galaxies, e.g. red and blue galaxies; or between galaxies at different redshifts. The latter measurement would help isolate the effect of lensing by using the galaxies only as a tracer population, with minimal assumptions required about their evolution in time relative to the matter distribution.

There are two key observational challenges in making these measurements of weak lensing.

The first is instrumental: systematic distortions induced by the observing instrument need to be sufficiently low to measure the real distortions in galaxy images. The second is that the redshifts of the imaged faint galaxies need to be measured to fully use the measurements of weak lensing for theoretical interpretation. There has been great progress on both issues in recent years, and the coming years promise further advances. The outlook is therefore bright for confronting the theoretical work described above with measurements of lensing of distant galaxies. (Bhuvnesh Jain)

2.11 Massive τ neutrinos and Big Bang nucleosynthesis

In the modern picture of cosmology, the Universe is believed to have originated in a very hot and dense initial state, the so-called Big Bang. This primeval fireball took place about 10 billion years ago; since then the Universe has expanded and cooled. Three observations support this so-called standard model: 1. The linear relation between the distance and the velocity of galaxies which results from the universal expansion (the Hubble expansion). 2. The cosmic microwave background radiation which is interpreted as the relic photon distribution, sometimes called "the echo of the Big Bang". 3. The relative abundances of the light elements which are predicted by the standard theory of Big Bang nucleosynthesis (BBN).

This article will focus on the third point, the creation of the light elements in the Big Bang, namely deuterium (D), the two helium isotopes helium-3 (^{3}He) and helium-4 (^{4}He), and lithium-7 (^{7}Li). The theory is called *standard* BBN, because it is based on the standard models from the two most fundamental branches of physics, particle physics on the one hand and the cosmology on the other. Because of this connection between physics on very large and very small scales, Big Bang nucleosynthesis is one of the most fascinating playgrounds in the field of astroparticle physics.

About 0.01 seconds after the Big Bang, the Universe cooled down to a temperature of about 100 billion Kelvin (K). The abundance of high-energy photons in the cosmic plasma was too high for the light elements to exist in non-negligible amounts. As soon as a nucleus formed, it was destroyed by high-energy photons. Only protons and neutrons, the constituents of the nuclei, were abundant, because they cannot be destroyed by photons. Protons and neutrons were constantly interconverted by reactions due to so-called weak interactions. As a result, the neutron-to-proton ratio took a value which depends only on the masses of these two particles and on the cosmic temperature. As cooling proceeded down to about 10 billion K, the weak reaction rates were no longer fast enough to maintain this equilibrium and the relative number of neutrons to protons became constant, the neutron-to-proton ratio is said to have frozen out. Neutrons, however, are unstable; they decay into protons, electrons and (anti-)neutrinos and so the neutron-to-proton ratio continued to decrease slowly.

At a temperature of about 1 billion K, the density of high-energy photons is no longer high enough to destroy nuclei and practically all remaining free neutrons are converted via deuterium and tritium or ^{3}He into ^{4}He. Some traces of the intermediate elements survive and a tiny amount of ^{7}Li is synthesized as well. The final ^{4}He abundance is therefore highly sensitive to the number of free neutrons at a temperature of 1 billion K. This number in turn depends on the neutron-to-proton ration at the moment of freeze-out and on the time available for free neutron decay between this moment and ^{4}He production.

The timescale on which the Universe cools is determined by its expansion rate, which depends in turn on its energy density. The energy density itself depends on the number of so-called degrees of freedom; this is basically the number of different types of light or even massless particles. Light in this context means that energy equivalent to the particles mass is less than that of typical photons in the cosmic plasma. In the standard model of particle physics, five particles fall into this category. The first two are the massless photon and the electron with its mass of 511 keV. The remaining three are the three different types of neutrino. In the standard model of particle physics, neutrinos are assumed to be massless, but this is not proven by experiment. Only upper limits on their masses are so far available.

The higher the energy density in the early Universe, the faster is the expansion and the less time is available for neutron decay between the freeze-out of the neutron-to-proton ratio at approximately 10 billion K and the ^{4}He production at approximately 1 billion K. The faster the Universe cools, the more neutrons survive this period and the more ^{4}He is created.

The recombination of nucleons and therefore the final abundances of the light elements depend on the density of nucleons relative to photons, or in other words on the baryon content of the Universe. Within the standard model of cosmology and the standard model of particle physics, this is the only unknown parameter in the calculation of the primordial abundances of the light elements. Such a nucleosynthesis calculation is performed using a numerical code which combines a nuclear reaction network and a calculation of the temperature, pressure and energy density of the expanding Universe.

The results of a standard BBN calculation using a newly developed MPA code are shown in Fig. 2.18. The predicted values for the mass fraction of ^{4}He and the number densities of D and ^{7}Li relative to hydrogen are displayed as a function of the baryon-to-photon ratio η. They agree very well with results published previously in the literature.

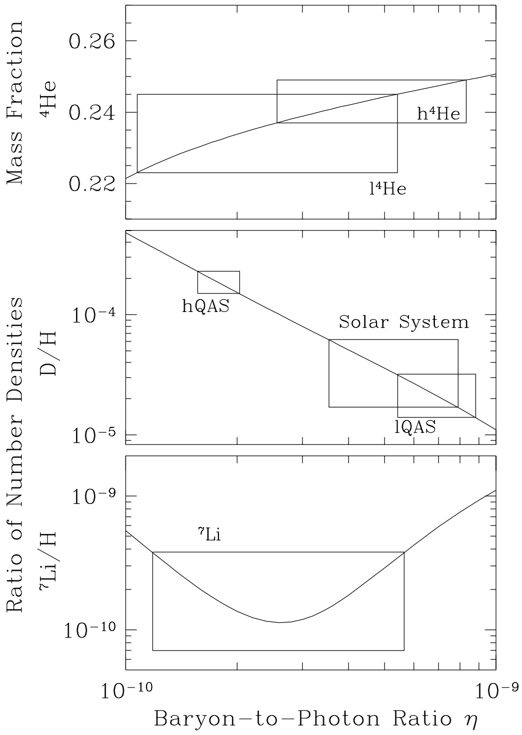

Figure 2.18: Primordial abundances of the light elements as a function of the baryon-to-photon ratio, predicted by a standard Big Bang nucleosynthesis calculation. The boxes indicate some current limits for the primordial abundances inferred from observations. Each box represents a value obtained with a different method and is based on observations of different cosmic regions.

The baryon content of the Universe is still unknown and is one of the most important uncertainties in modern cosmology. By comparing the computed element abundances with those inferred from observations, the theory of BBN can in principle predict this baryonic content. The bad news is that the various limits inferred from observations do not agree. The present-day abundances are observed in a variety of astronomical sites and from these values the primordial abundances must be deduced with different methods. A detailed discussion of the current observational situation is beyond the scope of this article. The boxes in Fig 2.18 indicate some values which can be found in the literature. At the moment it is controversial whether a convincing common range exists for the parameter η, where all the predicted abundances for the light elements lie within the observationally inferred regions.

In view of this somewhat confusing situation it is worthwhile to study variations of the standard theory of BBN outlined above. MPA scientists have been particularly interested in the influence of a putative mass for one of the three neutrinos, the so-called τ neutrino. As described earlier, the expansion rate and therefore the ^{4}He abundance is highly sensitive to the energy density of the primordial plasma. A massive neutrino would contribute differently to the energy density than a massless one, and so the predicted abundances for the light elements change. Including the effects of a massive τ neutrino, Fig. 2.19 presents the results of a BBN calculation using the MPA code. It shows lines of constant calculated abundance for the light elements as the two parameters, the baryon-to-photon ratio and the τ neutrino mass, are varied. For each of the three elements ^{4}He, D, and ^{7}Li a so-called concordance region is marked. These regions represent the combinations of the two parameters, which yield agreement between the computed and the observationally inferred abundances for the element under consideration. In this figure a subset of the observational data shown in Fig. 2.18 has been used. By choosing this specific set of observations we do not want to give the impression that this is the best one. Fig 2.19 is meant as an illustration for the influence of a massive τ neutrino on the primordial abundances of the light elements.

A valid theory has to predict the correct abundances for all three elements with the same set of parameters. Only in the dark shaded areas do all the three concordance regions overlap. In this example, the agreement between theory and observation is not improved relative to the massless case. For some values of the τ neutrino mass there is no η value for which the observed values are predicted by the calculations. In the small mass regime the results of Fig. 2.18 are reproduced. For other possible combinations of the observational data there is no concordance region in the standard scenario, as can be seen in Fig. 2.18. In this case a massive τ neutrino is a possibility to again reach agreement between theory and observations. So far we have only taken into account *stable* τ neutrinos (on the BBN timescale), in a future project we will also investigate the influence of *decaying* massive τ neutrinos on the primordial abundances.

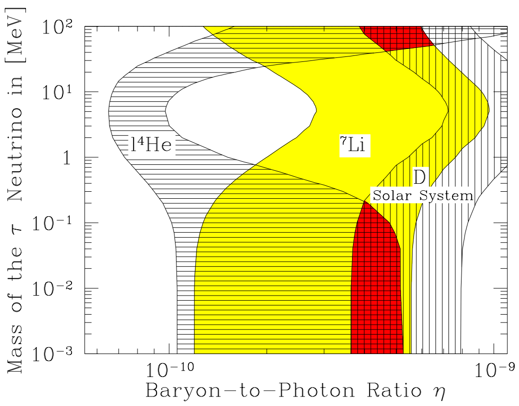

Figure 2.19: Isoabundance contours for the light elements if the τ neutrino is massive. The contours have been drawn for a specific combination of observational data. The concordance regions for η and the τ neutrino mass for each of the three elements are marked. Only combinations of the parameters where all three regions overlap are acceptable (dark shaded regions).

The arguments can be turned around and the results can be used to derive limits on the mass of the τ neutrino, which are tighter than the ones obtained in terrestrial laboratories. In the example presented in Fig. 2.19 the τ neutrino has to be lighter than 0.3 MeV, but could as well be massless. The concordance region in the large mass regime (larger than 40 MeV) is already forbidden by the laboratory limit which rules out a mass larger than 18 MeV. If the cosmological and the terrestrial limits are combined, one can conclude that the τ neutrino has to be lighter than about 0.1 to 1 MeV, depending on the chosen subset of the observational data. There is a another limit, again cosmological: any *stable* neutrino has to be lighter than about 30 eV. A *decaying* neutrino could evade this limit, but would still be constrained by the bounds derived from BBN considerations.

Provided that better observational data become available, BBN can be used as a reliable tool to predict both particle physics parameters like neutrino masses and cosmological parameters like the baryon content of the Universe. (Jan B. Rehm)

3 Research Activities

3.1 Sun and interplanetary matter

R. Wegmann developed new MHD models for the plasma flow around a comet which include now in a self-consistent way all important chemical processes for the water group ions and molecules and a detailed energy balance for the electrons. The agreement between model ion densities and spacecraft observations has improved considerably compared with earlier models. In collaboration with H.U. Schmidt, C.M. Lisse (Goddard), K. Dennerl and J. Englhauser (both MPE) these models have also been used to study the X-ray emission generated by the interaction of hot electrons or heavy solar wind ions with the neutral gas coma of a comet.

Z. Gan-Baruch, working with R.Wegmann, H.U.Schmidt, and A. Eviatar (Tel-Aviv University), continued her work on a two fluid model with pressure anisotropies for the interaction of the solar wind with a comet. She finished her PhD thesis at Tel-Aviv University. A new mechanism for the acceleration of ions along the magnetic field at the bow shock has been detected.

By comparison with MHD-models, H. Rauer (Paris-Meudon), F. Roesler, F. Scherb (both Univ. of Wisconsin), H.U. Schmidt and R. Wegmann explained why observed line profiles of H_2O^+ at comets are asymmetric with a high velocity wing. They discussed the problem of why a large fraction of the water ions escapes detection by ground-based observations.

U. Anzer and P. Heinzel (Astronomical Institute Ondrejov) started a systematic investigation of solar prominence parameters obtained from MHD equilibrium models and NLTE radiative transfer models. They found large differences between the parameters determined with one method and those gained with the other. Differences were found both for individual prominences as well as for the whole sample. The search for possible explanations is still under way.

H. Schlattl has finished his diploma work on solar models (supervisor A. Weiss). Besides transforming the standard MPA stellar evolution code to a high-precision solar model code, he also updated the physics to latest standards (e.g. equation of state, diffusion). A significant improvement in the agreement with observed solar p-mode frequencies was obtained by implementing detailed atmosphere models (J. Bernkopf, Universität München) and a variable mixing-length parameter; for the latter 2-d hydrodynamical models by H.-G. Ludwig were employed to determine adjustable parameter values.

H.U. Schmidt, K. Jahn (Warsaw University Observatory), and R. Schlichenmaier (MPE) continued their investigation of the migration of fluxtubes in a deep penumbra.

N.A. Inogamov (Landau Institute for Theoretical Physics, Chernogolovka) studied the turbulent convective cascades in the convective zone of the Sun, the upper cascade near the surface and the lower cascade near the boundary between the convective and radiative zones. He also investigated high frequency acoustic oscillations at the boundary between chromosphere and upper convective zone.

A. Tkachenko's (Space Research Institute, Moscow) postgraduate work is devoted to investigating the temporal and spectral characteristics of high energy solar flares. While at MPA, he studied the nuclear lines and deuterium synthesis of the May 11, 1990 gamma-ray solar flare.

