Max-Planck-Institut
für
Astrophysik

Annual Report 2001

Contents

1 General Information

1.1 A brief overview of the MPA

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

Research at MPA is devoted to a broad range of topics in theoretical astrophysics. Major concentrations of interest lie in the areas of stellar evolution, nuclear and neutrino astrophysics, supernovae, astrophysical fluid dynamics, high energy astrophysics, radiative processes, structure, formation and evolution of galaxies, gravitational lensing, the large-scale structure of the Universe, particle astrophysics and cosmology. For many years the MPA had a strong group in General Relativity, but in mid-1995 most of this group moved to the newly founded MPI für Gravitationsphysik in Golm near Berlin. Their departure allowed a consolidation of MPA activities in extragalactic astrophysics, as well as an expansion in a new area, high energy astrophysics. But relativistic astrophysics remains to be an active field of research at MPA.

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

Work at MPA related to the Planck mission commenced in 1998. A team of programmers and scientists was set up, and the design of a data-analysis software prototype was started in due course. This team was supported by the General Administration of the Max-Planck Society until late 1999, when Germany's space agency (DLR) started to provide substantial support. This allows an appropriate expansion of the team as the project progresses. Currently, the team is working on three areas, i.e. the data-simulation pipeline, the software infrastructure for data analysis, and an archive system for the data products. According to current plans, the team will have 14 members at peak time just after launch.

In 2000, MPA became a partner of the "Sloan Digital Sky Survey" (SDSS) project. This survey will map in detail one-quarter of the entire sky, determining the positions and absolute brightnesses of more than 100 million celestial objects.

It will also measure the distances to more than a million galaxies and quasars. SDSS is a joint project of The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Princeton University, the United States Naval Observatory, and the University of Washington. Apache Point Observatory, site of the SDSS telescopes, is operated by the Astrophysical Research Consortium (ARC). After more than a decade of planning, building, and testing, the Sloan Digital Sky Survey was officially dedicated in 2000; by the end of 2001 about 25% of the survey has been completed.

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

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

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

Finally, in 1999, the idea to establish a Max-Planck Cosmology Group at the the Shanghai observatory was realized. The group has approximately 8 to 10 researchers, mainly young postdocs and graduate students, and a very active exchange between that group and MPA continued in 2001.

1.2 Current MPA facilities

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

The MPA and the MPE share a large and fully stocked astronomical library located in the MPA building. It holds at present more than 16000 books and conference proceedings and all major astronomical books and periodicals are available. The library staff can also provide access to a variety of on-line archives. Researches at both institutes have electronic access to most of the journals the library has subscribed, and to even more journals access is supplied by the headquarter of the MPG in Munich. Further library material is available at ESO which in addition maintains a complete collection of optical sky maps and photographic sky surveys. Other large data analysis facilities are available at the MPE which is the European data centre for the ROSAT satellite and is providing a data centre for the ISO satellite mission.

The MPA has always placed considerable emphasis on computational astrophysics and has therefore ensured access to forefront computing facilities. The current in-house system is based on a central cluster of 6 IBM RS6000 workstations, with additional Sun and SGI graphics workstations for data analysis and graphics applications. Users have free access to all workstations and are in general connected via large-screen X-window terminals or desk-top Linux workstations. In 2000 the MPA bought a 16-processor IBM SP3 supercomputer which was installed at the central computing centre of the Max-Planck-Gesellschaft at Garching (often abbreviated RZG), in addition to the already existing 18-processor IBM SP2. For still larger computing tasks MPA scientists can use a 816-processor CRAY T3E, a 4-processor NEC SX-5, and, most recently, a new IBM supercomputer of six 32-way "Regatta" nodes (based on Power 4 processors) which will run at a speed of 3.8 TFlop/s once its installation is completed. Moreover, they have access to a large cluster of high-end workstations and tera-byte mass storage systems at RZG.

MPA scientists not only access to the RZG, but they are among the top users of the facilities there. An AFS file system ensures that the transfer of data among the MPA machines and from MPA to the RZG is now almost transparent to the user. Further computing power is available at a second Max-Planck Society computer centre which is operated jointly with the University of Göttingen, and provides additional access to large parallel machines. Finally, MPA scientists can apply (and have applied successfully) for time on the tera-flop tera-byte supercomputer Hitachi SR8000 of the Leibnitz-Rechenzentrum in Munich.

1.3 2001 at the MPA

As in every year since 1997, the MPA invited a world-class theoretical astrophysicist to give three talks over a one month period on a subject of his or her choice. This set of prize lectures, known as the Biermann Lectures, were given in 2001 by Jim Truran from the University of Chicago. The subject of his lectures was "Nuclear Astrophysics" and covered this wide field in a comprehensive and fascinating way. All lectures were very well attended, as was the farewell party at the end of his successful visit.

In May the 75th birthday of MPA's second director Rudolf Kippenhahn was celebrated. A scientific colloquium given by several of his former students and collaborators was followed by a historic review of the early days of MPA presented by Reimar Lüst.

Several workshops and conferences were organized by MPA scientists in 2001, including a MPA/ESO/MPE Conference on "Lighthouses of the Universe" which took place in Garching from July 29 through 31, a workshop on "Relativistic Jets" at the Ringberg Castle in September, a workshop of the RTN-Network CMBNet entitled "Galaxy Clusters as CMB Forgrounds" also in September, and, last but not least, the "Joint European and National Astronomical Meeting (JENAM) 2001" from September 10 to 15 which attracted almost 700 scientists from 35 countries to Munich. The main topics and highlights included the presentation of new results on supermassive black holes in the centres of galaxies and on the discovery of extrasolar planets.

MPA's national and international cooperations and collaborations flourished also in 2001. An initiative designed in 1999 to further enhance the visibility of astronomy in Garching/Munich and to increase collaboration between the different institutions by means of a newly created International Max-Planck Research School (IMPRS) in Astrophysics at the Ludwig-Maximilians-University was taking shape. In early fall the first 21 graduate students from all over the world arrived in Garching. After an introductory workshop that ended with an excursion (in the rain) to the Wendelstein Observatory the course programme started at the end of September, and meanwhile all students are also working on their theses in research groups linked to the school.

As a consequence of the various European TMR- and RTN- Networks coordinated by MPA scientists also colleagues from all over Europe were frequent visitors at Garching. A serious problem turned out to be the quest for housing for long and short term guests, new postdocs, and graduate students. Plans of the MPG to build a guesthouse with 80 apartments on campus did not materialize since there were strong objections against such plans raised by the City of Garching. However, a new attempt to improve the housing situation will be made in 2002, hopefully with more success.

The on-going growth of MPA needed to be accompanied by an expansion of office space. Fortunately, the laboratory space in the ground floor of our building, set free by MPE, became available for us, and could be converted into office space. During all of 2001 scientists had to suffer the inconveniences caused by major reconstruction activities, but were also looking forward to the additional space. Timely at the end of 2001, the converted ground floor was opened and the usual party at the end of each year took place in what is to become the library-annex. The renovated ground floor will primarily host the PLANCK-group, including their computer centre, and the administration. In addition, MPA finally has a seminar room of sufficient size and a representative conference room that will be equipped with modern video- and teleconferencing facilities.

1.4 How to reach us

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  Germany

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

- Electronic address:

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

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

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

- MPA (reference) library:

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

2 Scientific Highlights

2.1 ^{7}Li from the Big Bang in low-mass stars

Lithium (more precisely its isotope ^{7}Li) is the heaviest element that is created in notable amounts in the Big Bang. ^{3}He, ^{4}He, and deuterium (D) are produced along with Lithium. The amount of these primordial elements that was generated depends on the cosmological density of baryons (just neutrons and protons at the beginning of nucleosynthesis). Fig. 2.1 illustrates the standard result of Big Bang Nucleosynthesis – the dependence of the light element abundances on the ratio of baryon- to photon-density, η. The latter is measurable today as the energy density of cosmic microwave background (CMB) photons, which are another relic of the Big Bang. If one can determine the primordial abundances of the various elements, one can measure the cosmological baryon density ($\Omega_{\rm B}\, h^2$ (h is the Hubble constant in units of $100\,{\rm km}\,({\rm s\,Mpc})^{-1}$), i.e. the contribution of "ordinary matter" to the total mass-energy-budget of the Universe. Of course, the different primordial abundances must be consistent with each other (corresponding to a vertical line in Fig. 2.1).