3.2 Stellar structure and evolution

The study of Asymptotic Giant Branch (AGB) stars in the Magellanic Clouds was continued. M. Groenewegen, in collaboration with J. Blommaert and N. Trams (VILSPA, Spain), A. Zijlstra and J. van Loon (ESO), P. Whitelock (SAAO, South Africa) and L. Waters (Amsterdam, The Netherlands), obtained spectral types of AGB stars in the SMC. A photometric monotoring program of IRAS detected AGB stars in the LMC was finished, and preliminary ISO data on AGB stars in the LMC were obtained. Model fits to the spectral energy distributions of about 15 IRAS detected stars in the LMC with long pulsation periods were performed. It appears that the period-luminosity relations derived for both carbon stars and oxygen-rich stars for periods below 500 days, holds for longer periods as well.

Together with the 3-month visiting student Fenglei Li (University Paris) molecular CO and infrared data of Galactic supergiants were studied. A large variety in mass loss rates and line profiles is found. In many cases the line profiles are very different from those observed in AGB stars. The origin is unclear but points to a complex geometry of the circumstellar material.

M. Groenewegen together with P. Whitelock (SAAO, South-Africa) derived a period-luminosity relation for carbon-rich Miras variables, based on literature data of such variables in the LMC.

M. Groenewegen together with L.B. van den Hoek (University of Amsterdam, The Netherlands) calculated the so-called yields of AGB stars for carbon, oxygen, nitrogen, i.e. the mass per unit initial mass shed to the interstellar medium. These data are important in chemical evolution models of galaxies. This dataset supersedes the work of Renzini and Voli of 1981.

H. Spruit and E. Phinney (Caltech) developed the idea that the cores of red giants corotate with their envelopes, due to magnetic coupling. Non-rotating single white dwarfs are explained naturally in this scenario. Rotating single white dwarfs may be formed in a merging common envelope phase while a significant fraction of pulsars may have received their rotation during the supernova explosion as a by-product of the process that gave them their kick velocities.

In collaboration with B. Freytag (Universität Kiel), M. Steffen (Astrophysikalisches Institut Potsdam), and J. Wagenhuber, H.-G. Ludwig investigated the variation of the mixing-length parameter α in solar-type stars using detailed radiation-hydrodynamics simulations. Independent of observational constraints the functional dependence of α on effective temperature, gravitational acceleration, and chemical composition was derived. Together with M. Salaris these findings were used to calculate evolutionary models free of uncertainties associated with the mixing-length description.

In collaboration with Å Nordlund (NBIfAFG, Copenhagen) the first 3D hydrodynamical model of surface convection in a white dwarf was constructed by H.-G. Ludwig, aiming at a comparison with existing 2D results.

The results of a numerical study of a whole grid of AGB evolutionary sequences, covering all relevant initial masses and metallicities, were collected in a PhD thesis by J. Wagenhuber, supervised by W. Hillebrandt and A. Weiss. Emphasis was laid upon the investigation of the influence of different physical assumptions. It could be shown that in metal-poor low-mass AGB stars even standard treatment of convection can lead to the entrainment of protons in the helium-burning shell which could in turn lead to s-process nucleosynthesis. Those properties of secular AGB evolution which could be shown to be independent of input physics and of the numerical treatment were made available for further research in the form of a software package which was developed in collaboration with M. Groenewegen; in doing so, the influence of free parameters such as the mixing length parameter was determined and taken into consideration in leading order. Also, the impact of a mass loss formula developed by A. Fleischer and T. Arndt (TU Berlin) upon AGB evolution was studied and compared with observations.

Together with A. Weiss and M. Salaris, M. Bartelmann has designed a statistical technique to compare color-magnitude diagrams of globular clusters. This method makes use of the entire two-dimensional information available and is designed to include observational errors. It can be applied to comparing observed clusters with each other in order to find age or metallicity differences, or to comparing observed clusters to theoretically simulated ones in order to determine, e.g., ages or the binary fraction.

Globular cluster ages as derived from stellar evolution models provide a strong lower limit on the age of the Universe. Achim Weiss, M. Salaris and S. Degl'Innocenti started a major project aimed at determining cluster ages using updated stellar models and reliable methods. As a first result they could show that the age of three of the most metal-poor clusters – believed to be the oldest ones as well – is only 12 ± 2 Gyr, contrary to previously quoted numbers, which were as large as 16–18 Gyr. The difference is mostly due to the use of an improved equation of state and a purely theoretical method to determine the horizontal branch luminosity, necessary for obtaining the distance to the cluster. In a follow-up project, ages of more metal-rich halo clusters have been determined. It appears that there is only a very small age-metallicity-relation, such that one can conclude that the whole halo cluster system formed within 2–3 Gyr. In a related project, the agreement between observed and theoretical luminosity functions of globular clusters was examined to investigate earlier claims about discrepancies which could be thought of as indications of WIMPs acting in stars. Such discrepancies were not found; however, it also became evident that present luminosity functions do not help to improve cluster age determinations.

In collaboration with W. Hillebrandt, S. Yamada, H. Suzuki (KEK, Tsukuba, Japan), K. Takahashi and T. Janka, K. Sumiyoshi studied the explosion of neutron stars having a mass just below the minimum mass. Adopting an implicit code by S. Yamada, K. Sumiyoshi investigated the dynamical instability of neutron stars driven by neutron captures and beta decays. The implicit method was shown to be powerful to follow the evolution of static configurations and explosions for a time scale much longer than the hydrodynamical time scale. Instabilities of neutron stars were found to be sensitive to the equation of state of dense matter in non-equilibrium and the beta decay rates, which compete with the hydrodynamical time scale.

The possibility of mixing by shear instabilities in differentially rotating stars was analyzed by W. Hillebrandt by means of numerical experiments. It was shown that, depending on the properties of the flow field, instabilities can occur even if the Richardson-criterion predicts linear stability. Their physical nature is investigated in collaboration with S. Pistinner.

Effects of differential rotation on the early evolution of massive stars have been investigated by J. Fliegner in his thesis work, supervised by N. Langer. Together with K. Venn (Univ.-Sternwarte München), they found the stellar surface boron abundance to be an unambiguous test for rotational mixing. A. Heger, in his thesis work supervised by N. Langer, considered effects of rotation in late evolutionary stages of massive stars. Together with S.E. Woosley (Santa Cruz, USA), they evolved the first models of rotating stars to core collapse. A. Heger and N. Langer have investigated the effects of an optically thick stellar wind on the internal structure of hot stars, and derived a model for the driving of the winds of Wolf-Rayet stars. N. Langer has defined the Ω-limit as a replacement for the Eddington stability limit in rotating massive stars. With G. García-Segura (UNAM, Mexico) and M.-M. Mac Low (MPIA, Heidelberg), N. Langer has performed multi-dimensional hydrodynamic simulations of the evolution of circumstellar matter around massive stars, from their birth until the pre-supernova stage. By considering the winds of rotating stars, they derived a model for the Homunculus-nebula of η Carinae. They applied the same technique to simulate the various shapes observed for planetary nebulae. In collaboration with G. Weigelt, R. Osterbart, K.-H. Hofmann (all MPIfR, Bonn) and Y. Balega (SAO, Russia), N. Langer has analyzed, using the results of diffraction-limited speckle-masking observations, the sub-arc-second structure of proto-planetary nebulae and circumstellar structures of AGB stars and red supergiants. Together with A. Pasquali, C. Leitherer, A. Nota (STScI, Baltimore), and W. Schmutz (ETH, Zürich), N. Langer has investigated the UV spectral properties of Ofpe/WN9 stars from *HST* ultraviolet observations, and derived conclusions about their evolutionary status and the role of rotation in massive stars.

The evolution of rotating massive stars was studied by A. Heger, supervised by N. Langer and in collaboration with J. Fliegner, to determine their influence on the interstellar matter and the structure of the latter at the time of the explosion of type IIa supernovae. Metal-poor massive stars were investigated together with S.E. Woosley (UCSC/Lick Observatory, Santa Cruz) for a possible mechanism for the production of primary ^{14}N. In collaboration with I. Baraffe and L. Jennin (both ENS, Lyon) high-amplitude stellar pulsations found in the most luminous of the evolutionary models were studied.

3.3 Supernovae and nucleosynthesis

In a collaboration of S. Yamada, H.-Th. Janka, and H. Suzuki (KEK, Tsukuba), the neutrino transport in Type II supernovae and protoneutron stars was investigated by numerical simulations with a new solver for the Boltzmann transport equation in spherical symmetry. Close comparison between simulations with the Boltzmann solver and Monte Carlo simulations is underway. It has been found that the Boltzmann solver works well both for emission and absorption dominated situations and for scattering dominated static background. The code is intended to be used for studying effects of different neutrino reactions on the energy spectra of neutrinos to be observed for a next nearby supernova by detectors like Superkamiokande.

In his PhD Thesis, W. Keil, supervised by H.-Th. Janka, performed the first two-dimensional, hydrodynamic simulations which followed the neutrino cooling of newly formed rotating and non-rotating neutron stars in supernovae for a period of more than one second. The simulations were done with a version of the PPM code *Prometheus* that allowed for different angular resolution and different time stepping in different regions of the star, which used a state-of-the-art description of the neutrino transport and nuclear equation of state, and which included general relativistic corrections to the gravitational potential. It was shown that within about one second, Ledoux convection can involve the whole neutron star and can significantly change the neutrino emission from supernovae with potentially important consequences for the explosion mechanism and heavy element nucleosynthesis. A theoretical understanding of the convective processes requires a detailed discussion of the properties of the nuclear equation of state and of the interaction between diffusive neutrino transport and convective transport of lepton number and energy.

In collaboration with S.E. Woosley (UCSC/Lick Observatory, Santa Cruz) and W. Hillebrandt, J.C. Niemeyer analyzed various mechanisms for thermonuclear explosions of Chandrasekhar mass white dwarfs that give rise to Type Ia supernovae (SNe Ia). In the case of a pure turbulent deflagration, it was found that a healthy explosion is produced if the flame front moves with the "Sharp-Wheeler" growth rate of nonlinear Rayleigh-Taylor mixing regions. An examination of the conditions for delayed detonations in SNe Ia showed that these events might take place during the transition of the combustion front from the "flamelet" to the "distributed burning" regime.

A cellular automaton model for turbulent interface propagation was developed by J.C. Niemeyer. It was used to study the influence of various probability distributions of the turbulent velocity field on the turbulent flame speed, and demonstrated that rare peaks of the flame speed cannot be responsible for delayed detonations in Type Ia supernovae.

A time-independent NLTE modelling of the early-time spectra of thermonuclear Type Ia supernovae was the subject of the Ph.D. thesis of M. Duschinger, supervised by A. Pauldrach (Sternwarte München) and E. Müller. The thesis work suggests that a correct modelling of the Compton downscattering of the gamma-rays produced by radioactive nickel and iron nuclei synthesized in the supernova event is crucial for reproducing observed Type Ia spectra.

P. Ruiz-Lapuente examined the issue of the progenitors of Type Ib/Ic supernovae. For this purpose spectral calculations of the hydrodynamic models proposed by Woosley, Langer and Weaver (1994) were done. Calculation of bolometric light curves, monochromatic light curves and overall conclusions are on their way.

P. Ruiz-Lapuente and A. Burkert (MPIA) studied the effect of supernovae modulating the star formation history in dwarf spheroidal galaxies. Those galaxies display long periods of inactivity between subsequent star formation epochs. It was proposed that such periods of "dormancy" can result from the action of Type Ia supernovae heating the interstellar medium and preventing the formation of molecular clouds. The predicted periods of "inactivity" in star formation agree well with the observed ones, and the [Fe/H] difference between the early and late population is well accounted for.

P. Ruiz-Lapuente, A. Burkert, and P. Patsis (MPIA) were exploring the age of Type Ia supernovae from their location in spiral galaxies. In collaboration with R. Canal (U. Barcelona) they kept exploring possible scenarios for those SNe and predicted their occurrence in different galaxy types.

The gravitational radiation emitted during non-axisymmetric rotational core collapse and by merging neutron stars was the subject of the diploma work of M. Rampp, supervised by E. Müller and M. Ruffert. Contrary to common expectations, the occurrence of tri-axial dynamical instabilities during rotational core collapse did not lead to a significant enhancement of the emission of gravitational radiation compared to axisymmetric models. E. Müller and H.-Th. Janka have evaluated their two- and three-dimensional supernova models for the characteristics of the gravitational wave emission (luminosities, spectra, waveforms) caused by convective activity near the neutrinosphere, by large-scale convective overturn in the neutrino-heated postshock region, and by the associated anisotropic emission of neutrinos. These signals should be measurable with the next generation of gravitational wave detectors presently under construction (LIGO, VIRGO, GEO600), if the supernova occurs in our Galaxy.

F. Meyer suggested a solution to the problem how the outer rings of SN 1987A formed. In this model pressure gradients arise from density gradients in an originally cool red supergiant wind by ionization and heating during a subsequent blue supergiant evolutionary phase. These induce hydrodynamic motions that naturally lead to the formation of rings of narrow width and high density contrast.

T. Plewa and M. Różyczka (Nicolaus Copernicus Centre, Warsaw) discussed some typical problems related to numerical hydrodynamics of a dense interstellar medium. A newly developed hydrodynamical code based on adaptive mesh refinement techniques was presented and applied to simulate the evolution of a supernova remnant in a high-density medium. Advantages and disadvantages of this new approach in comparison to commonly used hydrodynamical methods were briefly discussed.

Together with D. Hartmann (Clemson, USA) and others, N. Langer developed a model for the peculiar supernova remnant Cas A, which can simultaneously account for very different observational constraints.

The interaction of supernovae with the interstellar medium (ISM) was investigated in the diploma thesis of M. Gaudlitz, supervised by M. Steinmetz and E. Müller. This work was continued in a common project between K. Thornton, J.W. Truran (both Univ. of Chicago), H.-Th. Janka, M. Gaudlitz, and M. Steinmetz (UC Berkeley) who investigated supernova explosions concerning their input of kinetic and thermal energy to their environment. To this end, one-dimensional hydrodynamic simulations of the evolution of supernova remnants were performed for different explosion energies and for different densities and metallicities of the interstellar medium. Over a large portion of the parameter space, the scaling with the ISM density and metallicity can be well approximated by power–laws. Two dimensional simulations, however, show that Rayleigh-Taylor instabilities can occur in the supernova remnants. These instabilities give rise to an enhanced mixing between the metal-enriched supernovae ejecta and the interstellar medium.

H.-Th. Janka and W. Keil, together with T.W. Baumgarte, S.A. Teukolsky (Cornell Univ., Ithaca), and S.L. Shapiro (Center for Astrophysics and Relativity, Ithaca), have studied the delayed collapse of hot neutron stars to black holes, which can occur for sufficiently massive proto-neutron stars when the supranuclear equation of state softens due to the formation of new hadronic degrees of freedom (like hyperons or kaons) in the process of the increasing neutronization of the star. The fully general relativistic, one-dimensional hydrodynamic simulations followed the last stages of the collapse until the surface of the star had reached the event horizon.

K. Sumiyoshi, W. Hillebrandt and S. Yamada have started to compute the dynamical evolution and explosion of neutron stars at their minimum stable mass by means of an implicit hydrodynamical code and with up-to-date nuclear input physics. One aim is to follow the decompression of cold neutron star matter as a possible site for r-process nucleosynthesis.

H.-Th. Janka and K. Takahashi (TU München) have continued their analytical studies of the properties of neutrino-driven winds from newly formed neutron stars or merging binary neutron stars, and have discussed their results concerning the implications for the nucleosynthesis of heavy elements.

The nucleosynthesis of rotating massive stars has been studied by N. Langer J. Fliegner, and A. Heger together with S.E. Woosley (Santa Cruz, USA). In metal-poor stars, primary production of both nitrogen isotopes and high neutron fluxes have been found due to rotationally induced mixing processes during late burning phases. N. Langer investigated the yields of all stable oxygen isotopes in massive stars and determined the uncertainties of these yields due to uncertain physics in stellar evolution and nucleosynthesis calculations. N. Langer and S.E. Woosley (Santa Cruz, USA) investigated the importance of the various types of supernova progenitors for galactic nucleosynthesis and the chemical evolution of galaxies.

M.M. Sharma and W. Hillebrandt, in collaboration with J. Meng, G.A. Lalazissis and P. Ring (Technische Universität, München), have continued their calculations of nuclear properties near the neutron-drip line based on the relativistic mean field theory. In particular, masses and neutron separation energies for very neutron-rich Ni-isotopes were computed. Good agreement with experimental data was found whenever they were available.

3.4 Close binaries and accretion

Dwarf nova outbursts were studied in the framework of the disk-instability model by K. Ludwig in a thesis, supervised by F. Meyer. A new numerical code was developed that allows to follow simultaneously vertical thermal and radial viscous evolution of accretion disks. This is essential for determining formation, structure, and propagation of transition fronts which are a fundamental constituent of the dwarf nova cycle. The simulations of dwarf nova outbursts with this code give a good agreement of theoretical light curves with the observations.

E. Meyer-Hofmeister and B.F. Liu investigated the effect of new opacities on accretion disk structure. B.F. Liu computed the evaporation of the inner cool disk in dwarf nova systems during quiescence. The resulting changes of the distribution of mass in the disk have significant consequences on the following dwarf nova outburst.

Y. Lyubarskiy (Institute of Radio Astronomy, Kharkiv) studied evaporation of accretion disks and transformation of the standard cold disks into advection dominated ones. It was shown that electron thermal conductivity is quite efficient in coronae above cold accretion disks and may provide such a transformation.

R. Stehle finished development of a hydrodynamical and a magnetohydrodynamical code for accretion disks. The hydrocode allows for the vertical expansion and contraction of the disk, and has been applied to study the tidal excitation of nonlinear wave modes. With the magnetohydrodynamical code a global nonlinear instability has been found operating in strongly magnetic disks which redistributes angular momentum and produces a spreading similar to that in a viscous disk. H. Spruit begun work on the hard X-ray spectra of accreting black holes and obtained first results for cool disks embedded in a hot virialized flow. H. Spruit, T. Foglizzo and R. Stehle finished work on collimation of jets from accretion disks by the poloidal magnetic field distribution of the disks, and found that this is a more likely process than collimation by 'hoop stresses' (toroidal collimation). H. Spruit and R. Rutten (ING, La Palma) obtained spectra of high spectral and temporal resolution of the eclipsing cataclysmic variables HS 1804+67 and WZ Sge at the WHT (La Palma) as part of a program to study the outer regions of accretion disks.

H.-C. Thomas together with K. Reinsch (Universitätssternwarte Göttingen) analyzed photometric and spectroscopic observations of the new AM Herculis binary AX J2315-592 and showed that the emission lines in the spectra have two components which originate in the accretion stream and on the heated surface of the secondary companion, while the continuum radiation is dominated by optically thin cyclotron emission. In collaboration with K. Beuermann (Universitätssternwarte Göttingen) and his group H.-C. Thomas continued his investigations of several ROSAT discovered polars and supersoft X-ray sources. Spectroscopic and photometric observations of the black hole candidate GRO 1655-40 together with R. Hessman and A. van Teeseling (Universitätssternwarte Göttingen) allowed to refine the binary period and to estimate the distance from the interstellar lines of Na D. The cooling of the white dwarf in the dwarf nova EK TrA after an outburst was studied by H.-C. Thomas with B. Gänsicke and K. Beuermann (Universitätssternwarte Göttingen) through the analysis of IUE and optical spectra.

F. Meyer, E. Meyer-Hofmeister and S. Schandl investigated newly available light curves of supersoft X-ray sources. Using the computer code developed for the simulation of the CAL 87 light curve it was found that these accretion disks in different sources, which have as common features the strong irradiation from the white dwarf heated by the nuclear burning and the high mass overflow rate, all have an elevated outer rim. Taking this into account F. Meyer and E. Meyer-Hofmeister interpreted long-term changes of the Galactic source RX J0019.8. They also studied with M. Kato (Keio Univ., Yokohama) and I.Hachisu (Univ. of Tokyo) the application of radiation pressure driven winds during the nova decay phase to supersoft sources. F. Meyer and E. Meyer-Hofmeister investigated the changes between high and low states of RX J0513.9 which might be an observation important for the understanding of supersoft X-ray sources. S. Schandl worked together with H. Barwig and T. Will (Univ. München) on the interpretation of their observational data of RX J0019.8.

H. Ritter, in collaboration with A. King (University of Leicester), U. Kolb (University of Leicester) and J. Frank (LSU, Baton Rouge), carried out a global analysis of mass transfer cycles in semi–detached compact binary systems where mass transfer is driven by either nuclear evolution of the donor star or by loss of orbital angular momentum. It could be shown that mass transfer can evolve through a limit cycle only if the donor star's change of radius due to thermal relaxation depends explicitly on the instantaneous mass transfer rate. Application of this formalism to systems in which the donor star is a giant shows that such systems are extremely vulnerable to irradiation–driven, large amplitude mass tansfer cycles. Furthermore, an approximate analytic solution of the equations governing the mass transfer cycles in the limit of large amplitudes could be given. It could also be shown that intermittent irradiation has a stabilizing effect. Furthermore, the occurrence of transient, dwarf nova–like mass accretion in long–period, low–mass X–ray binaries containing a giant donor star was investigated. It could be shown that despite irradiation of the accretion disk, transient behaviour is the rule among such systems systems. Stable, persistent accretion is expected only in systems where mass transfer is quite close to thermal instability, i.e. if the donor star is sufficiently massive.

H. Ritter together with J.–M. Hameury (University of Strasbourg) computed the emerging stellar flux of an irradiated photosphere as a function of the irradiating flux over a rather wide grid of effective temperature and surface gravity. These data were then used to derive a generalized Stefan–Boltzmann law as an outer boundary condition for computing the evolution of irradiated stars. Numerical results were derived for the special case of a Roche lobe–filling star illuminated by a point source.

F. Meyer showed that an accretion disk containing a vertical magnetic field of sufficient strength becomes unstable to tilting out of the symmetry plane and precession. This is suggested to cause the dwarf nova oscillations and the precession in superluminal galactic black-hole candidate systems.

M. Gilfanov, in collaboration with M. Revnivtsev (Space Research Institute, Moscow) E. Churazov and R. Sunyaev, studied properties of X-ray emission from X-ray bursters. Using the archival data of EXOSAT, ROSAT, GINGA, EINSTEIN and GRANAT observatories it was demonstrated that X-ray bursters show bimodal spectral behavior similar to that observed for black hole binaries. The transition from the optically thick regime to the optically thin one occurs nearly simultaneously for the boundary layer and the accretion disk. The transition occurs at approximately the same luminosity level as for black hole binaries although the mass of the compact object might differ by an order of magnitude. In collaboration between S. Trudolyubov (Space Research Institute, Moscow) E. Churazov and R. Sunyaev it was shown that the most likely mechanism for GX339-4 outbursts are radiation driven instabilities in the low mass binary system. M. Gilfanov, in collaboration with E. Churazov and R. Sunyaev, studied the spectral variability of black hole binaries. The observations with ASCA and GRANAT/SIGMA show that the outer, optically thick part of the accretion flow beyond $\sim 15R_g$ could contribute a non-negligible fraction to the X–ray luminosity in the low spectral state. Increase of the mass accretion rate leads to an increase of the temperature and luminosity of this outer optically thick part of the accretion flow and to a decrease of its inner radius which probably approaches $\sim 3R_g$ in the soft spectral state. Along with that, a change of the characteristics of the hard spectral component is observed: an increase of the slope of Comptonized radiation, a decrease of the electron temperature and a decrease of the level of aperiodic short term variability.

S. Sazonov (Space Research Institute, Moscow) continued work on his thesis under the supervision of R. Sunyaev. An analysis of joint observations of the Galactic superluminal-jet source GRO 1655-40 by three different high-energy astrophysics experiments CGRO/BATSE, GRANAT/WATCH and ASCA was carried out in collaboration with scientists from the corresponding teams. The spectral and temporal information obtained in this study are important for understanding the physics involved both in galactic black-hole and extragalactic superluminal radio-jet systems.

S. Sazonov also analyzed GRANAT/WATCH observations of the BATSE bursting pulsar GRO J1744-28. It was shown that at its maximum the persistent luminosity of the source was highly super-Eddington. A theoretical consideration of the experimental results based on the accretion column model by Basko and Sunyaev is in progress.

N. Inogamov carried out a stability analysis of the radiative cooling process in the magnetized plasma column in the polar region of a magnetized compact star. This research was suggested by R. Sunyaev in connection with the recent discovery of an X-ray source of a new type, the bursting pulsar GRO J1744-28.

S. Trudolyubov (Space Research Institute, Moscow), under the supervision of R. Sunyaev, was finishing his graduate research on the low states of black hole candidates, based on the results obtained by GRANAT/SIGMA, ASCA, ROSAT and other X-ray instruments.

V.V. Zheleznyakov (Institute of Applied Physics, Nizhny Novgorod) worked on the problem of radiation transfer in strong magnetic fields of white dwarfs and neutron stars including the interpretation of the observed optical and X-ray spectra of these stars.

S. Grebenev studied X-ray properties of disk accreting black holes and new black hole candidates in the Galactic center field.

N. Sakhibullin (Dept. of Astron., Kazan State University/Engelgardt Astron. Obs.) discussed different aspects of the interaction of X-ray radiation with the atmospheres of normal stars with R. Sunyaev, using the achievements gained at Kazan State University by detailed numerical calculations. The model X-ray illuminated atmospheres allow to interpret the spectra of close binaries in more detail than before.

N. Shakura (Sternberg Astronomical Institute of Moscow University) together with R. Sunyaev investigated the turbulent viscosity in the boundary layer of accretion disks. An expression for the coefficient of the turbulent viscosity in the boundary layer was found using Prandtl's well known empiric law. It was shown that the restrictions imposed by the magnitude of the sound velocity on the velocity amplitudes of the turbulent motion result in reducing the turbulent mixing length down to values significantly less than the width of the boundary layer.

M. Ruffert and H.-Th. Janka, in collaboration with G. Schäfer (Univ. Jena), have continued their three-dimensional hydrodynamic simulations of merging neutron stars. H.-Th. Janka and M. Ruffert have evaluated these models for the neutrino emission during the merging and for the efficiency of neutrino-antineutrino annihilation into electron-positron pairs in the surroundings of the merger, and have discussed implications of their results for models to explain the cosmic origin of gamma-ray bursts observed by the Compton Gamma Ray Observatory. Simple analytical estimates were employed to estimate the neutrino emission properties of the thick accretion torus that develops around the central black hole forming only milliseconds after the merging. First steps were taken to follow the evolution of this torus by hydrodynamic simulations. Together with K. Takahashi (TU München) aspects of the synthesis of heavy elements in the dynamically ejected material and in the neutrino-heated ejecta of such mergers were investigated. M. Ruffert, M. Rampp, and H.-Th. Janka have extended the numerical simulations to the merging of neutron stars that are described as polytropes. In order to explore the effects of the numerical scheme and of the treatment of the gravitational wave backreaction, they have compared the properties of the associated gravitational wave emission with published results obtained with different codes. The polytropic models were also compared with the merger simulations of M. Ruffert and H.-Th. Janka, who made use of a microphysical description of the nuclear equation of state and of neutrino effects.