There are various ways to measure primordial element abundances in the present-day Universe. Here, we concentrate on the abundance of ^{7}Li, which can easily be determined from spectra of galactic stars. Fig. 2.2 displays a collection of results from recent observations (courtesy S.G. Ryan) for the photospheric ^{7}Li abundance as function of iron abundance [Fe/H]. At high iron abundances, there is a large spread in Lithium abundance, which reflects the fact that ^{7}Li is both produced and destroyed in stars and in the Galaxy. The various production and destruction processes are not understood completely, but it is clear that ^{7}Li is destroyed in stars by proton-capture at temperatures of $2 \cdot 10^6$ K and higher in the outer layers of stars. The ^{7}Li abundance in meteorites is believed to reflect the metallicity of the material that formed the solar system. Meteorites have [Li] = 3.3 (the brackets indicating logarithmic number abundances on a scale where that of hydrogen is set to 12). In the solar photosphere the Lithium abun-

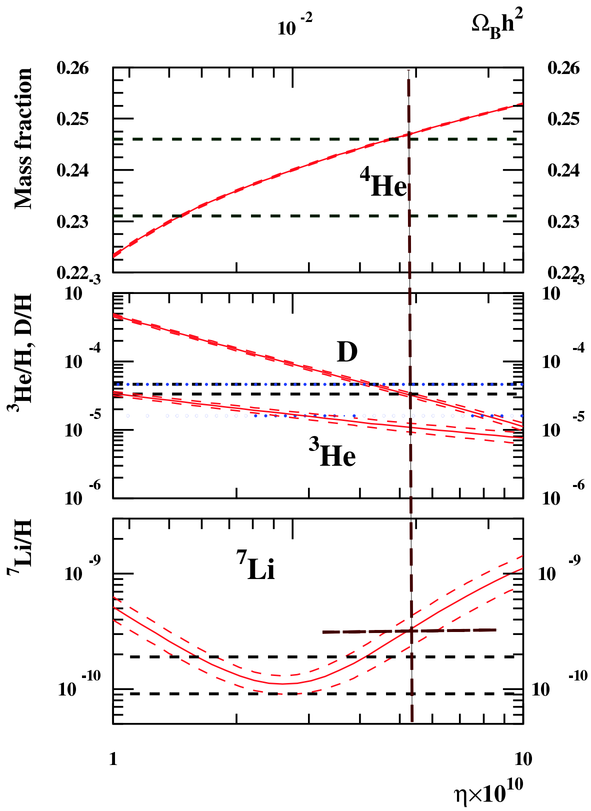

Figure 2.1: Big Bang Nucleosynthesis: for any given value of η, the ratio of baryon-to-photon-density, certain amounts of ^{4}He, ^{3}He, D and ^{7}Li are produced (solid lines with theoretical error ranges). Measured primordial abundances must therefore lie on vertical lines to be consistent. Recent determinations and their error ranges of ^{4}He, D, and ^{7}Li are indicated by dashed horizontal lines. Note that for ^{7}Li there are in principle two η-values, but here only the high-density branch is considered. The long-dashed horizontal line inthe lower panel refers to our predicted abundance and the vertical one demonstrates its consistency with D and ^{4}He. Abundances are given here as number fractions relative to hydrogen. (Original figure and calculations by E. Vangioni-Flam)

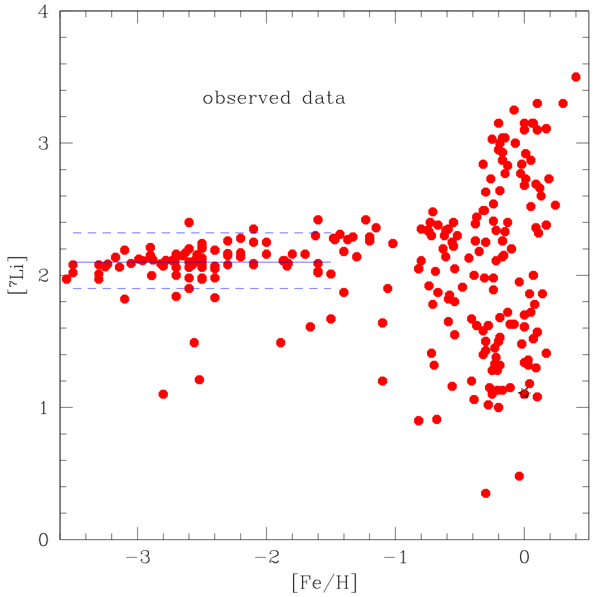

Figure 2.2: Observed ^{7}Li abundances in galactic stars as a function of metal content. The Sun is marked by a star symbol at [Fe/H] = 0. The observational data are from several sources and were kindly provided by S.G. Ryan (The Open University, Milton Keynes, England). The mean value of the Lithium-plateau is indicated by the solid blue line, the dashed lines indicate the variation around it.

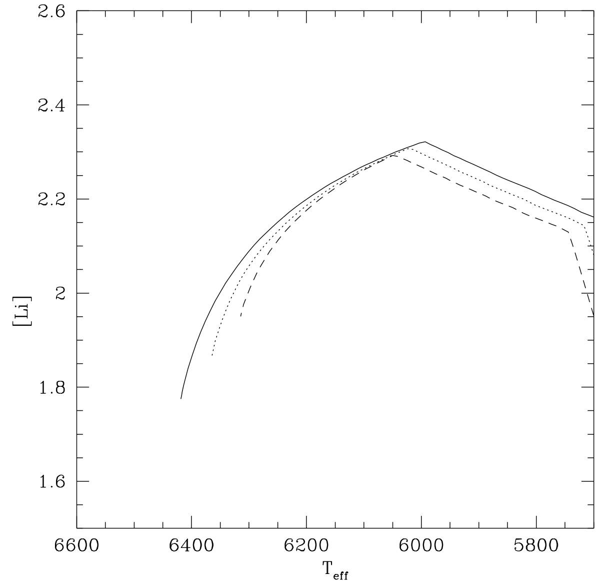

Figure 2.3: Lithium abundance as function of effective temperature along isochrones of 12 (solid) to 14 Gyr (dashed) from stellar models taking into account sedimentation, the effect of which is visible as the downturn for the hottest stars. The Li-depletion on the cool end is due to pre-main sequence Li-burning in lower mass stars.

dance is a factor ≈ 130 lower. This must be due to ^{7}Li destruction (burning) in the solar interior. However, solar evolution models predict a depletion by only a factor of 10 at most. This *solar lithium problem* is still unsolved and is connected with badly understood mixing processes.

In Fig. 2.2 it is striking that at the low iron abundances the Lithium abundances appear to be constant and constitute the so-called *Lithium-* or *Spite-plateau* (named after M. and F. Spite). Given the spread at the right edge of the diagram, the natural interpretation of the plateau is that it reflects the true primordial abundance of ^{7}Li, before any depletion, destruction, or creation processes took effect in these stars. Since the iron content in galactic stars is also a measure of their formation epoch, the metal-poor stars are probably among the oldest galactic objects. In fact their measured ages are similar to that of the Universe. This is further evidence that the abundances measured in these stars reflect the ^{7}Li abundance from the time of BBN.

If one adopts the plateau value of Li $= 2.1 \pm 0.2$ as the primordial one, one obtains a baryon density of $\Omega_\mathrm{B} \approx 0.014\,h^{-2}$ (see Fig. 2.1). This value of Ω_B derived from ^{7}Li is evidently inconsistent with that derived from deuterium, currently believed to be the most reliable of the BBN light element abundances (Fig. 2.1, central panel). The baryon density derived from Lithium is also inconsistent with that derived from the fluctuations in the cosmic microwave background determined recently by balloon experiments ($\Omega_\mathrm{B} = 0.03 \pm 0.01\,h^{-2}$). In summary, the ^{7}Li plateau value is in contradiction with other methods of determining the cosmic baryon density.

From studies of the structure of the Sun, we know that sedimentation of elements (i.e. the sinking of elements heavier than hydrogen towards the center of the star) is taking place. Although it is a very slow process the effect is measurable. Both the Sun and the stars on the Spite-plateau have a convective envelope in which fast mixing of matter takes place. Here, sedimentation cannot operate, but it takes place at the bottom of the convective zone, which then serves as a reservoir for the heavier elements. The hotter the star, the thinner the convective zone, the smaller the reservoir, and therefore the depletion of the heavier elements due to sedimentation is more noticeable. If one calculates the ^{7}Li-abundance for plateau-stars of a given age as function of effective temperature, there is a clear downturn of up to 0.5 dex relative to the primoridal abundance at the highest temperatures corresponding to the turn-off (Fig. 2.3).

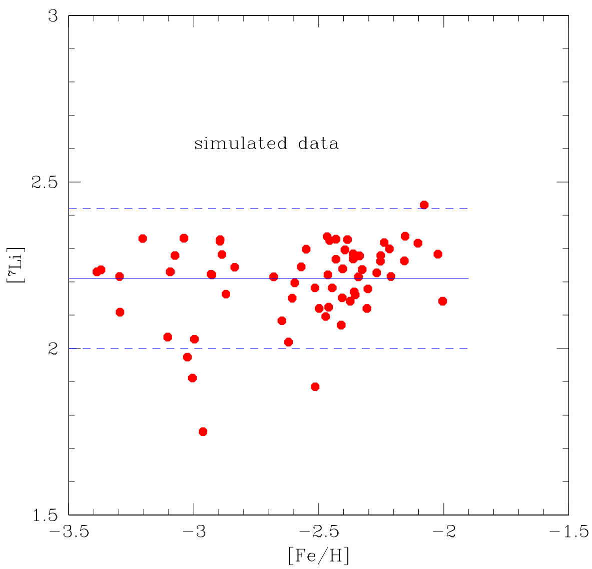

Figure 2.4: Lithium abundance as function of metallicity for a simulated sample of observed stars on the Lithium-plateau. The input were the stellar models including sedimentation of Fig. 2.3. The initial ^{7}Li abundance was assumed to [Li] = 2.5. This figure is to be compared to the observational counterpart, Fig. 2.2.

Since such a decline in ^{7}Li is not observed, one could only conclude that some mixing process, for example mixing induced by differential rotation, is inhibiting sedimentation.