Hydrodynamic simulations of the classic Bondi-Hoyle-Lyttleton accretion surprisingly yield unstable flow patterns and fluctuating accretion rates. The behavior is qualitatively different in 2D and 3D calculations and depends critically on sufficiently high numerical resolution. Present investigations by M. Ruffert using a multiply nested refined grid code, aim at finding and describing dependencies of this complex behaviour on physical parameters, e.g. Mach number, accretor size, adiabatic index, and gradients within the incoming flow. It was shown that when velocity gradients exist in the incoming flow, some 3% to 70 % of the angular momentum in the accretion cylinder are actually accreted.

U. Anzer, G. Börner, A. Feldmeier (University Observatory, Munich) and F. Nagase (ISAS, Japan) continued their investigation of the effects of X-ray ionisation on wind accretion flows.

U. Anzer, G. Börner, T. Matsuda (Kobe University, Japan), E. Shima (Kawasaki Heavy Industries, Japan) and H. Boffin (University of Cardiff, UK) studied two-dimensional models for wind accretion. They investigated how the results depend on the size of the inner boundary. They also began a systematic comparison of models calculated with finite difference schemes and those obtained from smooth particle hydrodynamics.

A. Kercek, in a thesis supervised by W. Hillebrandt, is performing 3-dimensional numerical simulations of thermo-nuclear burning of hydrogen-rich matter accreted onto a white dwarf. The aim of this study is to explain the mixing of carbon and oxygen into the hydrogen layer which is observed in classical nova outbursts, and to investigate possible asymmetries.

E. Müller and W. Brinkmann (MPE) have continued a numerical study of the precessing twin jets of SS433 with the aim to try to explain the observed X-ray emission of the 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 jets starting at a distance of 0.01 light years from the source and covering the evolution of eight 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 $\approx 10^4$) are encountered which heat the interstellar gas to very high temperatures (several 10^{10} K).

In his thesis work guided by N. Langer, H. Braun has investigated the effects of binary-specific internal mixing processes and nucleosynthesis of accreting massive stars; thereby they have obtained the first numerical models for accreting stars including time-dependent thermohaline mixing.

3.5 The Galaxy, external galaxies, and Active Galactic Nuclei

Together with Y.-N. Chin, C. Henkel (both MPIfR, Bonn), E.B. Churchwell (Madison, USA), and R. Mauersberger (Tucson, USA), N. Langer has investigated the isotopic sulfur abundance ratios in the Galaxy; the first detection of a ^{36}S-bearing molecule in interstellar space allowed conclusions about the s-process nucleosynthesis in stars.

The long term evolution of powerful axisymmetric relativistic jets has been simulated by J.M. Marti (Univ. Valencia, Spain), E. Müller and T. Plewa using the Adaptive Mesh Refinement technique. The latter technique allows one to both resolve fine details of the flow and to cover a large computational domain of 220 by 85 (perpendicular to the symmetry axis) initial jet radii. The initial data were chosen to represent a powerful jet with a beam kinetic power of 10^{47} erg/s when scaled to a jet radius $R_b = 0.35$ kpc and and a density of the ambient medium of $\rho_b = 10^{-26}$g/cm^3. The simulations show that the long term evolution of a mildly–relativistic (beam flow Lorentz factor 6.0), highly–supersonic (beam Mach number 9.0), light jet (beam proper rest-mass density 0.0034 ρ_b) reproduces some properties (hot spot pressure, hot spot advance speed, lobe inflation) observed in powerful extragalactic radio sources. A hot spot advance speed of about 5% of the speed of light is obtained after the deceleration phase occurring at early times in the source evolution. The beam flow is decelerated at internal shocks, which also cause the beam broadening that leads to a deceleration of the jet.

T. Plewa, G. García-Segura (UNAM) and J. Franco (UNAM) presented a model describing the interaction of massive stars with their parental molecular clouds. A summary of the dynamical evolution of HII regions and wind-driven bubbles in high-pressure cloud cores was given. It has been demonstrated that both ultracompact HII regions and ultracompact wind-driven bubbles can reach pressure equilibrium with their surrounding medium. The structures stall their expansion and become static and, as long as the ionization sources and the ambient densities remain about constant, the resulting regions are stable and long lived. For cases with negative density gradients, and depending on the density distribution, some regions never reach the static equilibrium condition. For power-law density stratifications, $\rho \propto r^{-w}$, the properties of the evolution depend on a critical exponent, w_{crit}, above which the ionization front cannot be slowed down by recombinations or new ionizations, and the cloud becomes fully ionized. This critical exponent is $w_{crit} = 3/2$ during the expansion phase. For $w > 3/2$ the gas expands supersonically into the surrounding ionized medium, and there are two regimes separated by $w = 3$. For $3/2 < w \leq 3$, the slow regime, the inner region drives a weak shock moving with almost constant velocity through the cloud. For $w > 3$, the fast regime, the shock becomes strong and accelerates with time.

T. Plewa in collaboration with J. Franco (UNAM) and G. García-Segura (UNAM) determined the main features in the evolution of the gas pressure in star forming regions, from the formation of the parental cloud to the moment when the region is pressurized by interacting stellar winds. The main processes for cloud destruction and the self-limiting properties of star formation were given. It was suggested that the high star forming efficiency in nuclear starbursts can be a consequence of the high gas pressures typical for the central regions of massive stellar clusters.

D.A. Varshalovich (Department of Theoretical Astrophysics, A.F. Ioffe Institute of Physics and Technology, St.-Petersburg) investigated the possibility of observing the 85 μm Line of the ortho-para H_2 transition. The fluxes in the 85 μm emission line corresponding to the ortho-para conversion of H_2 - molecules in the ground state, as well as the fluxes in the rotational lines of 28.2 and 17.0 μm were estimated for the Giant Molecular Clouds OMC1, OMC2, Sgr B2, and other objects. The possibility of observation of these lines with the ESA FIRST facilities was analysed.

S. Trudolyubov and R. Sunyaev studied some aspects of the accretion processes going on in Active Galactic Nuclei.

The origin of gamma-ray bursts was further constrained by statistical studies of the spatial distribution of the BATSE 3B data set in a collaboration of M. Tegmark with D. Hartmann (Clemsen), M. Briggs and C. Meegan (Huntsville) and M. Hakkila (Mankato). The extreme isotropy on all angular scales revealed by a spherical harmonic analysis excludes many models with a Galactic halo origin, and rules out a large class of models where gamma-ray bursts repeat.

M. Gilfanov and R. Sunyaev derived constraints on the amount of neutral gas around the hard Galactic center source 1E1740.7–2942, using ASCA X–ray observations of this source in 1993. Lack of emission from the source in the iron fluorescent line at 6.4 keV does not support the assumption that the source is located in the very center of a dense molecular cloud, as was anticipated on the basis of radio data.

S. Grebenev (Space Research Institute, Moscow) investigated the formation and observational appearance of HII regions around bright Galactic X-ray sources.

Archived ROSAT X-ray observations for 26 bright Seyfert galaxies were analyzed by H. Arp and H.-D. Radecke. It was found that a minimum of 46 bright X-ray sources were in excess around the Seyferts with a significance of 7.4 sigma. The X-ray sources tended to be paired across the Seyferts and 12 Seyferts were found with 21 pairs of X-ray sources which were either quasars or blue stellar objects which were candidates for quasars.

J. Schäfer continued calculations of two-component fits of FIRAS-COBE spectra measured close to the Galactic plane.

3.6 Gravitational lensing

Together with B. Jain and J. Villumsen, R. Moessner studied the effect of magnification bias due to lensing by large-scale structure on the angular correlation function of faint galaxies, using the full nonlinear evolution of the power spectrum. Assuming time-independent bias, they found that lensing changes the ratio of the correlation functions for red and blue galaxy samples with mean redshifts between 1 and 2 by a factor of about 1.2 to 2, depending on the cosmological parameters Ω_0 and Ω_Λ and the relative bias of the samples.

Together with R. Perna and A. Loeb (Harvard-Smithsonian Center for Astrophysics), M. Bartelmann studied the influence of dust in spiral lenses on the inferred density of neutral hydrogen in these galaxies. The simultaneous effect of dust obscuration and lensing magnification was taken into account.

C.S. Kochanek (Harvard-Smithsonian Center for Astrophysics), T.S. Kolatt (University of California at Santa Cruz) and M. Bartelmann investigated how quadruply imaged radio quasars can be used to infer the proper motion of the lensing galaxies. Besides measuring the proper motion of individual galaxies at high redshift, this approach allows to infer whether the peculiar motions exhibit the same dipole as observed in the cosmic microwave background radiation.

The lensing-induced cross-correlation function between distant quasars and foreground galaxies was studied in arbitrary Friedmann cosmologies with linear and fully non-linear density-perturbation power spectra by K. Dolag in his Diploma thesis, supervised by M. Bartelmann. The influence of the cosmic parameters was studied in detail, and it was shown in particular that non-linear effects increase the correlation function by an order of magnitude on small angular scales.

M. Bartelmann studied the strong-lensing properties of a universal dark-matter halo profile which was recently suggested by Navarro et al. It was shown that this profile necessarily produces radial and tangential arcs despite its central density singularity, and it was described how the parameters of observed clusters can be derived in cases when a radial and a tangential arc is present.

With T.S. Kolatt (University of California, Santa Cruz), M. Bartelmann studied how the three-dimensional structure of galaxy clusters can be determined by combining X-ray and weak-lensing observations. This method uses the fact that the X-ray emission and the weak lensing effect both measure projections of the Newtonian potential of clusters. It can also be used to measure gas fractions in galaxy clusters with higher accuracy.

As part of her dissertation work, S. Seitz has presented a detailed investigation of the gravitational lens-induced QSO-galaxy associations which have been detected. In contrast to previous work the observational biases which prevent the detection of faint galaxies near bright QSOs where accounted for, microlensing was explicitly considered, as well as the influence of the cosmological model. Predictions of the angular dependence of the galaxy overdensity and the redshift distribution of QSOs and galaxies in associations were presented.

The previously developed methods for the reconstruction of the mass density in clusters of galaxies via weak gravitational lensing were applied to several clusters. Using *Hubble Space Telescope* data and high-quality data from CFHT, S. Seitz, C. Seitz, Y. Mellier, B. Fort (both IAP) and P. Schneider have obtained a detailed mass map of the cluster Cl0024+16; in particular it has been shown that the tidal gravitational field obtained from both data sets using the ellipticity of faint galaxies are in very good mutual agreement and that the resolution of this method is capable of resolving the mass in the center of the cluster. S. Seitz, R. Bender and R. Saglia (both USM) have shown from WFPC2 images obtained with the HST that the 'most actively star forming galaxy' cB58 in the cluster MS1512 is in fact a gravitational arc and thus highly magnified. Although the value of the magnification cannot be determined accurately, several detailed models were explored, and the star-formation rate is considerably lower than has been obtained without employing the lensing nature of this system. As part of her dissertation, S. Seitz has developed and thoroughly tested a new Maximum Likelihood method for cluster mass reconstructions, generalizing an earlier method by considering the observed image ellipticities directly, not their smoothed version. It uses a Maximum Entropy regularization with adaptive prior and performs considerably better than earlier reconstruction techniques; in particular, narrow mass peaks can be resolved since the resolution of this method adapts to the local signal of the data.

The shear field obtained from the images of high-redshift galaxies can be used not only to determine the mass of known clusters, but also to discover mass concentrations from their gravitational action alone. P. Schneider has shown that by defining an appropriate filter function, the shear field convolved with that filter produces a map whose peaks signify the presence of a mass concentration. The statistical significance of such peaks is readily quantified which promises this method to be able to define a mass-selected sample of (dark) halos, with velocity dispersion in excess of $\sigma_v \sim 600\,\mathrm{km/s}$. A generalization of this method has been obtained by P. Schneider and M. Bartelmann. By choosing appropriate filter functions, the mass multipoles of matter distributions can be measured directly from the ellipticity of background galaxies. This method was tested on simulated cluster mass profiles and shown to yield fairly accurate estimates of the quadrupole tensor of their mass.

Together with B. Fort and Y. Mellier (both IAP), B. Jain, P. Schneider and S. Seitz have reanalyzed the shear around three high-redshift radio QSOs. Using several statistical tests, and a careful analysis of the variation of the point-spread function across the field, they have shown that the shear is highly statistically significant in at least one of these fields. The strongest shear known around a QSO was found by S. Seitz, B. Fort (IAP), S. D'Odorico (ESO) and others. This high-redshift QSO BR1202−0725 (at $z = 4.7$) appears to be significantly magnified by gravitational light deflection caused by foreground material, and at the 'center' of the shear field a concentration of galaxies is seen.

L. Van Waerbeke (Toulouse), Y. Mellier (IAP), P. Schneider, B. Fort (IAP) and G. Mathez (Toulouse) put foreward the idea that not only the images of identifiable isolated galaxies are sheared by tidal gravitational forces, but also the extragalactic background light if it stems from (unresolved) high-redshift galaxies. This effect has been quantified by the anisotropy of the auto-correlation function of the background light. This new method for measuring shear has been extensively tested on synthetic data and applied to the shear field around the cluster Cl0024+16 and the multiple QSO 2345+007. To clarify whether the double QSO2345+007 is gravitationally lensed or a binary QSO, deep VLA imaging of this system was performed by A.R. Patnaik (MPIfR), P. Schneider and R. Narayan (CfA). Unfortunately, the QSO is so faint at radio frequencies that only the A component has been detected. Given the flux of this image and the flux ratio as obtained from optical images, the B component should be too weak to be detected significantly. However, the binary QSO hypothesis cannot be ruled out from these results.

The apparently large number of close pairs of QSOs with different redshifts was statistically investigated by G. Burbidge (UCSD), F. Hoyle (Dorset), and P. Schneider, and an explanation for the statistically significant overabundance of such pairs was put forward in terms of magnification by gravitational light deflection.

S. Mao studied gravitational microlensing in our local group. With B. Paczyński (Princeton), using Monte Carlo simulations, it was found that more than one hundred microlensing events have to be identified before a reliable determination of the mass function can be made. On the other hand, the high optical depth observed (which, to first order, is independent of the mass function) already provides strong constraints on the total mass, axis ratio and orientation of the bar in the Galaxy. This was the conclusion reached in a study with H.S. Zhao. ith D. Lennon, M. Fuhrmann, T. Gehren (Universitäts-Sternwarte, Munich), the first spectroscopic observations have been carried out for a binary lensing event which was undergoing a high magnification caustic crossing. The study yielded the most detailed information about the lensed source to date so far.

With U. Seljak (CfA), B. Jain computed the effects of weak lensing by large scale structure in inducing correlated ellipticities in the images of high-redshift galaxies. The 2-point ellipticity correlation was predicted for a variety of cosmological models. Its dependence on angular scale and on cosmolgical parameters was explored, taking into account nonlinear effects which enhance the signal on angular scales of a few arcminutes.

J. Villumsen, W. Freudling (ESO) and L. da Costa (ESO) investigated the two-point correlation function of galaxies in the Hubble Deep Field. Correlations were detected for galaxies as faint as $R = 29$. In addition, the effect of magnification bias from lensing has been analyzed, but found to be too small to be detectable in the HDF.

3.7 Clusters of galaxies, large scale structure, and galaxy formation

Using high resolution N-body simulations, G. Tormen, F. Bouchet (IAP, Paris) and S. White (MPA) have studied the density and velocity profiles of dark matter halos in rich galaxy clusters. In follow-up work, G. Tormen has studied in more detail the infall of halos onto the main cluster progenitor during the process of cluster formation. He has found that infall of satellites onto the main cluster is very anisotropic, and that such anisotropy is to a large extent responsible for the shape and orientation of the final cluster, and of its velocity ellipsoid. He has also found that, in lower mass clusters, a higher fraction of the final virial mass is provided by small, dense satellites. These sink to the centre of the parent cluster and so enhance its central density. This mechanism is partially responsible for the fact that lower mass clusters have a steeper dark matter density profile than bigger clusters.

In collaboration with M. Gilfanov, W. Forman (SAO/CFA, Cambridge) and C. Jones (SAO/CFA, Cambridge), E. Churazov developed methods for reconstruction of two-dimensional maps of the gas temperature distribution in clusters of galaxies (using ASCA data). Application of the methods to the brightest cooling flow clusters have demonstrated that along with a prominent drop of the temperature in the central region moderate (± 25%) asymmetrical variations of the temperature are present in Perseus and Centaurus clusters, which can be interpreted as evidence for moderate merger activity.

Observational selection effects in constructing catalogues of galaxy clusters were studied by M. van Haarlem, C.S. Frenk (both Durham) and S.D.M. White using large cosmological N-body simulations. This work demonstrated that many rich clusters selected by traditional techniques are expected to be significantly contaminated as a result of projection effects, and that such problems are expected to be particularly bad for distant systems. Projection effects are often difficult to identify from the accessible observational information and are likely to produce a spurious "tail" of clusters with anomalously high apparent velocity dispersions.

Together with J.F. Navarro (U Arizona) and C.S. Frenk (Durham) S.D.M. White has continued to study the density profiles of the dark halos which form by hierarchical clustering from an initially gaussian field of density fluctuations. By carrying through a large programme of simulations of individual objects they were able to show that the shape predicted for the density profile is independent of the mass of the object, of the power spectrum of initial density fluctuations, and of the global cosmological parameters, Ω, Λ and H_0. Furthermore, the characteristic density of an object of any given mass turns out to be proportional to the density of the universe at the time when typical objects of that mass were forming. The universal profile does not show a constant density central core, but rather a cusp-like central behaviour with density inversely proportional to distance from the centre.

In his PhD thesis, A. Huss investigated the formation of galaxy clusters in various cosmological models by means of numerical simulations (supervised by M. Steinmetz and B. Jain). The simulations were performed using a newly developed multi-mass scheme which combines a PM code with a high resolution N-body code. Models with massive neutrinos have been considered as well as open models and models with a cosmological constant. It could be shown that in spite of different cosmological parameters, the formation pattern is very similar. Differences between different realizations of galaxy clusters dominate over differences due to the differing cosmological evolution. At all considered redshifts and for all considered cosmological models, the density distribution of the virialized portion of a galaxy cluster is well described by the profile proposed by Navarro, Frenk & White (NFW), and the differing cosmological parameters only manifest in the central density of the cluster. These results extend earlier findings to other cosmological models and support the interpretation that the NFW profile is generic for all hierarchically clustering scenarios.

The spatial clustering of dark matter haloes was studied by H.J. Mo and S.D.M. White using an analytical model and N-body simulations. They showed that such a model is useful for us to understand how the galaxy distribution traces the mass distribution in the universe. In collaboration with Y.P. Jing, they applied this model to study the correlation function and the number density of clusters of galaxies, and found that the cosmic density parameter and the amplitude of the initial density perturbations can, in principle, be determined from the measurements of the number density and correlation function of clusters. They constructed a similar model for the high-order moments of the dark halo distribution and found that the high-order moments of the galaxy distribution can be used to constrain the degree of the bias of the galaxy distribution relative to the mass distribution.

H.J. Mo, Y.P. Jing and G. Börner developed analytical approximations to the low-order statistics of the dark matter distribution. It was found that in a hierarchical clustering model all low-order statistics of the density and the peculiar velocity field can be calculated directly from the initial density perturbation spectrum for any given cosmological model. These approximations may have significant implications for the reconstruction of the cosmic density field from measurements in redshift space.

G. Börner and Y.P. Jing investigated the three-point correlation function of matter in second-order perturbation theory and in numerical simulations for several models. They found that the dependence on triangle shapes can be used to discriminate between different models. The data of the Las Campanas Survey were analysed, and the 2-point correlation functions have been calculated.

V. Springel and S.D.M. White have been studying structure in the newly completed PSCz redshift survey of about 15000 galaxies selected to a flux limit of 0.6Jy in the IRAS Point Source Catalog. In his diploma thesis V. Springel analysed the evolution of this galaxy population and showed it to be strong and in agreement with that inferred from earlier surveys. In addition he showed that the topology of the galaxy distribution in this survey is consistent with that of a gaussian random field and placed stronger limits on possible deviations from gaussian behaviour than have been possible using any previous survey.

A. Nusser and R. Sheth (Berkeley) developed an analytic method for computing the structure of dark matter halos in hierarchical formation of structure. Their results for the halo density profiles are consistent with the universal profile found in N-body simulations by J.F. Navarro, C.S. Frenk and S.D.M. White. A. Nusser and A. Dekel (Hebrew University, Jerusalem) developed a novel method for reconstructing large scale velocity and density fields and simultaneously estimating the cosmological density parameter. An application of this method to currently available data showed that a nontrivial biasing relation is needed in order to obtain a reliable estimate for the density parameter. The sense of this biasing relation is that galaxies are more clustered than the dark matter on small scales ($\sim$ 1000km/s) while they roughly trace the dark matter distribution on larger scales. A. Nusser, in collaboration with M. Davis (UC Berkeley) and J. Willick (Stanford), addressed the consistency of the IRAS redshift survey with the Mark III Tully-Fisher data and found a general good agreement indicating a moderately large value for the cosmological density parameter.

B. Jain studied the evolution of gravitational clustering, as reflected in statistical measures like the correlation function as well as in the structure of dark matter halos. He studied the stability of gravitational clustering on small scales and suggested an improvement on a power law parameterization of the evolution of the correlation function at high redshift. With R. Sheth (Berkeley) he used a relation between density profiles of dark matter halos to the correlation function of the matter, to predict the amplitude of the small scale correlation function.

A new Eulerian code able to follow the evolution of large-scale structures in the Universe in the weakly nonlinear regime has been developed by T. Plewa in collaboration with A. Kudlicki (N. Copernicus Astronomical Centre, Warsaw) and M. Różyczka (Warsaw University Observatory and N. Copernicus Astronomical Centre). The test results with an N-body code and analytical results were presented demonstrating robustness and correctness of the new method.

As part of the VIRGO and GIF consortia (the first is a large Anglo-German collaboration, the second a German-Israeli collaboration) J. Colberg and S.D.M. White have continued carrying out large, high resolution cosmological simulations on the Garching T3D parallel supercomputer. Two suites of simulations are now complete, one to study large-scale structure and the other to study galaxy formation. These demonstrate that in current cosmological models a large fraction of the mass of the universe is predicted to occupy a small fraction of its volume and to be arranged in a complex network which connects the individual density peaks which correspond to groups and clusters of galaxies. Studies of peculiar velocities of dark matter particles show that they are larger than the observed small-scale peculiar velocities of galaxies for *any* cosmological model which produces the observed abundance of rich galaxy clusters.

The spectral evolution of galaxies in cosmological scenarios was the subject of the diploma work of G. Contardo, supervised by M. Steinmetz and E. Müller. The aim of the work was to apply the methods of spectral synthesis to numerical models of galaxies in order to investigate in a self-consistent manner the star formation history and chemical evolution of galaxies and to determine their color evolution. It was found that the evolution of the apparent brightness of simulated galaxies agrees very well with that of observed ones. The qualitative analysis revealed the presence of a distinct galactic bulge and disk, whose brightness ratio and sizes are in very good accordance with observations. The color gradients found in the analyzed numerical models are similar to those observed in galaxies and are mainly due to metallicity effects. In their early evolution the numerically simulated galaxies show bright compact structures, which have recently been observed in galaxies at large redshifts. Thus, besides having the observed size and structural components, the simulated galaxies do also exhibit the observed evolution history.

G. Kauffmann, S. Charlot (IAP) and S.D.M. White showed that recent deep surveys of distant galaxies are not compatible with the standard hypothesis that elliptical and S0 galaxies all formed at high redshift and that their stellar populations have just evolved passively since that time. A classical $\langle V/V_{max}\rangle$ test shows that objects with the colours of passively evolving systems are preferentially concentrated at low redshift. By a redshift of one about two thirds of nearby bright E's and S0's no longer look like passively evolving systems; either they must be in several pieces or they must be actively forming stars.

Together with D. Zaritsky (UC Santa Cruz), R. Smith (Cardiff) and C.S. Frenk (Durham), S.D.M. White has put together an expanded catalogue of satellite galaxies around bright field spirals. This is by far the largest and most homogeneous sample of satellites available and can be used to constrain the mass and extent of spiral dark halos. These appear to extend to beyond 300 kpc and to have masses of several times $10^{12} M_\odot$. These same authors also showed that satellites at intermediate distances tend to orbit their primaries in the same sense as their disk rotates, while satellites at large distances tend to avoid the plane of the disk. No clear explanation of the latter effect is available and it is absent in available simulations of the formation of galaxy/satellite systems.

G. Kauffmann modelled the observed evolution of damped Lyman-α systems by assuming that they are disk galaxies which form by continuous cooling and accretion of gas within a merging hierarchy of dark matter halos. It was shown that this model can reproduce many of the observed properties of typical present-day spiral galaxies such as the Milky Way, as well as the evolution in the abundances, column density distribution and metallicities of the damped QSO absorption systems at high redshift.

The influence of a photoionizing background on the formation of disk galaxies was studied by M. Steinmetz, in collaboration with J. Navarro (Arizona and MPA). Gas dynamical simulations without an 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 then forming and the disagreement between simulated and observed galaxies is even worse.

G. Kauffmann studied the ages of the stellar populations of elliptical galaxies under the assumption that they formed by the mergers of disk systems and showed that the tightness of the observed colour-magnitude relation of ellipticals is entirely consistent with this picture, contrary to popular belief.

In collaboration with M. Fukugita (IAS, Princeton), H.J. Mo studied the constraints on the cosmic structure formation models from observations of the early formation of giant galaxies. They show that several currently popular models of structure formation do not have large enough perturbation power on galactic scales to produce the observed number density of big galaxies at high redshifts.

M. Haehnelt and M. Steinmetz in collaboration with M. Rauch (Caltech, Pasadena) used Smoothed Particle Hydrodynamics simulations combined with the photoionization code CLOUDY to establish the connection between newly-forming galaxies at high redshift and the occurrence of CIV absorption features in QSO spectra. Extending the work to a wider variety of ionic species it was found that different ionic species can be used as tracer of gas in different dynamical states during the galaxy formation process. Good agreement with the observed column density ratios of the different ionic species at redshift three was obtained for a metallicity [Z/H]$=-2.5$ and relative abundances as observed in metal-poor stars. It was demonstrated that as yet unvirialized gas should also be already significantly metal-enriched suggesting either that the gas has been subject to a widespread phase of stellar nucleosynthesis well before redshift three or that efficient metal transport outward from galaxies forming at these redshifts has occurred. The scatter in [C/H] predicted by the numerical simulation is larger than that in published high-resolution data indicating that at least some of the metal enrichment took place in situ.

Theoretical predictions for the minimum mass of the first cosmological objects were computed by M. Tegmark and T. Abel, in collaboration with J. Silk (UC Berkeley), M. Rees (IoA, Cambridge), A. Blanchard (Obs. Strasbourg) and F. Palla (Obs. Arcetri). Cooling by molecular hydrogen was found to drive this baryonic mass limit down to about $10^5 M_\odot$ at $z = 30$ and $5000 M_\odot$ at $z = 100$.

H.J. Mo and J. Miralda-Escude (IAS, Princeton) proposed an alternative model for the gaseous structure of galactic haloes. They used this model to interpret the observed QSO absorption line systems associated with galaxies.