However, it was not realized until recently that the evolution speeds up towards the turn-off such that in a random sample of low-mass (old) stars along the main sequence, the probability of observing turn-off stars is relatively low. In an sample of stars covering a range of different metallicities, it is the lowest metallicity and not necessarily the hottest stars that are closest to the turn-off.

In a joint research project M. Salaris (Liverpool John Moores University and MPA) and A. Weiss (MPA) investigated this problem again. They used the most up-to-date stellar models representing the stars on the Lithium-plateau. The physics incorporated is the same as that used in accurate solar models and for the age determinations of globular cluster stars. It includes diffusion and the effect of sedimentation. The models were evolved from the pre-main sequence phase to ages of 12-14 Gyr, corresponding to the age of the Universe. The models were used to simulate observed samples of stars, taking into account effects such as metallicity and age spreads, the age-metallicity relation, uncertainties in effective temperature determinations and, most importantly, sample size effects. The resulting data show that the surface lithium abundance is depleted due to sedimentation, but that the depletion is almost constant for all stars, so the plateau-like structure is preserved (Fig. 2.4). Only at the most metal-poor end do a few strongly depleted stars show up - just as is found in real observations (see Fig. 2.2). The simulations also predict that in samples of about 200 stars the variation of the depletion from star to star should become clearly visible, and the plateau should disappear. These theoretical predictions can therefore be tested.

At this stage the results only indicate that in the present observations, the plateau-feature cannot by itself be taken as evidence against the presence of sedimentation in these old stars. They also do not prove the existence of this effect. However, from the observed plateau value and the theoretically known depletion factor of ≈ 0.3 dex, one can infer a true primordial value of 2.5 – about twice as large as that of the plateau. Returning to Fig. 2.1, where this value is indicated by the long-dashed line in the lower panel, it is clear (vertical dashed line) that this value is completely consistent with that inferred from primordial deuterium and in agreement with some determinations of a high primordial helium content around $Y_{\rm p} \geq 0.24$ (relative mass fraction). The corresponding baryon density is $\Omega_{\rm B} \approx 0.019\,h^{-2}$, well within the range allowed by the most recent analyses of cosmic microwave background measurements. The new models can therefore resolve the discrepant results of the different determinations of the matter density in the Universe.

Studies of old stars in our Galaxy using new stellar models thus yield valuable information about the conditions in the Big Bang and about the composition of matter in the Universe (Achim Weiss).

2.2 Extracting Physical Parameters from the spectra of galaxies

The integrated light from galaxies should reflect the properties of the stars within them, providing us with important clues about the history of star formation and chemical enrichment. Stellar population synthesis, the modeling of the spectral energy distribution (SED) of specific populations of stars, is a natural approach to identifying such clues. The first attempts to model and intepret spectra of galaxies relied on *trial and error* analyses. In this technique, one reproduces the SED of an observed galaxy with a linear combination of individual stellar spectra of various spectral types and luminosity classes taken from a comprehensive library. The solution is found by numerical minimization of the difference between models and data. Additional constraints such as positive star numbers, increasing number of stars with decreasing mass on the main sequence, and consistent numbers of evolved red giant stars and main-sequence progenitors are also invoked in order to obtain physically-realistic solutions. This technique was abandoned in the early 1980's.

More recent models are based on the *evolutionary population synthesis* technique. In this approach, the main adjustable parameters are the stellar initial mass function, the star formation rate and the rate of chemical enrichment as a function of time. For given assumptions about these parameters, one computes the time-dependent distribution of stars in the Hertzsprung-Russell diagram, from which the integrated spectral evolution of the stellar population can be obtained. These models have become standard tools in the interpretation of galaxy colors and spectra. Most modern population synthesis models are able to account for the effects of stellar age and metallicity on galaxy spectra, but they still suffer from serious limitations. In particular, most models neglect the transfer of the stellar radiation through the interstellar medium, which consists of a mixture of gas and dust. They are thus unable to predict emission line strengths and the attenuation by dust that affects both the line and the continuum emission. Up to recently, in fact, no population synthesis model has been able to reproduce consistently all the spectral properties of nearby galaxies. Thus, the constraints set by these properties on physical parameters such as age, SFR and metallicity have not yet been properly quantified.

S. Charlot (MPA), M. Fall (STScI, Baltimore, USA) and M. Longhetti (OAB, Milan, Italy) have developed a new method of including the transfer of stellar radiation through the interstellar medium in evolutionary population synthesis models of galaxies. This approach is based on a simple, but physically-motivated description of the interstellar medium (see Fig. 2.5), in which star form inside dense molecular clouds, which dissipate after $\sim 10^7$ years. This corresponds to the estimated dispersal timescale of giant molecular clouds in the Milky Way. The ionization of HII regions and the production of emission lines within these 'birth clouds' are computed using a standard photoionization code. Line photons produced in the HII regions and the non-ionizing continuum photons from young stars propagate through the outer neutral (and molecular) envelopes of the birth clouds before they escape from the galaxy. Both the ionized and neutral regions of the birth clouds may contain dust, and in the 'ambient' (i.e. diffuse) ISM, the dust may be distributed in a smooth or patchy way. The birth clouds, however, have finite lifetimes. Thus, photons from stars that live longer than the birth clouds are absorbed only by dust in the ambient ISM, whereas photons from massive, short-lived stars are absorbed both within the birth clouds and in the ambient ISM.

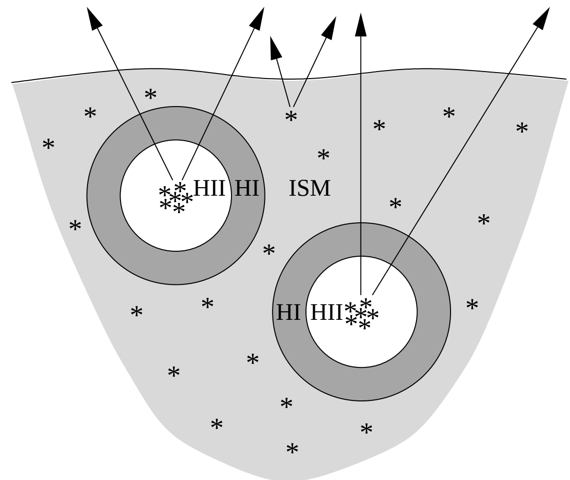

Figure 2.5: Schematic representation of the main components of the interstellar medium in a model where the production of stellar radiation and its transfer through the interstellar medium are treated in a physically consistent way. Rays leaving in different directions are also shown. The dense molecular clouds in which stars form ('birth clouds') dissipate after $\sim 10^7$ years. The radiation from older stars is affected only by the 'ambient' interstellar medium.

The finite lifetime of stellar birth clouds in the model is the key to resolving an apparent discrepancy between the attenuation of line and continuum photons in starburst galaxies. In such galaxies, the attenuation inferred from the $H\alpha/H\beta$ ratio is typically *higher* than that inferred from the ultraviolet and optical spectral continuum. This is a natural prediction of the model, in which the stars dominating the line emission are more obscured than those dominating the UV emission, because they have lifetimes ($\lesssim 3 \times 10^6$ yr) shorter than the typical timescale for the dispersal of the clouds in which they form. The model succeeds in reproducing the complete spectral energy distributions of nearby star-forming galaxies of various types, including the relative ratios and the equivalent widths of prominent nebular emission lines (e.g., [O II], Hβ, [O III], Hβ, [N II] and [S II]), the ratio of far-infrared to ultraviolet luminosities, the stellar continuum at optical and near-infrared wavelengths, and the ultraviolet spectral slope.

Thus the whole spectral energy distribution, including lines and continuum, can be used to obtain *quantitative* constraints on the parameters describing the stars, the gas, and the dust. S. Charlot, G. Kauffmann, S. White and collaborators have used this model to derive star formation rates, gas-phase oxygen abundances and dust absorption optical depths for a sample of galaxies drawn from the Stromlo-APM spectroscopic survey (1671 galaxies at a median redshift of 0.05). They considered a sample of 705 galaxies with measurements of the fluxes and equivalent widths of Hα, [O II], [N II] and [S II]. A subset of the galaxies also had 60- and 100-μm IRAS fluxes, which provided further constraints on the star formation rate and dust content. They investigated the reliability of three standard estimators of the star formation rate, which have been used widely to estimate the total star formation density of galaxies at the present day and at high redshift. In particular, the analysis showed that the standard Hα estimator tends to *underestimate* the star formation by a factor of 2–3.

In January 2001, the MPA joined the Sloan Digital Sky Survey (SDSS) as a Participating Institution. The SDSS is the most ambitious astronomical survey project ever undertaken. It will image one quarter of the sky in five photometric bands and will obtain spectra of a million nearby galaxies over a wavelength range from 3800 to 9200 Å at a resolution of 1800. This range includes all the main key emission lines (e.g. [O II], Hβ, [O III], Hβ, [N II] and [S II]), that are important to derive tight constraints on physical parameters. The spectra from the SDSS are thus ideally suited to analyses using the methods developed by the MPA group.