3.8 Physical cosmology

H. Russ (Tübingen) in his Ph.D.Thesis, supervised by G. Börner, and in collaboration with M. Kasai (Hirosaki, Japan) and M. Soffel (Dresden) investigated the influence of inhomogeneities on the global expansion factor of a cosmological model. O. Ullmann in his Ph.D. thesis supervised by G. Börner, analysed the claim by I.E. Segal that the magnitude-redshift relation is better fitted by a distance square dependence than by the linear Hubble relation. He could show that the truncation of the data and selection effects can indeed conspire to give a square law fit. Proper sample definition and reliable statistics lead back to the linear law, however.

In preparation for the upcoming MPA-participation in the ESA COBRAS/SAMBA microwave background satellite mission, a number of data-analysis methods have been developed by M. Tegmark to enable accurate measurement of cosmological parameters given various real-world constraints such as foreground contamination, in collaboration with G. P. Efstathiou (Univ. Oxford), finite computer resources, in collaboration with A. Taylor and A. Heavens (ROE, Edinburgh), incomplete sky coverage, and pixelization. The general conclusion is that unless current foreground estimates turn out to be overly optimistic, none of these problems will substantially degrade the accuracy with which cosmological models can be constrained. Such methods have been applied to the Saskatoon data by M. Tegmark and A. de Oliveira-Costa in collaboration with M. J. Devlin, C. B. Netterfield, L. Page and E. J. Wollack (Princeton Univ.), producing the largest degree-scale CMB (Cosmic Microwave Background) map to date, and to the four-year COBE data, finding a good fit to standard CDM-type models.

There is a connection between anisotropy in the CMB and the topology of the universe. In collaboration with G. F. Smoot (LBNL/UCB, Berkeley) and A. A. Starobinsky (Russian Acad. Sci., Moscow), Angelica de Oliveira-Costa proposed a new data analysis method that searches for specific kind of anisotropies produced by toroidal universes. The four-year COBE/DMR data were found to rule out all toroidal universes as interesting cosmological models.

A.J. Banday in collaboration with K.M. Górski (TAC), C.L. Bennett (NASA GSFC), G. Hinshaw (NASA GSFC), A. Kogut (HSTX), C. Lineweaver (Strasbourg), G.F. Smoot (LBL) and L. Tenorio (Mexico) investigated the properties of the COBE-DMR Four Year Anisotropy Sky Maps. The cosmic microwave background anisotropy signal was found to be consistent with a scale-invariant-power-law model of primordial anisotropy and Gaussian statistics. The effects of Galactic foreground emission were quantified, and limits placed on contributions from plausible non-cosmological foregrounds. A detailed systematic error analysis was presented.

In collaboration with K.M. Górski (TAC) the possible signature of a putative X-ray halo due to gas in the Local Group of galaxies in the COBE-DMR data was investigated. No evidence of such a halo was found, and combined with COBE-FIRAS limits on the Compton y-parameter the possibility that the corresponding Sunyaev-Zel'dovich effect from such a halo could alter cosmological inferences from the DMR data was refuted. With K.M. Górski (TAC), B. Ratra (Kansas), R. Stompor (Copernicus Centre), and N. Sugiyama (Tokyo) A.J. Banday investigated open inflationary cosmological models. The COBE-DMR data are unable to constrain such models at a statistically significant level, but in combination with other current estimates of large-scale structure statistics a value for the critical density of the universe $\Omega_0 \sim 0.4 - 0.6$ is favoured. Together with G. Hinshaw (NASA GSFC) and A. Kogut (HSTX) the COBE-DMR data were used to place constraints on global rotation and shear in the early universe as prescribed by Bianchi VII_h cosmological models. A.J. Banday was awarded a NASA-ADP grant and guest-investigator status on the COBE project to investigate high order correlations in the DMR data. He is also involved with studies relating to the COBRAS-SAMBA CMB anisotropy satellite.

M. Haehnelt investigated the prospects of the COBRAS/SAMBA satellite for measurements of the Sunyaev-Zeldovich effect. Straightforward interpolation of X-ray observations of the 200 X-ray brightest clusters gave a firm lower limit of about 3000 detected clusters of which roughly half should be resolved. It was furthermore found that if the gas distribution of clusters should turn out to be favourable and/or the cluster evolution with redshift is weak, this number could be higher by a factor of up to ten.

R. Kneissl, together with R. Egger (MPE), G. Hasinger (AIP), A.M. Sołtan (Copernicus Astronomical Center, Warsaw) and J. Trümper (MPE), worked on a cross-correlation analysis between the COBE DMR 4yr and ROSAT All-Sky Survey data. A Galactic correlation on large angular scales, not conflicting with the CMB interpretation of the DMR data, was found. From the lack of a significant correlation between the microwave background and the extragalactic soft X-ray background, processes such as the Sunyaev–Zel'dovich effect in different astrophysical environments, the integrated Sachs–Wolfe effect, as well as common point sources are constrained. The difficulty of extracting an extragalactic X-ray dipole from the data was also studied.

J. Schmalzing (also at the University of Munich) and R. Kneissl used the Koenderink filters to investigate the Gaussian nature of CMB fluctuations seen in the COBE DMR data.

Supervised by G. Raffelt (MPI Physik, München) and Achim Weiss, J. Rehm completed his diploma thesis, in which Big Bang Nucleosynthesis in the presence of stable massive τ-neutrinos was investigated. Two major results were obtained: (i) the effect of a massive τ-neutrino cannot be simulated by an "effective" number of light neutrinos, and (ii), consistency with observations excludes τ-neutrino masses between 0.1 and 30 MeV.

3.9 Gravitation theory

Merging binary neutron stars or neutron star black hole binaries are one of the most promising sources to be discovered by the gravitational wave detectors currently being built (LIGO, VIRGO, GEO600, TAMA). Exact templates of the strains are essential to separate the gravitational waves from the background and detector noise. Three-dimensional, hydrodynamical simulations of merging neutron stars were performed with a physical equation of state for nuclear matter by M. Ruffert, H.-Th. Janka, and W. Keil, in collaboration with G. Schäfer (MPG-AG, Univ. Jena), and with adiabatic equations of state by M. Rampp as part of his diploma thesis work, supervised by M. Ruffert, in collaboration with H.-Th. Janka. Gravitational wave emission and backreaction were included in the simulations and the dependences of the results on the initial conditions were discussed. The emitted gravitational waves do not only contain information about the macroscopic properties of the neutron stars, e.g. their masses, radii, and spins, but also about the microscopic properties of the equation of state.

3.10 Physical processes

In collaboration with R.Sunyaev the astrophysical implications of the Compton scattering of X–ray photons by electrons bound in neutral atoms were studied by E. Churazov. On the basis of these studies new methods for the diagnostics of scattering media have been suggested.

T. Foglizzo (SAp, Saclay) and M. Ruffert analytically studied the Bondi-Hoyle-Lyttleton accretion flow, especially the instabilities that occur in numerical simulations, called flip flop flow in 2D models. Some general properties were found (e.g. the position of the sonic surface) and a mechanism for the instability was proposed, which is based on the shearing instability induced by vorticity generated at the position of the maximum entropy gradient behind the shock front. We achieved better agreement with the simulations compared to previous tentative explanations.

Investigations of the effects of nucleon spin fluctuations on the neutrino opacity and on neutrino and axion emissivities of dense matter in supernovae and proto-neutron stars were continued by W. Keil, H.-Th. Janka, G. Raffelt (MPI Physik), and D. Seckel (Bartol Research Institute, Delaware). An additional mode for substantial energy transfer between neutrinos and the stellar medium around the neutrinosphere was found and may have important implications for the neutrino fluxes and spectra emitted from supernovae. In a collaboration of H.-Th. Janka and W. Keil with G. Sigl, D.N. Schramm, M.S. Turner (Univ. of Chicago/FNAL, Batavia), the predicted saturation of the axion emission rate at high densities due to many-body effects was explored in its consequences for the axion mass limit deduced from the neutrino signal of SN 1987A, using new measurements of the axial-vector coupling strength of axions and nucleons.

3.11 Numerical methods

R. Wegmann developed a numerical method for the calculation of two-dimensional flow problems with a free surface. The method is based on conformal mapping and can include also the effect of surface tension.

The neutrino transport code recently developed by S. Yamada, which is based on a discrete angle method, was tested against the Monte Carlo transport code written by H.-Th. Janka. Application of both methods to typical neutrino transport conditions in proto-neutron star atmospheres was used to debug the discrete angle method and to determine its accuracy in dependence of the chosen radial, energy, and angular resolution.

T. Plewa in collaboration with E. Müller proposed a Consistent Multifluid Advection (CMA) scheme which allows for substantial reduction of nonconservation errors of the components in multifluid flows. This method also reduces the level of numerical diffusion that appears at the interfaces separating different fluids to a minimum.

T. Plewa and J. Marti (Univ. Valencia) adopted the relativistic flow solver to the adaptive mesh refinement code developed by T. Plewa and E. Müller. This code will be used in numerical studies of the long-term evolution of relativistic jets.

M. Steinmetz and S.D.M. White showed that discreteness effects related to classical two-body relaxation produce spurious heating of the gaseous component in numerical simulations of galaxy formation. A simple analytic calculation demonstrated that this artificial heating will dominate radiative cooling in any simulation where the mass of an individual dark matter particle exceeds a certain critical value. This maximum mass depends only on the cooling function of the gas, on the fraction of the material in gaseous form, and (weakly) on typical temperatures in the gas. It is comparable to, or smaller than, the dark matter particle masses employed in most published simulations of cosmological hydrodynamics and galaxy formation. Any simulation which violates this constraint will be unable to follow cooling flows, although catastrophic cooling of gas may still occur in regions with very short cooling times. The predicted effect could be verified in a series of N–body/smoothed particle hydrodynamics simulations.

3.12 Quantum mechanics of atoms and molecules; astrochemistry

Theoretical studies are being persued to investigate the electronic structure and dynamics of low lying Rydberg states of atoms and diatomic molecules, of their van der Waals complexes with rare gas atoms and with diatomic molecules, as well as embedded into small clusters and into the condensed phase. A series of Rydberg molecules have been studied containing hydrogen or lithium and one of the rare-gas atoms helium, neon, argon, or krypton. In case the electronic spectra of the partners overlap (HAr and HKr) the Rydberg excitation is accessible energetically at both partners and rather complex potential curves have been computed which are characterized by many avoided crossings indicating the change of excitation from one center to another along the potential energy curve. (E.W. Schreiner, G.H.F. Diercksen) Investigations are planned in close cooperation with experimental spectroscopists (R.J. Donovan, K.P. Lawley; Edinburgh, UK) on van der Waals clusters involving the iodine or iodinebromine molecule as cromophores and different rare gas and diatomic ligands. Results are expected from these studies about changes on the chromophore due to the interaction with different environments.

Experiments have indicated, for the first time, the existence of a triply charged molecular cation, S_2^{3+}. The results of rigorous quantumchemical studies using the coupled-cluster method confirm the existence of metastable electronic ground and excited states for both the molecular cations S_2^{2+} and S_2^{3+}. Studies are in progress to determine their vibrational spectrum and lifetime (M. Urban; Bratislava, Slovak Republic).

States have been characterized experimentally in nitroprussid molecular crystals by X-ray crystallography that are believed to be long-lived excited electronic states. Theoretical studies have been continued in order to determine the structure of these states and to explain the processes of their formation and depletion. A search has been performed for an appropriate theoretical method to treat both the ground and excited states of transition metal complexes. Various rigorous quantumchemical methods have been applied to study the geometrical and electronic structure of Cyclopentadienylnickelnitrosyl (C_5H_5NiNO) known to have in the gas phase a linear Ni-N-O structure in its electronic ground state and a bent structure in the first excited electronic state. The theoretical studies confirm these results and indicate a strong multiconfigurational nature of this complex at both the ground and the excited electronic states. (NSERC Canada Cooperative Project: P. Coppens; Buffalo, USA; V.H. Smith and J. Wang; Kingston, Canada).

The photodynamic therapy (PDT) of cancer is based on the use of light sensitive molecules, called photosensitizers. A concerted experimental, theoretical and clinical effort is being persued to understand the molecular processes involved in this therapy. The results of theoretical studies of the low lying excited states of substituted protoporphyrins, the basic structural unit of the applied photosensitizers, using the configuration interaction method, are in very good agreement with spectroscopic results. (R. Pottier, V.H. Smith; Kingston, Canada; S. Yamamoto; Toyota, Japan).

Nuclear shape resonances play a crucial role in molecular collision processes such as radiative association reactions. Attempts to observe these resonances directly in laboratory association experiments have failed because of the low resolution power of the experimental setups. The rigorous quantum mechanical determination of the quasi-bound rotation-vibrational states is a major challenge for theory. Reliable predictions are presently limited to the one-dimensional vibrational case of diatomic molecular ions. Recent *ab initio* studies of the temperature dependence of radiative association formation rates of various interstellar diatomic ions have been discussed in a review article (W.P. Kraemer, M. Juřek, V. Špirko). The extension of these calculations to general triatomic systems is still unfeasible unless some approximations are introduced such as for example the application of the concept of the Born-Oppenheimer adiabatic separation to nuclear vibrational motions with different energy contents. For the HeH_2^+ complex different separation schemes for the vibrational motions have been tested and the low-lying metastable states have been determined at these approximation levels (V. Špirko, M. Jurek, P. Soldán; all Czech Academy of Sciences, Prague).

Electronic resonances are intermediate reactive states formed in electron-ion collisions. Depending on their lifetime they can stabilize the electron capture initiating a dissociation process to neutral fragments. A large number of experiments have been performed in the past determining the rate constants of such dissociative recombination reactions, but only very recently it has become possible to analyze in detail the dissociation products of polyatomic systems. In these experiments it has been possible to verify previous qualitative predictions of the dissociation products of electron recombination of interstellar HCO^+ ions (W.P. Kraemer and A.U. Hazi; Lawrence Livermore Laboratories, USA). Previous calculations have now been extended to provide all relevant information for a statistical phase space treatment of the $e^- + HCO^+$ reaction (W.P. Kraemer and E. Herbst; Ohio State University, USA). The development of methods for a rigorous quantum-mechanical treatment of the dissociative recombination reaction of diatomic ions has also been continued (P.-Å. Malmqvist; University of Lund, Sweden).