Fig. 2.6 shows the first results obtained by C. Tremonti, T. Heckman (JHU, Baltimore, USA), G. Kauffmann and S. Charlot by applying the models to derive the stellar masses and metallicities of a sample of 20,000 SDSS galaxies. These results show that the metallicities of galaxies are highly correlated with their masses below a stellar mass of $10^{10}\,M_{\odot}$. It was found that the correlation of metallicity with mass is considerably tighter than the corresponding correlation with optical luminosity previously documented in the literature. At stellar masses greater than $10^{10}\,M_{\odot}$, the mass-metallicity relation flattens at a value close to solar. This "turnover" has long been a prediction of classic galactic wind models. In these models, the fraction of metals ejected by galaxies in supernova-driven winds is inversely proportional to the potential well depth of the galaxy. At a certain limiting mass, galaxies are no longer able to eject metals, and the galaxy is effectively a "closed box" system. The metallicity is then predicted to be equal to the yield of heavy elements produced by unit mass of stars (this is around the solar value for a standard stellar initial mass function).

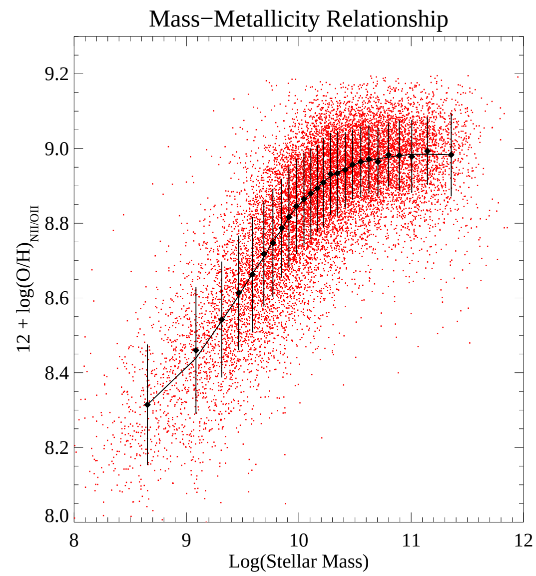

Figure 2.6: Metallicities estimated using the [N II]/[O II] emission line ratio are plotted as a function of stellar mass for a sample of 20,000 galaxies drawn from the Sloan Digital Sky Survey (Tremonti et al. 2002).

The discovery of the typical mass scale below which galaxies have been able to eject a substantial fraction of their metals (and perhaps their interstellar medium) has important implications for understanding a whole host of astrophysical phenomena, including the star formation histories of galaxies and the chemical enrichment of the intergalactic medium as a function of cosmic epoch (Stephane Charlot).

2.3 Probing the properties of the intergalactic medium with Lyman α forest

The Lyman-α forest is a collection of spectral absorption features observed along the line of sight of distant quasars. These features are believed to

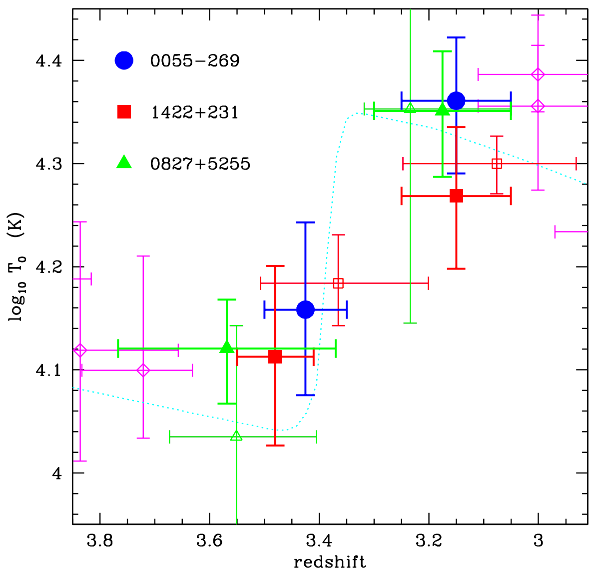

Figure 2.7: Temperature at the mean density, T_0, versus redshift. Open symbols with error bars are taken from Schaye et al. (2000). Filled symbols with error bars and thicker lines refer to estimates of T_0 based on the mean wavelet amplitudes, with errors on T_0 of 30 per cent for a stretch of spectrum of 5000 km s^{-1}. Errors in the redshift direction refer to the redshift extent of the sampled region. Symbol types refer to the QSOs. We have assumed $\gamma = 1$ below $z = 3.3$, and $\gamma = 5/3$ above $z = 3.3$ to convert $T_{1.2}$ to T_0. The dotted line is the temperature evolution in a simulation where HeII reionizes at redshift ~ 3.4. It fits the data very well.

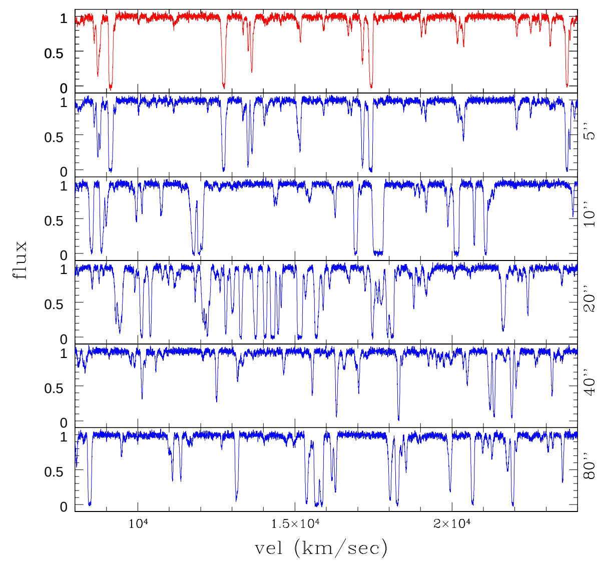

Figure 2.8: Simulated QSO spectra at redshift $z \sim 2$, along lines of sight at different separations. The y-axis shows the flux while the x-axis represents the velocity of the cosmic expansion in km/s. Notice that the coincidences of the absorption features between the red and blue spectra become weaker as the separation increases, from 5 arcsec to 80 arcsec (i.e. from about 200000 light years to 2.5 million light years).

be due to the resonant absorption in the Lyman-α transition of neutral hydrogen. Early theoretical models attributed these phenomena to absorption by discrete gas clouds between us and the quasar. The clouds are either confined by a hot intergalactic medium (IGM) or by gravitationally bound dark matter 'mini-haloes'. Recent years have witnessed a significant transformation in the understanding of the Lyman-α forest for two main reasons: First, the availability of high resolution spectrographs on large telescopes has provided us with data of unprecedented quality. These data have allowed us to resolve the individual absorption features, usually refered to as absorption lines, in great detail and with very high signal-to-noise. Second, a theoretical paradigm has emerged within the context of the cold dark matter cosmology. In this picture, the absorption is produced by a volume filling, photo-ionised gas containing most of the baryons at redshifts $z \sim 3$. The absorbers are locally over-dense extended structures. In summary, the combination of a predictive theory and superb data has led to a genuine revolution in IGM studies.

On large scales, the gas distribution is similar to that of the underlying dark matter. Therefore, the large-scale structure in the Lyman α forest can be used to infer the clustering properties of dark matter in the universe and to probe the primordial perturbations responsible for the formation of galaxies and the large-scale structure in the universe. On small scales, where the effects of gas dynamics become important, the properties of the absorption, such as the shapes and widths of individual absorption features, depend on the thermal history of the IGM and the intensity of the ionizing background. Detailed analyses of the absorption lines can therefore be used to infer the thermal and ionization history of the IGM. In the past year, a group of MPA researchers, in collaboration with scientists from Cambridge and Padova, have been working on both aspects of the IGM.

To study the thermal properties of the IGM, MPA scientists have developed a wavelet based method to measure the temperature of the IGM. The method quantifies the distribution of widths of the Lyman-α absorption features, especially the narrowest ones, along the observed spectrum. The width of the narrowest absorption lines is mainly set by the temperature of the IGM. When the method was applied to eleven high-resolution quasar spectra, strong evidence was found for a marked jump in the characteristic temperature (T_0) of about 60 per cent around a redshift $z \sim 3.3$. The jump can be seen in all the available (three) spectra that straddle redshift 3.3, at a significance of ≥ 99 per cent (see figure 2.7). Below $z \sim 3.1$, the analysis results are consistent with a smooth cooling of the universe, as expected when adiabatic expansion dominates over photo-heating by a UV-background from QSOs and galaxies. The analysis found no evidence of thermal fluctuations on scales ≥ 5000 km s^{-1} larger than 50 per cent, which could have been detected by the method. The jump in IGM temperature can be used to constrain the reionization history, because reionization can heat the gas and because low density gas (as probed by the Lyman-α forest) can retain a memory of its heating *history*. The jump found at $z \sim 3$ can be attributed to the reionization of HeII . The observational results can also be used to infer the characteristic temperature of the IGM. The implied temperature is about 1.2×10^4K at $z \geq 3.6$. Such high temperatures suggest that Hydrogen reionization occured relatively recently, at a redshift $z \leq 10$.

In order to study the large-scale structure in the Lyman α forest, MPA scientists have developed an effective method to simulate the Lyman α forest along multiple lines of sight to distant quasars in a cosmological setting (see figure 2.8). This method accounts for the correlations between absorption systems of different lines of sight due to the clustering of the underlying matter distribution on large scale, and suggests a number of ways to recover the clustering properties of the mass density field from observations of the Lyman α forest. In particular, the cross-correlation of the absorption systems in adjacent sightlines is found to be a robust measure of the clustering of matter on large scales. About 30 quasar pairs with an angular separation between 1 and 2 arcmin on the sky can recover the distribution of matter in the Universe over distances of several 100 million light years. Such observations can be made from large QSO surveys, such as the Sloan Digital Sky Survey. (Houjun Mo and Saleem Zaroubi)

2.4 The Local Universe at $z = 0$

Large-scale structure in the Universe is generally thought to arise from the gravitational amplification of small density perturbations seeded by an inflationary epoch in the very early evolution of space-time. The statistical properties of these primordial density fluctuations are well specified by the currently favoured theoretical paradigm. Together with the assumption that the dominant mass component consists of so-called cold dark matter (CDM), it then becomes a primary task of theoretical cosmology to accurately compute the expected structure in the galaxy distribution at the present day, and to compare the resulting predictions to observational data.

To this end, numerical simulations of structure formation are carried out at MPA, allowing the computation of the highly non-linear gravitational clustering process that ultimately determines the assembly history of galaxies and their spatial distribution. However, such numerical models of galaxy formation have been plagued by *cosmic variance*. This has resulted in difficulties in drawing firm conclusions when comparing quantities measured for nearby galaxies to those measured in simulations of cosmological volumes, where the particular realization of the final dark matter density field may differ significantly from the one actually seen nearby.

A new project at MPA, carried out by H. Mathis, S. D. M. White and G. Lemson (Hebrew University, Jerusalem), set out to change this. They reconstructed mock galaxy distributions that were constrained to be as similar as possible to the one seen in our cosmological neighbourhood. The initial conditions for the simulations were derived by first smoothing the neighbouring galaxy distribution in the IRAS 1.2 Jy redshift survey and extrapolating backwards in time to the starting redshift. The resulting field of density fluctuations on large-scales was then used to statistically constrain the random realization of the CDM model such that the numerical simulations, when run forward in time, would reproduce the most prominent structures seen in the Local Universe.

Two variants of the CDM scenario were analyzed: an Einstein-de Sitter universe with tilted initial power spectrum (τCDM), and a flat, low density universe (ΛCDM), which currently represents the scenario that best agrees with a large variety of data. In both cases, the final outcome of the simulations, which were carried out on the T3E supercomputer of the Max-Planck Society's computer centre in Garching, yielded galaxy populations in good agreement with the one observed locally. This pioneering study, which used more than 70 million particles in each run, represents a new milestone in simulation technology.

For the two simulated variants of the CDM cosmology, we show in the top panels of Fig. 2.9 the present-day dark matter distribution in a slice of width 30 h^{-1} Mpc centred on the supergalactic plane, and projected along SGZ. The left and right panels show the ΛCDM and the τCDM model respectively. Prominent nearby clusters of galaxies are labelled. They are recovered at positions and with masses close to those of their real counterparts, as are the largest empty regions, the so-called voids. It thus appears that the morphology of the large structures of clusters and supercluster seen in the Local Universe can consistently arise within a CDM universe.

As part of the study, a galaxy formation algorithm developed by G. Kauffmann has been grafted onto the dark matter skeleton provided by the simulations. In this technique, simplifying physical approximations are employed to model the baryonic processes that give rise to the hierarchical build up of the luminous stellar component of galaxies. The bottom panels of Fig. 2.9 shows the resulting distribution of galaxies in the same slice as in the top panels, together with the dark matter distribution. The sizes and colours of the symbols scale with their luminosity and their $B-V$ colour-index, respectively. It is striking how red galaxies (mostly ellipticals) tend to reside in clusters, while blue star-forming galaxies primarily trace out the filaments of dark matter. On the other hand, regions below the mean density are populated by many fewer galaxies. Galaxies are bluer in the τCDM model due to a higher mean present-day star formation rate. Properties like luminosity, colour, and morphology of the brightest simulated galaxies in the most massive dark matter haloes agree reasonably well with those of the corresponding observed cluster populations, provided corrections for dust extinction are taken into account.

It is interesting to note that only very few galaxies are found in the large voids, which are clearly apparent in the top panels of Fig. 2.9 as large regions underdense in dark matter. In fact, we have been able to show that simulated samples of galaxies do not populate the voids homogeneously. This is in agreement with observations which suggest that different types of galaxies all respect the voids defined by the bright spirals. Almost half of the volume of the Local Universe has a density less than 10% of the mean value. Our model can explain this so-called void phenomenon down to the scale of a typical dwarf galaxy in the Local Group.

On large scales, we gauged the success of the numerical scheme by comparing the mock distributions with the optical UZC and with the far infrared PSCz catalogues, which cover one third and 83% of the sky, respectively, and reach a depth of $cz \sim 8000\,\mathrm{km\,s^{-1}}$. In the infrared, the amplitude of clustering of the simulated galaxies in both cosmologies is very close to that of real galaxies. At optical wavelengths, the correlation function of mock galaxies matches that of the optical catalogue without significant bias in ΛCDM, while it shows significant antibias in τCDM. Because our new mock catalogues reproduce the local structure seen in the surveys, one can also evaluate the cross-correlations between the model galaxies and the observed galaxies. Good agreement is found on scales larger than the smoothing scale employed on the initial conditions, as expected. Because an infrared galaxy catalogue was used to constrain the simulations, we find that the match to the PSCz is better than to the UZC catalogue.

We have made our new mock galaxy catalogues publically available[1]; they can for instance be used to calibrate methods for estimating the cosmological density parameter from the observed peculiar velocity field of galaxies. The constrained simulations of the Local Universe can also be employed to study the formation history of local clusters like Coma, or to predict the fate of high redshift galaxy populations like Lyman Break Galaxies or QSO hosts. (Hugues Mathis and Volker Springel)

[1] http://www.mpa-garching.mpg.de/NumCos/CR

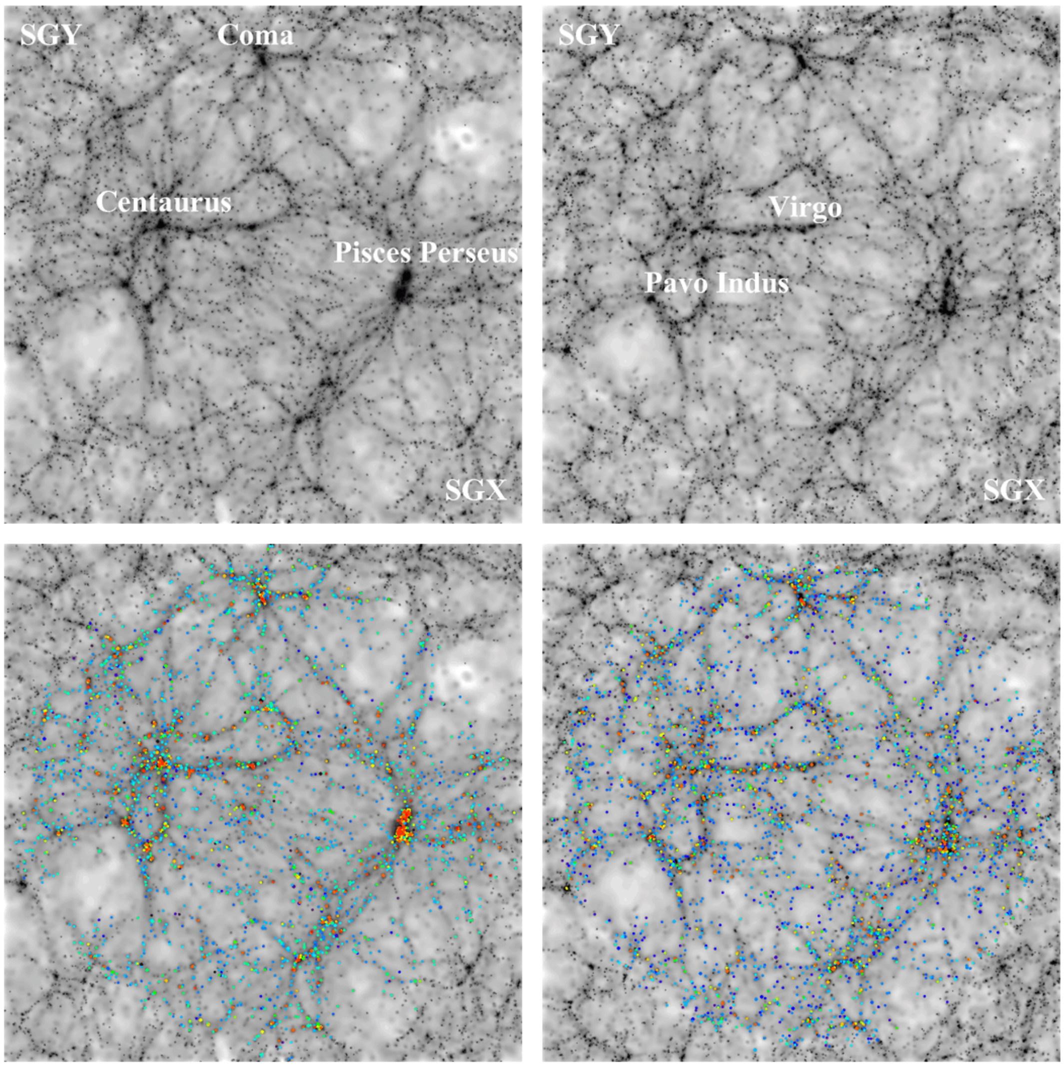

Figure 2.9: Top panels: the present-day dark matter distribution in the constrained simulations of the Local Universe. The slice shown is $30\,h^{-1}$ Mpc thick, centred on the SG plane. The side of the picture is $180\,h^{-1}$ Mpc. The ΛCDM and τCDM models correspond to the left and right column respectively. Bottom panels: the galaxy distribution on top of the dark matter, in the same slices.