Recently developed methods to calculate rotation-vibration spectra of Renner-Teller coupled electronic states of triatomic molecules have been applied to study the BH_2 molecule (M. Kolbuszewski, P.R. Bunker; National Research Council of Canada, Ottawa and G. Osmann, P. Jensen; Universität Wuppertal).

Ab initio collision calculations of H_2 and He, H_2 have been started in order to obtain H_2 relaxation rate coefficients (J. Schäfer).

The concept of an intelligent, stepwise evolutionary, open software environment in theoretical chemistry has been persued further. The OpenMol Version alpha.0.1 has been released at the end of December 1996. It has been developed by an international cooperation involving groups from Estonia (T. Jürimae, M. Karelson; Tartu), Finland (L. Laaksonen; Espoo), Germany (G.H.F. Diercksen, E.W. Schreiner; Garching), Japan (S. Osamura; Tokyo; S. Yamamoto; Toyota), Poland (W. Duch, K.H. Grudzinski, J. Karwowski; Torun; B. Jeziorski, T. Korona, R. Moszinski; Warsaw), the Slovak Republic (V. Kellö, M. Urban; Bratislava), Spain (J. Perez-Jorda; Allicante) and Venezuela (A. Hernandez, Caracas). It provides numerical software to study the properties of ground and excited electronic states of molecular systems by configuration interaction and coupled cluster methods, including relativistic effects. It provides as well software to study solvation effects on molecular properties by using continuum and molecular dynamics models. The graphical user interface gOpenMol provides functions to display and edit molecular structures, energy hypersurfaces and electron densities. Recently, the design of the structure of a case-base has been completed. It will form the basis for the development of the case-based reasoning system, cbOpenMol, which will provide the user guidance and the evaluation and interpretation of results. Data classes have been derived for documenting cases in computational chemistry based on the data determined in the process of studying physical effects by computational quantum chemistry. The detailed documentation of OpenMol can be accessed by internet at URL: http://www.mpa-garching.mpg.de.

4 Publications

4.1 Publications in journals

4.1.1 Publications that appeared in 1996:

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4.3 Popular articles and books

Börner, G.: Hawking, die Schwarzen Löcher und das Universum. Süddeutsche Zeitung vom 4.1.

Colberg, J.M. and S.D.M. White: Dunkle Materie, Galaxien und die Dichte des Universums. Sterne und Weltraum **35**, 824–831 (1996).

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4.4 Preprints ("Green Reports")

The following preprints appeared in 1995 as official MPA "Green Reports":

Bartelmann, M.: Arcs from a universal dark-matter halo profile. MPA 923

Bartelmann, M., R. Narayan, S. Seitz and P. Schneider: Maximum-likelihood cluster reconstruction. MPA 914

Bartelmann, M. and M. Steinmetz: A comparison of X-ray and strong lensing properties of simulated X-ray clusters. MPA 937

Bartsch, A., P. Schneider and M. Bartelmann: Reanalysis of the association of high-redshift 1-Jansky quasars with IRAS galaxies. MPA 922

Blinnikov, S.I., N.V. Dunina-Barkovskaya and D.K. Nadyozhin: Equation of state of a Fermi gas: approximations for various degrees of relativism and degeneracy. MPA 943

Bartsch, A., P. Schneider and M. Bartelmann: Reanalysis of the association of high-redshift 1-Jansky quasars with IRAS galaxies. MPA 922

Blinnikov, S.I., N.V. Dunina-Barkovskaya and D.K. Nadyozhin: Equation of state of a Fermi gas: approximations for various degrees Burbidge, G., F. Hoyle and P. Schneider: Very close pairs of quasi-stellar objects. MPA 916

Cassisi, S. and M. Salaris: A critical investigation on the discrepancy between the observational and theoretical red giant luminosity function 'bump'. MPA 974

Churazov, E., M. Gilfanov and R. Sunyaev: Is 1E1740.7–2942 inside the dense molecular cloud? Constraints from ASCA data. MPA 946

Degl'Innocenti, S., A. Weiss and L. Leone: The level of agreement between theoretical and observed globular cluster luminosity functions. MPA 932

Denissenkov, P.A., J. Wagenhuber and A. Weiss: Could intermediate-mass AGB stars produce star-to-star abundance variations in globular-cluster red giants? MPA 941

Feldmeier, A., R.-P. Kudritzki, R. Palsa, A.W.A. Pauldrach and J. Puls: The X-ray emission from shock cooling zones in O star winds. MPA 985

Fliegner, J., N. Langer and K.A. Venn: Boron in main sequence B stars: a critical test for rotational mixing. MPA 935

Foglizzo, T. and M. Ruffert: An analytic study of Bondi-Hoyle-Lyttleton accretion. MPA 949

Gautschy, A., H.-G. Ludwig and B. Freytag: Overtures to the pulsational instability of ZZ Ceti variables. MPA 915

Geiger, B. and P. Schneider: The lightcurve reconstruction method for measuring the time delay of gravitational lens systems. MPA 926

Groenewegen, M.A.T.: A revised period-luminosity relation for carbon Miras. MPA 933

Groenewegen, M.A.T.: IRC+10 210 revisited. I. the circumstellar dust shell. MPA 960

Haehnelt, M.G., M. Rauch and M. Steinmetz: Non-equilibrium effects on line-of-sight size estimates of QSO absorption systems. MPA 980

Hameury, J.-M. and H. Ritter: Illumination in binaries. MPA 988

Heger, A. and N. Langer: Stationary hydrodynamic models of Wolf-Rayet stars with optically thick winds. MPA 944

Hillebrandt, W.: Supernova theory: an overview.
Woosley, S.E.: Type Ia supernovae: flame physics and models.
Hillebrandt, W. and J.C. Niemeyer: Turbulence and thermonuclear burning.
Niemeyer, J.C. and W. Hillebrandt: Microscopic and macroscopic modeling of thermonuclear burning fronts.
Ruiz-Lapuente, P.: The late emission of thermonuclear supernovae. MPA 948

Hoek, L.B. van den and M.A.T. Groenewegen: New theoretical yields of intermediate mass stars. MPA 987

Imshennik, V.S. and D.V. Popov: Pulsar recoil due to asymmetry of rotating supernova explosion. MPA 940

Inogamov, N.A.: Analytic description of five-minute oscillations of the Sun. MPA 956

Jain, B. and U. Seljak: Cosmological model predictions for weak lensing: linear and nonlinear regimes. MPA 1002

Janka, H.-Th.: Numerical models of protoneutron stars and Type II supernovae – recent developments. MPA 983

Kauffmann, G., S. Charlot and S.D.M. White: Detection of strong evolution in the population of early-type galaxies. MPA 967

Keil, W., H.-Th. Janka and E. Müller: Ledoux convection in protoneutron stars — a clue to supernova nucleosynthesis? MPA 971

King, A.R., J. Frank, U. Kolb and H. Ritter: Global analysis of mass transfer cycles in cataclysmic variables. MPA 939

Kolb, U. and R. Stehle: The age of cataclysmic variables. MPA 970

Kneissl, R., R. Egger, G. Hasinger, A.M. Soltan and J. Trümper: Search for correlations between COBE DMR and ROSAT PSPC all-sky survey data. MPA 995

Kudritzki, R.-P.: Spectral diagnostics of luminous blue supergiants. MPA 993

Kudritzki, R.-P., D.J. Lennon, S.M. Haser, J. Puls, A.W.A. Pauldrach and K. Venn: Hot luminous stars in nearby galaxies. MPA 925

Kudritzki, R.-P., R.H. Mendez, J. Puls and J.K. McCarthy: Winds in the atmospheres of central stars of planetary nebulae. MPA 996

La Dous, C., F. Meyer and E. Meyer-Hofmeister: UV observations of dwarf novae in quiescence — effects of evaporation? MPA 964

Langer, N.: Oxygen isotopes from massive stars. MPA 977

Langer, N. and S.E. Woosley: Supernovae and their progenitors. MPA 936

Langer, N., J. Fliegner, A. Heger and S.E. Woosley: Nucleosynthesis in rotating massive stars. MPA 978

Lennon, D.J.: Revised spectral types for 64 B-supergiants in the Small Magellanic Cloud: metallicity effects. MPA 952

Ludwig, H.-G., B. Freytag, M. Steffen and J. Wagenhuber: The mixing-length parameter for solar-type convection zones inferred from hydrodynamical models of the surface layer. MPA 924

Meyer, F.: Formation of the outer ring of SN 1987A. MPA 1004

Meyer-Hofmeister, E., S. Schandl and F. Meyer: The structure of the accretion disk rim in supersoft X-ray sources. MPA 979

Mo, H.J. and M. Fukugita: Constraints on the cosmic structure formation models from early formation of giant galaxies. MPA 962

Mo, H.J. and J. Miralda-Escudé: Gaseous galactic halos and QSO absorption line systems. MPA 947

Mo, H.J., Y.P. Jing and G. Börner: Analytical approximations to the low-order statistics of dark matter distributions. MPA 992

Mo, H.J., Y.P. Jing and S.D.M. White: High-order correlations of peaks and halos: a step toward understanding galaxy biasing. MPA 938

Mo, H.J., Y.P. Jing and S.D.M. White: The correlation function of clusters of galaxies and the amplitude of mass fluctuations in the Universe. MPA 934

Müller, E. and H.-Th. Janka: Gravitational radiation from convective instabilities in Type II supernova explosions. MPA 927

Narayan, R. and M. Bartelmann: Lectures on gravitational lensing. MPA 961

Navarro, J.F. and M. Steinmetz: The effects of a photoionizing UV background on the formation of disk galaxies. MPA 953

Navarro, J.F., C.S. Frenk and S.D.M. White: A universal density profile from hierarchical clustering. MPA 997

Niemeyer, J.C. and S.E. Woosley: The thermonuclear explosion of Chandrasekhar mass white dwarfs.
Woosley, S.E.: Neutron-rich nucleosynthesis in carbon deflagration supernovae. MPA 968

Niemeyer, J., W. Hillebrandt and S.E. Woosley: Off-center deflagrations in Chandrasekhar mass SN Ia models. MPA 966

Patnaik, A.R., P. Schneider and R. Narayan: Deep radio observation of the gravitational lens candidate QSO 3245+007. MPA 920

Radecke, H.D.: I. X-ray sources $<$ 1 degree from Seyfert galaxies.
Arp, H.: II. Identification of X-ray sources $<$ 1 degree from Seyfert galaxies. MPA 965

Rehm, J.B., G.G. Raffelt and A. Weiss: Primordial nucleosynthesis with massive τ neutrinos. MPA 999

Ruffert, M.: Non-axisymmetric wind-accretion simulations. I. Velocity gradients of 3% and 20% over one accretion radius. MPA 955

Ruffert, M., M. Rampp and H.-Th. Janka: Coalescing neutron stars — gravitational waves from polytropic models. MPA 945

Ruffert, M., H.-Th. Janka, K. Takahashi and G. Schäfer: Coalescing neutron stars — a step towards physical models. II. Neutrino emission, neutron tori, and gamma-ray bursts. MPA 957

Ruiz-Lapuente, P., A. Burkert and R. Canal: SNe Ia: on the binary progenitors and expected statistics.
Burkert, A. and P. Ruiz-Lapuente: Dormant dwarf spheroidal galaxies, deactivated by Type Ia supernovae. MPA 989

Salaris, M., S. Degl'Innocenti and A. Weiss: The age of the oldest globular clusters. MPA 1000

Salaris, M., I. Dominguez, E. Garcia-Berro, M. Hernanz, J. Isern and R. Mochkovitch: The cooling of C-O white dwarfs: influence of the internal chemical distribution. MPA 975

Schäfer, J.: The far-infrared continuum spectrum of the Milky Way explained by a dust and gas model. MPA 931

Schlattl, H., A. Weiss and H.-G. Ludwig: A solar model with improved subatmospheric stratification. MPA 990

Schneider, P.: Detection of (dark) matter concentrations via weak gravitational lensing. MPA 917

Schneider, P. and M. Bartelmann: Aperture multipole moments from weak gravitational lensing. MPA 973

Schneider, P. and H.-W. Rix: Quantitative analysis of galaxy-galaxy lensing. MPA 928

Seitz, C. and P. Schneider: Steps towards nonlinear cluster inversion through gravitational distortions. III. Including a redshift distribution of the sources. MPA 921

Seitz, C., J.-P. Kneib, P. Schneider and S. Seitz: The mass distribution of CL0939+4713 obtained from a 'weak' lensing analysis of a WFPC2 image. MPA 919

Smartt, S.J., P.L. Dufton and D.J. Lennon: The chemical composition near the Galactic centre — a study of four blue supergiants. MPA 954

Spruit, H.C.: Magnetohydrodynamic jets and winds from accretion disks. MPA 929

Spruit, H.C.: Convection in stellar envelopes: a changing paradigm. MPA 951

Spruit, H.C. and R.G.M. Rutten: The stream impact region in the disk of WZ Sge. MPA 982

Stehle, R., U. Kolb and H. Ritter: Modelling population II cataclysmic variables. MPA 981

Steinmetz, M. and S.D.M. White: Two-body heating in numerical galaxy formation experiments. MPA 984

Sunyaev, R. and E. Churazov: Scattering of X-ray emission lines by the neutral and molecular hydrogen in the Sun's atmosphere and in the vicinity of active galactic nuclei and compact sources. MPA 972