2.5 The visible light from a black hole

As the name says, black holes are usually invisible. Most of the known black holes in our galaxy are in fact special cases among the much larger number of invisible holes: they have a companion star from which gas flows to the hole, a process called *accretion*. The accreting gas becomes hot through internal friction in the intense gravitational field near the hole and emits X-rays. Some of the gravitational energy released by accretion is also emitted at other wavelengths. Although the visible wavelengths only account for a small amount of energy radiated by the accreting hole, they are of special interest because of the detail with which they can be observed from the ground.

The visible light from accreting holes was until now thought to be due to a simple secondary effect, namely reprocessing of X-rays. X-rays from the central regions of the accretion flow are thought to illuminate and heat the outer regions of the accretion disk. The disk then re-radiates the incident X-ray energy at optical and ultraviolet wavelengths.

Unique new observations of the transient X-ray source KV UMa (also known as XTE J1118+480), obtained in a collaboration between MPA, MPE and the Osservatorio Astronomico di Brera, lead to a different view. These observations show that the visible light is not a side effect and is probably emitted from a very interesting region – the area close to the black hole where mass is flung out of the system by a very strong magnetic field rotating around the hole. In this view, the visible light is the cyclotron emission produced by electrons spiralling in the hot plasma flowing outward along the magnetic field lines. If this model applies more generally to accreting black holes, observations at visible and ultraviolet wavelengths can be used to study regions close to a hole in much more detail than previously thought possible. This holds promise for understanding the still somewhat mysterious physics of this region, including their magnetic fields and outflows.

The X-ray observations were done in July 2000 with NASA's Rossi X-ray Timing Explorer satellite (RXTE). Simultaneous optical observations were made with OPTIMA, a fast photometer developed at the Max-Planck Institute for Extraterrestrische Physik (MPE) attached to the 1.3m telescope at Mt. Skinakas on Crete (operated jointly by MPE and the Foundation for Research and Technology Hellas). This instrument counts individual photons and records their arrival times with a GPS-based clock, to an accuracy of a few microseconds. A total of 2.5 hrs of simultaneous observations were collected.

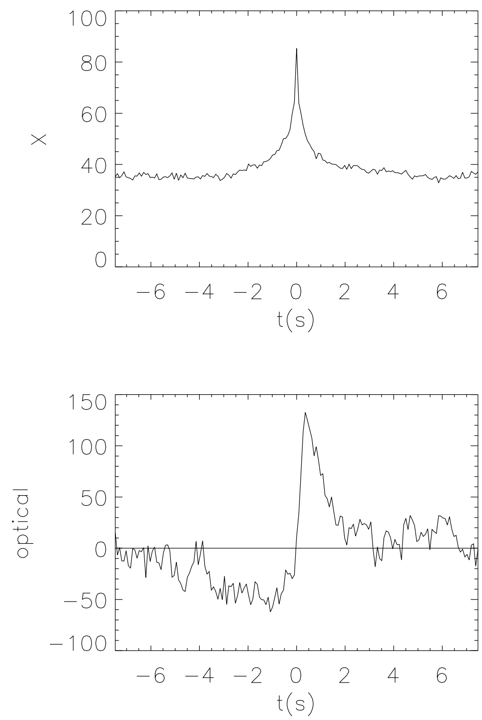

Figure 2.10: Average light curve of 100 burst events in the X-ray light curve of KV UMa (top), and the corresponding optical light curve (bottom, with the mean subtracted).

As is usual for accreting black holes, the X-ray flux from KV UMa was highly variable, consisting of spikes or 'bursts' with durations of the order of a few seconds. The visible light was also variable on short time scales, but its relation to the X-rays was not immediately apparent because of the noise in the data. By adding together a number of burst events, average burst light curves could be extracted from the noise. The result of this procedure (Fig. 2.10) showed that the visible light was related in a rather curious way to the X-rays. Part of it could be seen as a 'delayed response', peaking at 0.5 s after the X-ray maximum, but there was also a *decrease preceding* the X-rays.

Superposing events does not lead to precise answers, because of the irregular shape of the bursts. A more accurate view is obtained by computing the cross-correlation function between the X-ray and optical time series. As Fig. 2.11 shows, the shape of the cross correlation is quite similar to that of the visible 'burst' light curve of Fig. 2.10, but shows more detail. In particular, there is a very

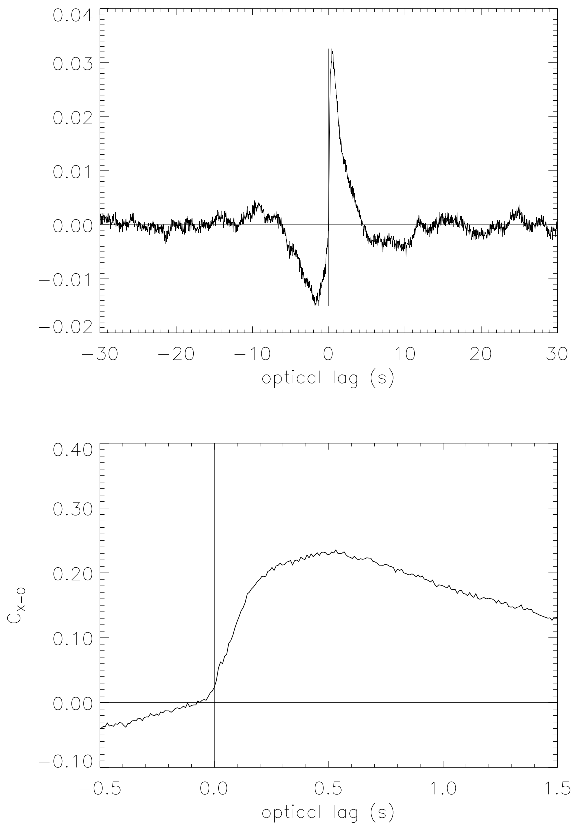

Figure 2.11: Top panel: cross-correlation between X-ray and optical light curves of KV UMa. Bottom: region around zero lag shown at higher resolution.

sharp change in slope around $t = 0$ (the maximum of the X-ray bursts).

The interpretation of this result is problematic. In particular, the combination of a dip preceding and a spike following the X-rays is hard to accomodate in a single physical model. However, can one be sure that the peak and the dip are produced by the same physical process? In fact, the shape of the cross correlation turned out to be somewhat variable, and this could be exploited to answer this question. Because of the long duration of the available observations, the statistical properties of the variation could be analyzed in detail using the technique of principal component analysis (PCA). The result of this analysis showed that the dip and the peak dip were actually separate components, with amplitudes that varied independently of each other. They were therefore probably due to unrelated processes.

Leaving aside the dip, whose origin remains somewhat obscure, we can look for possible explanations for the delayed peak in the visible light curve. At first sight, a promising model is the 'reprocessing' of X-rays. The central regions where the X-rays are produced heat the outer parts of the disk, which then radiate at visible wavelengths. The size of the disk is such that a delay of the order of a second is just what would be expected from the light travel time across the disk. However, when this is modeled in a quantitative way, it turns out to be impossible to reproduce the sharp rise at $t = 0$. The predicted optical response is much more smeared out. A second problem with this model is the amount of visible light in KV UMa, which is larger than can be comfortably accounted for in a reprocessing model.

In view of these difficulties, alternatives are needed. The combination of short variability time scales (of the order 50 msec, as seen in Fig. 2.11) and the high flux of visible photons suggests that the visible and UV light has a more interesting origin, namely cyclotron emission by a hot plasma in a strong magnetic field, of the order of $10^6 - 10^7$G. Such field strengths can occur in the inner regions of the accretion flow. The presence of such strong magnetic fields is also consistent with the relativistic jets associated with accreting black holes such as KV UMa. The best current model for such jets involves strong magnetic fields near the hole.

The delay of the optical variations with respect to the X-rays can be understood in the cyclotron model if the region emitting the visible light is part of an outflow. Modulations in the speed of this flow travel outward with it. They become visible first in the inner regions, where ultraviolet light and X-rays are emitted, and later at the somewhat larger distances where most of the visible light is produced. To explain the observed delay of a few seconds, the flow speed must be of the order 20000 km/s, much less than the speed of light. The model thus assumes that object produces not only a fast outflow (jet) but that the rotating magnetic field also ejects a slower, denser outflow (see Fig. 2.12). This would support the well- known analogy of the accreting black holes in binaries like KV UMa or Cygnus X-1, with the nuclei of active galaxies (AGN). The supermassive black holes in AGN produce spectacular relativistic radio jets which are often also associated with dense outflows at lower speeds (the so-called 'broad line regions' in quasars). (Henk Spruit, Gottfried Kanbach).