Syer, D. and S.D.M. White: Dark halo mergers and the formation of a universal profile. MPA 994

Tormen, G.: The rise and fall of satellites in galaxy clusters. MPA 991

Tormen, G., F.R. Bouchet and S.D.M. White: The structure and dynamical evolution of dark matter halos. MPA 942

Villumsen, J.V., W. Freudling and L.N. da Costa: Clustering of galaxies in the Hubble deep field. MPA 1003

Warner, B.: Torques and instabilities in intermediate polars. MPA 986

Warner, B., M. Livio and C.A. Tout: Dwarf nova outbursts in truncated accretion discs: down with low alphas. MPA 950

White, S.D.M.: Violent relaxation in hierarchical clustering. MPA 930

White, S.D.M.: The nature and observability of protogalaxies. MPA 958

Woosley, S.E. and R.G. Eastman: Type Ib and Ic supernovae: models and spectra. MPA 969

Yamada, S.: An implicit Lagrangian code for spherically symmetric general relativistic hydrodynamics with an approximate Riemann solver. MPA 918

Zaritsky, D., R. Smith, C.S. Frenk and S.D.M. White: Anisotropies in the distribution of satellite galaxies. MPA 998

Zaritsky, D., R. Smith, C.S. Frenk and S.D.M. White: More satellites of spiral galaxies. MPA 1001

Zhao, H. and S. Mao: On the microlensing optical depth of the Galactic bar. MPA 959

Zhao, H., R.M. Rich and D.N. Spergel: A consistent microlensing model for the Galactic bar. MPA 963

Zwerger, T. and E. Müller: Dynamics and gravitational wave signature of axisymmetric rotational core collapse. MPA 976

5 Personnel

5.1 Scientific staff members

R.–P. Andersen (Aug. 1 – Sept. 30), U. Anzer, A. Banday (since Jan. 1), M. Bartelmann, G. Börner, E. Churazov (since Oct. 15), G.H.F. Diercksen, S. Dieters (till May 3), T. Foglizzo (till May 31), M. Gilfanov (since Sept. 1), M. Groenewegen, M. Haehnelt, W. Hillebrandt, B. Jain, H.–T. Janka, K. Jedamzik (since Dec. 1), P. Kafka, G. Kauffmann (since June 1), U. Kolb (till Aug. 31, on leave of absence till Aug. 31), W.P. Kraemer, R.–P. Kudritzki, D. Lennon (Jan. 1 – June 30), H.–G. Ludwig (till Dec. 31), S. Mao, E. Meyer–Hofmeister, F. Meyer (retired on Oct. 31), H.J. Mo (on leave of absence Jan. 7 – April 7), R. Mößner, E. Müller, J.C. Niemeyer, A. Nusser (since Sept. 15), H. Ritter, M. Ruffert, J. Schäfer (till May 31), S. Schandl (till Aug. 31), P. Schneider, E. Schreiner (Sept. 1 – Dec. 31), R. Sheth (since Oct. 24), H.C. Spruit, M. Steinmetz (on leave of absence since Feb. 21), R. Sunyaev, D. Syer, H.–C. Thomas, J. Villumsen (till Dec. 31), J. Wagenhuber (since July 1), R. Wegmann, A. Weiß, A.G. Weiss (June 1 – March 31), S.D.M. White, H.S. Zhao (till June 30).

Emeriti: H. Billing, R. Kippenhahn, F. Meyer (since Nov. 1), H.U. Schmidt, E. Trefftz.

Heisenberg–grant: N. Langer (Göttingen).

Ph.D. students: R.–P. Andersen (till July 17), J.M. Colberg, G. Contardo (till Oct. 1), M. Duschinger, J. Fliegner (till April 30), B. Geiger, A. Heger (on leave of absence since Nov. 11), A. Huss, W. Keil, A. Kercek (since Jan. 1), R. Kneissl, K. Ludwig, J. Rehm (since July 1), H. Schlattl (since July 1), J. Schmalzing (since Sept. 1), E. Schreiner (till Aug. 23), C. Seitz (till June 16), S. Seitz, F. Sellmaier (Feb. 1 – Dec. 31), V. Springel (since Oct. 1), R. Stehle, G. Taresch (since June 1), O. Ullmann, J. Wagenhuber (till Aug. 2).

Diploma students: G. Contardo (till May 3), K. Dolag (since Feb. 1), T. Erben (since Feb. 1), M. Gaudlitz (till April 30), B. Perkens–Golomb (till Sept. 3), M. Rampp (since Jan. 2), J. Rehm (till June 10), H. Schlattl (till June 30), V. Springel (Jan. 2 – Sept. 30).

5.2 Staff news

M. Bartelmann was awarded the Ludwig–Biermann–Prize of the German Astronomical Society.

M. Steinmetz was appointed Assistant Professor and Assistant Astronomer at Steward Observatory, University of Arizona, Tucson.

J.C. Niemeyer was awarded both the Dieter–Rampacher–Prize 1995 and the Otto Hahn Medal 1995 during the General Assembly of the Max–Planck–Society at Saarbrücken.

S.D.M. White was the 1996 Grubb Parsons Lecturer at the University of Durham.

5.3 Visiting scientists

Name (home institution) duration of stay at MPA

MPG fellowships:
I. Baraffe (Lyon, France) March 4 – March 22 and May 9 – May 23; M. Barysz (Katowice, Poland) May 1 – May 31; S. Blinnikov (Moscow, Russia) March 1 – April 4; J. Cayssol (Paris, France) July 1 – Aug. 31; J. Cheng (Beijing, China) July 7 – Oct. 5; C. Clarke (Cambridge, UK) July 1 – July 31; S. Degl'Innocenti (Ferrara, Italy) till June 30; P. Denissenkov (St. Petersburg, Russia) Jan. 9 – March 17; W. Duch (Torun, Poland) July 1 – July 31; E. Falco (Cambridge, USA) Nov. 16 – Dec. 5; J. Frank (Baton Rouge, USA) May 29 – Aug. 18; A. Fullerton (Newark, USA) till Aug. 31; T. Gan–Baruch (Tel Aviv, Israel) since Oct. 1; G. Garcia–Segura (Mexiko City) April 28 – June 1; S.A. Grebenev (Moscow, Russia) Nov. 1 – Dec. 1; I. Hachisu (Kyoto, Japan) July 19 – Aug. 18; M. Hanasz (Torun, Poland) Jan. 21 – Feb. 3; A. Hernandez (Carracas, Venezuela) Aug. 4 – Aug. 11 and Aug. 22 – Aug. 30; R. Hoffmann (Santa Cruz, USA) March 5 – April 2 and April 30 – June 13; J.Mª. Ibáñez (Valencia, Spain) July 1 – Aug. 16; N.A. Inogamov (Moscow, Russia) April 2 – May 2; B. Jeziorski (Warsaw, Poland) Sept. 7 – Oct. 6; Y. Jing (Trieste, Italy) Feb. 1 – Oct. 31; M. Jurek (Prague, Czech Republic) Nov. 1 – Nov. 30; T. Jyrimae (Tartu, Estonia) Oct. 10 – Dec. 5; R. Juszkiewicz (Warsaw, Poland) Sept. 13 – Oct. 12; M. Karelson (Tartu, Estonia) Oct. 10 – Nov. 4; M. Kasai (Hirosaki, Japan) March 1 – April 30; M. Kato (Yokohama, Japan) July 19 – Aug. 18; T. Korona (Warsaw, Poland) Sept. 7 – Oct. 5; A. Kritsuk (St. Petersburg, Russia) June 20 – July 10; A. Kudlicki (Warsaw, Poland) Sept. 1 – Sept. 30; S.I. Kuznetsov (Moscow, Russia) Oct. 5 – Nov. 5; F. Li (Paris, France) July 1 – Aug. 31; B. Liu (Kunming, China) since Jan. 21; Y.E. Lyubarskiy (Kharkiv, Ukraine) Nov. 1 – Dec. 15; V. Luridiana (Mexico City) March 18 – April 6; P.–Å. Malmqvist (Lund, Sweden) Nov. 1 – Nov. 30; C.F. McCain (Mt. Stromlo, Australia) since April 1; Y. Mellier (Paris, France) Oct. 12 – Oct. 26; S. Moiseenko (Moscow, Russia) Feb. 1 – March 31; R. Moszynski (Warsaw, Poland) Sept. 7 – Oct. 6; F. Mrugala (Torun, Poland) Sept. 1 – Sept. 30; J. Navarro (Tucson, USA) July 8 – Aug. 18; A. de Oliviera–Costa (Berkeley, USA) Jan. 1 – Oct. 15; S. Osamura (Tokyo, Japan) July 15 – Sept. 14; T. Plewa (Warsaw, Poland) till Nov. 30; I. Panov (Moscow, Russia) March 25 – June 24; M. Rauch (Pasadena, USA) Sept. 9 – Sept. 27; H.–W. Rix (Tucson, USA) June 7 – July 23; P. Ruiz–Lapuente (Barcelona, Spain) since Oct. 1; M. Salaris (Teramo, Italy) till Sept. 30; N.A. Sakhibullin (Kazan, Russia) June 28 – July 26; S.Y. Sazonov (Moscow, Russia) April 2 – May 2 and Oct. 5 – Dec. 5; N.I. Shakura (Moscow, Russia) Nov. 1 – Nov. 30; M.M. Sharma (Kuwait) Jan. 20 – Feb. 8 and June 20 – Aug. 19; E. Shima (Kawasaki, Japan) July 14 – July 31; E. Skillman (Minneapolis, USA) till July 31; P. Soldan (Prague, Czech Republic) Nov. 1 – Nov. 30; V. Spirko (Prague, Czech Republic) May 20 – July 20 and Oct. 1 – Oct. 31; Y. Suto (Tokyo, Japan) July 12 – Aug. 11; H. Suzuki (Tsukuba, Japan) March 1 – July 20; A.Y. Tkachenko (Moscow, Russia) Nov. 5 – Dec. 5; K. Thornton (Chicago, USA) March 30 – April 12; G. Tormen (Cambridge, UK) June 1 – Dec. 31; S.P. Trudolyubov (Moscow, Russia) Oct. 5 – Dec. 5; M. Urban (Bratislava, Slovak Republic) Aug. 12 – Oct. 11; D.A. Varshalovich (St. Petersburg, Russia) Nov. 10 – Dec. 15; K. Venn (Austin, USA) till July 31; J. Wang (Halifax, Canada) May 1 – June 30; R. van de Weygaert (Groningen, Netherlands) Jan. 3 – March 31; G. Worthey (Ann Arbor, USA) Aug. 14 – Sept. 30; B. Wybourne (Torun, Poland) June 7 – June 30; S. Yamada (Tokyo, Japan); V.V. Zheleznyakov (Nizhny Novgorod, Russia) July 26 – Aug. 24.

Alexander von Humboldt–research awards and fellowships:

Alexander von Humboldt–awards: D. Micha (Gainesville, USA) May 9 – June 30; S.E. Woosley (Santa Cruz, USA) Jan. 15 – June 7 and Aug. 29 – Oct. 13;

Alexander von Humboldt–fellowships: Y. Jing (Trieste, Italy) till Jan. 31; K. Sumiyoshi (Hirosawa, Japan) since April 1; O.N. Ventura (Montevideo, Uruguay) Jan. 8 – March 31; S. Yamamoto (Toyota, Japan) since April 1.

DAAD–fellowships:
V. Kellö (Bratislava, Slovak Republic) Aug. 21 – Nov. 23; V. Quilis (Burjassot, Spain) April 1 – June 30; S. Pistinner (Beer–Sheba, Israel) since Oct. 1; A. Timokhin (Moscow, Russia) since Oct. 1.

DFG–fellowships:
E.W. Schreiner (Garching) till Aug. 31; K.H. Grudzinski (Torun, Poland) April 1 – Sept. 30.

EC–fellowships:
I. Aretxaga (Cambridge, UK) since Oct. 1; A. Diaferio (Cambridge, USA) since Sept. 15; J. Perez–Jorda (Alicante, Spain) since Sept. 2; G. Tormen (Cambridge, UK) till May 31.

ESF–fellowships:
J. Karwowski (Torun, Poland) March 21 – April 4 and Sept. 23 – Nov. 29.

5.4 Diploma and Ph.D. theses

Diploma theses:

G. Contardo: “Spektrale Entwicklung von Galaxien in kosmologischen Szenarien”, Technical University Munich;

M. Gaudlitz: “Ausbreitung von Supernovastoßfronten im inhomogenen interstellaren Medium”, Technical University Munich;

B. Perkens–Golomb: “Vergleich von numerischen Simulationen mit Voraussagen der Press–Schechter Theorie”, Ludwig–Maximilians–University Munich;

J. Rehm: “Der Einfluß neuer Neutrinoeigenschaften auf die Kernsynthese im frühen Universum”, Ludwig–Maximilians–University Munich;

H. Schlattl: “Numerische und physikalische Aspekte der Genauigkeit von Sonnenmodellen”, Technical University Munich;

V. Springel: “Die Topologie und die Leuchtkraftfunktion des PSCz Rotverschiebungskatalogs”, University Tübingen.

Ph.D. theses:

R.–P. Andersen: “Über die Entwicklung der Zwerggalaxien”, Ludwig–Maximilians–University Munich;

E. Schreiner: “Theoretische Untersuchungen von Wasserstoff/Edelgas– und Lithium/Edelgas–Rydberg–Clustern”, Technical University Munich;

C. Seitz: “Bestimmung der Massenverteilung in Galaxienhaufen durch gravitativ verzerrte Bilder von Hintergrundgalaxien”, Ludwig–Maximilians–University Munich;

J. Wagenhuber: “Entwicklung von Sternen verschiedener Massen und Metallizitäten auf dem asymptotischen Riesenast und danach”, Technical University Munich.