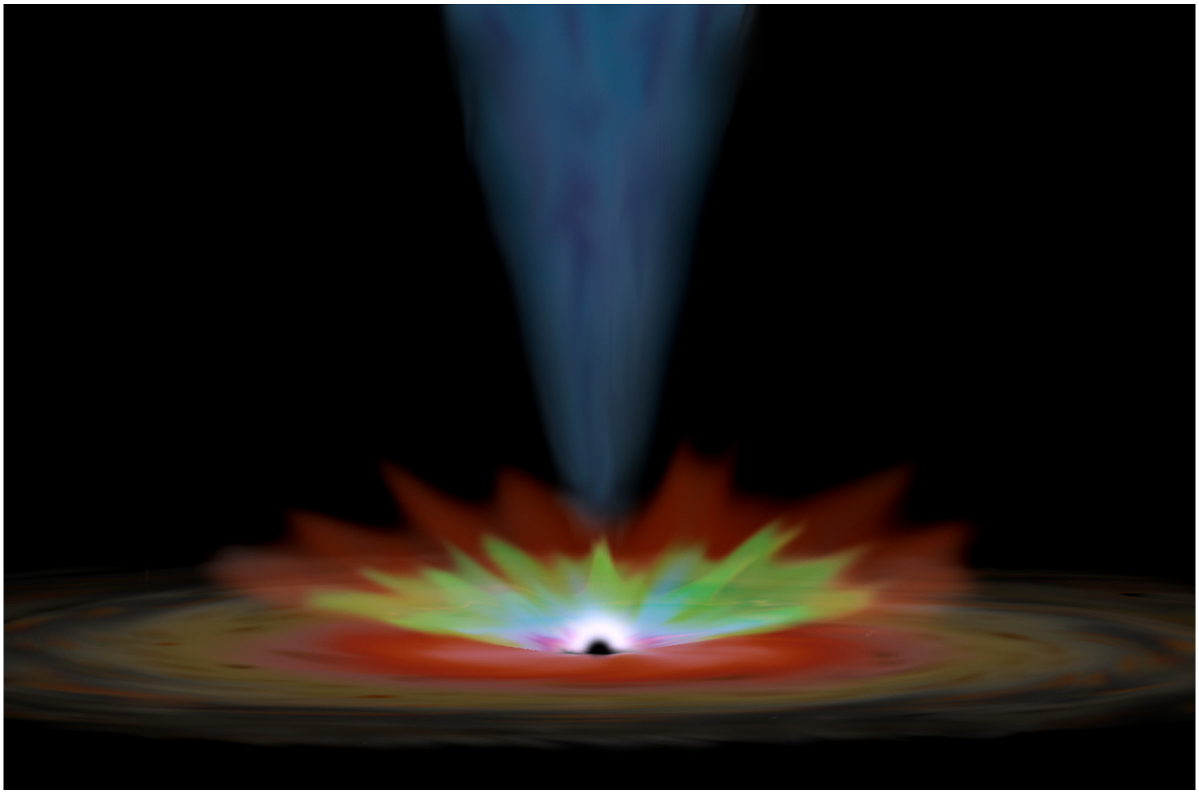

Figure 2.12: Artist's impression of the black hole in KV UMa, based on simultaneous X-ray and optical observations. Mass drawn from a secondary star forms an accretion disk which feeds mass to the hole (dark reddish and brown colors). During the infall X-rays (white region) as well as plasma outflows are emitted. A dense slow outflow produces strong ultraviolet (purple) and visible (green) radiation. The blue fuzz indicates the base of a much faster tenuous jet that produces radio emission.

2.6 Gravitational waves from core collapse supernovae

Whereas light or sound waves travel *through spacetime*, gravitational waves are propagating *ripples of spacetime itself*. Such distortions in spacetime, which can be measured as a periodic shift in the length of a suitably chosen "measuring rod", are generated by motions of aspherical matter concentrations. However, because this effect is so small, even the most violent astrophysical phenomena involving extremely compact objects (e.g. colliding and merging black holes or neutron stars, or collapsing stars) emit gravitational waves that manifest themselves on Earth as a tiny relative shift of only 10^{-20}

So it is not surprising that although gravitational waves were predicted by Albert Einstein in his theory of general relativity over 80 years ago, only now have new developments in technology enabled physicists to tackle the problem of detecting them. One type of detector currently being developed in a number of different countries is a large laser interferometer. (see figure 2.13). Even in the largest detectors, a detection of a gravitational wave translates into a measurement of a distance which is only about 1/100th of the size of an atomic nucleus! A successful direct detection of gravitational waves, which will probably occur within the next 5 years, will not only unequivocally prove Einstein's bold prediction, but even more interestingly, will open a completely new "window" onto the universe. By routinely observing gravitational waves, astrophysicists will gain new and otherwise entirely unattainable insights into such fascinating objects like black holes, the enigmatic cosmic gamma ray bursts, or the driving engines behind stellar supernova explosions.

Because the detection of gravitational waves is such a difficult task, very efficient electronic filters are used to extract the signal signal from the data measured by a detector. In order to find this "needle in a haystack", it is important to know the form of the prospective gravitational wave signal as precisely as possible. It is therefore important to predict these signals using theoretical models of various astrophysical sources of gravitational radiation (so-called *wave templates*). Moreover, by comparing the predicted signals with those actually detected, astrophysicists can test and constrain their models and eventually gain a better understanding of the fundamental physical processes which govern the event.

One example of a promising source of gravitational waves is the gravitational collapse of the rapidly rotating core of a massive star to a neutron star and the subsequent explosion of the star in a spectacular supernova event. Within fractions of a second a mass larger than that of our sun is compressed during the collapse to densities exceeding 10^{14} g/cm^3. The gravitational wave signals produced typically consist of a strong short burst with a complicated temporal structure, and they depend crucially on many aspects of the complicated physics involved in this powerful event. Researchers at the Max-Planck-Institut für Astrophysik have been modelling stellar core collapse with increasing complexity for many years using large-scale computer simulations. Although not yet realistic enough to provide detailed wave templates, these simulations indicate that gravitational wave signals from supernovae in our Galaxy are strong enough to be detectable by the new detectors which iwill soon be operational (see figure 2.15).

A group of scientists at the Max Planck Institute for Astrophysics has recently extended these simulations and has succeeded for the first time in simulating the collapse of a rotating stellar core to a neutron star including the effects of general relativity, This constitutes a major step towards realistic predictions of gravitational wave signals. Figure 2.16 shows the predicted signal for a typical rotating core collapse model. A comparison between the previous Newtonian simulation (red line) and the new improved general relativistic simulation (blue line) clearly reveals a qualitative change of the signal form. This demonstrates that improvements in the physical model underlying the numerical simulation can have a huge impact on the gravitational wave signal.

Interestingly, even when relativistic gravity is included, all the different types of hydrodynamic evolution known from previous Newtonian simulations are still observed. One example is the collapse of a particularly rapidly and very differentially rotating stellar core, leading to a toroidal proto-neutron star and the formation of a strongly anisotropic almost jet-like shock front, which propagates out from the proto-neutron star through the outer layers of the star (see figure 2.14).

The new core collapse simulations will help observers identify and extract gravitational wave signals in their future measurements. Furthermore, they will also allow observers to draw conclusions about the circumstances of the actual supernova event. This will greatly improve on the informa-

Figure 2.13: Aerial view of the LIGO gravitational wave observatory site located at Livingston, U.S.A.; the two interferometer arms (serving as "measuring rods" for probing spacetime), which extend to a length of 4 km, spreadout from the central building to the left and right upper corners of the photograph. Similar detectors are being built in the U.S.A., Italy, Germany, Japan, and Australia. There is close cooperation between the corresponding research groups.

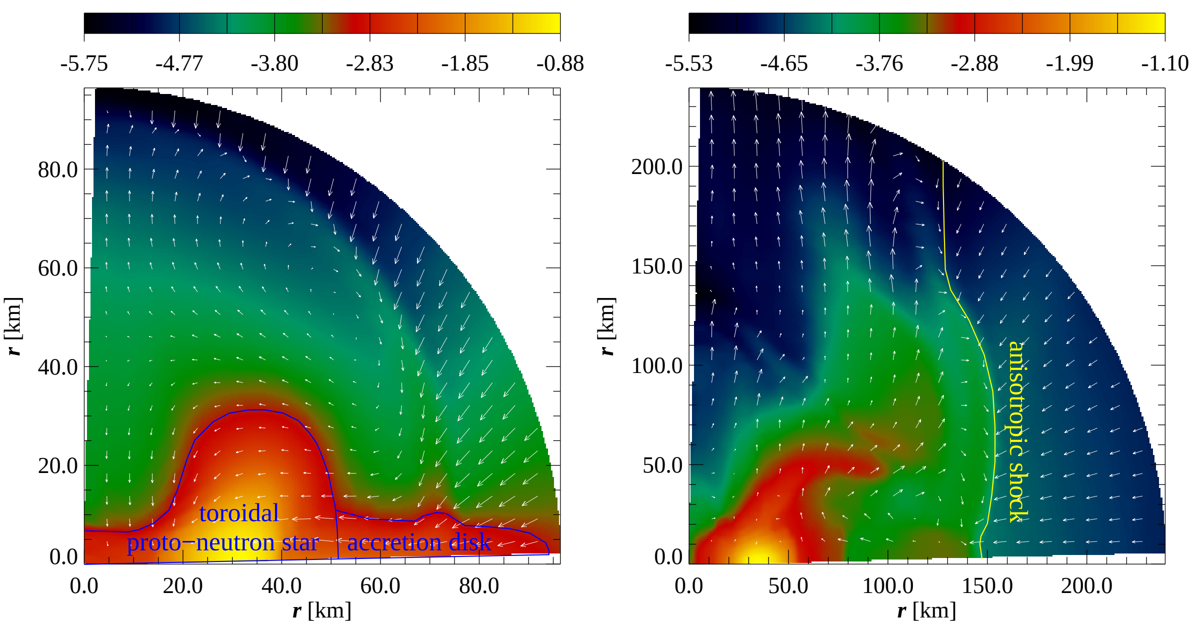

Figure 2.14: Density distribution in the meridional plane of a very rapidly rotating core collapse model: During the contraction of the core, the collapsing matter forms a high density torus. Shortly after the formation of the proto-neutron star (left panel), dense matter concentrates in the equatorial plane as an accretion disk. It is subsequently accreted by the toroidal inner core, which is surrounded by large scale velocity and density vortices (the white arrows mark the motion of matter). From the proto-neutron star, a shock front starts to propagate out, which becomes strongly anisotropic at later times due to the anisotropic density structure (right panel). The color coding specifies the logarithm of the density in units of 10^{14} g cm^{-3}.

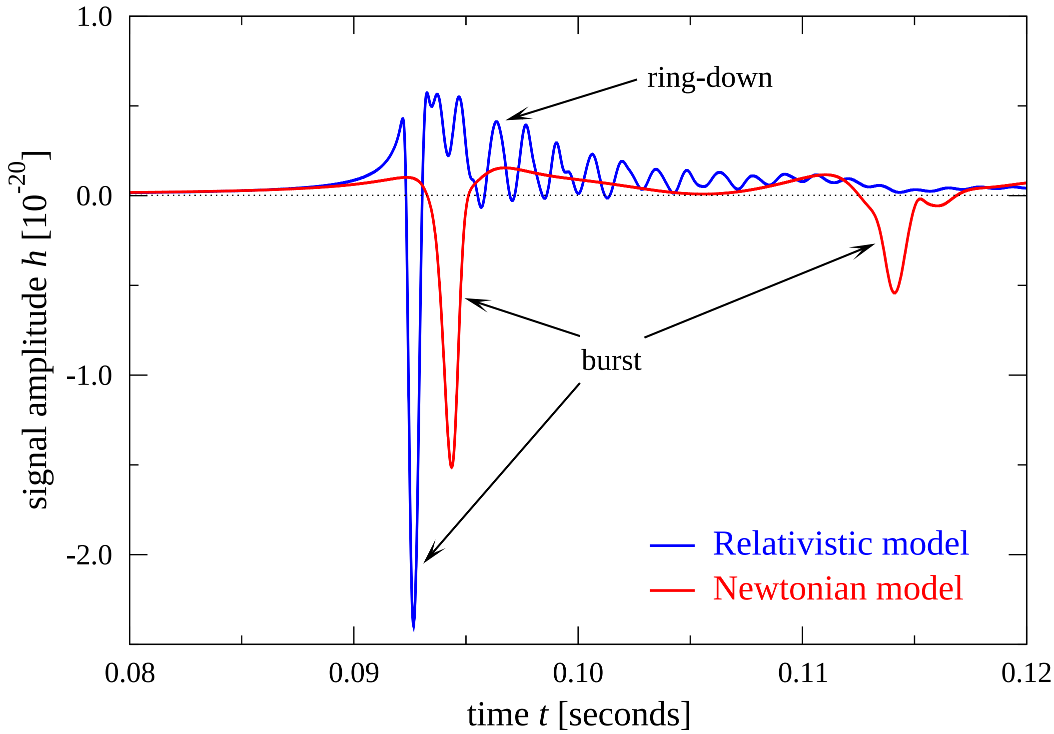

Figure 2.16: Predicted signal for the gravitational waves emitted by a core collapse supernova. Note the significant difference between the signal from the previous Newtonian (red line) and the new relativistic simulation (blue line). The change of the signal shape reflects a qualitative change in the collapse dynamics due to relativistic gravity. The collapsing core in the Newtonian model contracts and re-expands several times until it settles down to a proto-neutron star, emitting a burst of gravitational waves during each bounce. In the relativistic model the proto-neutron star forms instantly, resulting in a single wave burst followed by a typical "ring-down" signal.

tion that can be obtained from observations of the emitted light with conventional optical telescopes. With gravitational wave detectors becoming fully operational in the very near future, astrophysicists are now eagerly awaiting the next supernova in our Galaxy (Harald Dimmelmeier, José A. Font, Ewald Müller and Markus Rampp).

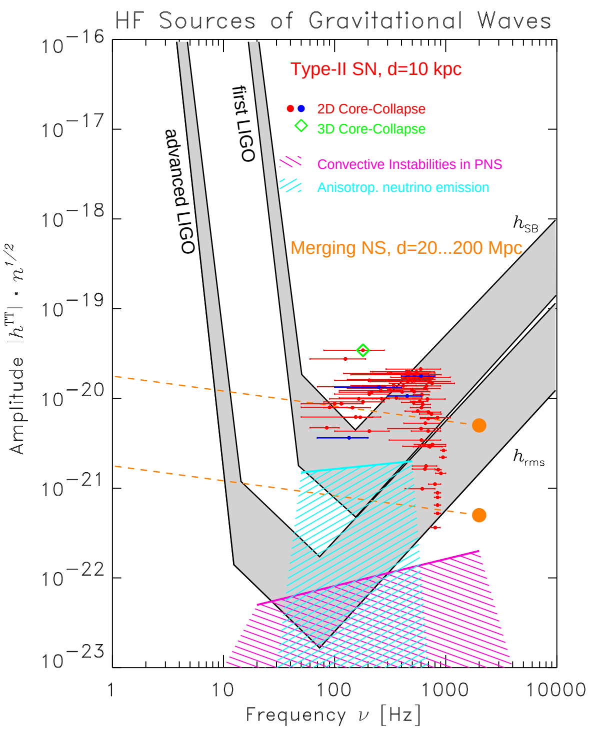

Figure 2.15: Properties of expected gravitational wave signals from core-collapse supernova events (shown as red, blue and green symbols) in our Galaxy. Depending on the assumptions taken for computing the different models (e.g. the amount and distribution of angular momentum of the initial model, different approximations of the microphysics, ...), typical frequencies of the signals range from 100 to 1000 Hertz. Relative amplitudes on earth are typically about 10^{-20}. Signals located within (or even above) the hatched areas marked as "first" or "advanced" in the plot can be detected with the corresponding versions of the LIGO detector. Convective hydrodynamical instabilities in the newly born neutron star or anisotropic neutrino emission give rise to appreciable gravitational wave signals (hatched areas). For comparison, expected signals from neutron star mergers occuring in our Galaxy or within the Virgo cluster of galaxies are shown as yellow dots.

2.7 Unveiling the secrets of superluminal sources

Extragalactic jets are channels of radio emitting plasma that transport matter and energy in opposite directions from the center of some Active Galactic Nuclei to distances of up to a few million light–years. There are several regions in these jets at varying distances from the Galactic Center that can be observed using different instruments. The most interesting region, about one parsec (3.26 light years) from the Galactic nucleus, is seen as a collection of bright blobs or "components" in radio maps. In many case, only a single jet is observable from Earth. This is explained as a result of relativistic Doppler beaming, whereby radiation emitted in the direction of the motion of the fluid is boosted, while radiation emitted in the opposite direction is dimmed. The effect becomes important when the emitting fluid moves with a velocity close to the speed of light. The jet that moves toward us can form any angle with the line of sight. This implies that any jet feature we observe in radio maps is actually a projection onto the plane of the sky. Hence, the magnitude of the motion of the features in a jet is not real but only *apparent*. Indeed, some features appear to move in the plane of the sky with *superluminal* velocities. Parsec–scale jets that display such features are called superluminal sources.

If extragalactic jets are made of relativistic plasma, it is possible to model the hydrodynamic evolution of the jet using a fluid-like approach. We have performed numerical simulations of parsec–scale, relativistic, radio jets using a state-of-the-art multidimensional hydrodynamics code (GENESIS) which integrates the relativistic Euler equations for any given initial configuration of a fluid. In much the same way that a laboratory experiment is used to explain physical observations, a numerical code can be used to generate models that explain observational data. The advantage of simulations is that we are able to control every physical parameter of the underlying model.

The radiation emitted from every point in an extragalactic radio source travels at the speed of light to the detector. Because radio jets are large, radiation produced at different points on the jet will reach the observer at different times. If the jets were steady, there would not be any difference between the radiation produced in the source and the radiation detected on Earth. However, if the emission changes with time, the inclusion of time delay effects in the simulations is necessary for reliable interpretation of observational data (Fig. 2.17). Unfortunately, the incorporation of these effects leads to a cosniderable increase in computational expense.

A number of recent observations point toward the existence of helical structures in relativistic jets. Time delay effects influence and even change the observed morphologies of these systems. In order to understand this in more detail, we have simulated the hydrodynamic evolution of helical jet components. In our simulations, a jet component is a blob of matter which has a higher density and pressure than the surrounding jet. The component initially propagates at the same velocity as the jet. We find that radio features develop that are not associated with a bulk motion of the fluid, but correspond to pattern motions induced by the underlying hydrodynamic structure of the jet. This has important observational consequences, because the standard interpretation assumes that jet components are blobs of matter that are flowing downstream and are expanding and cooling because they were initially over-pressured. Our results demonstrate that there are severe difficulties with this interpretation.

There are several intriguing effects associated with the propagation of components along a helical relativistic beam. The most interesting one is the enlargement and splitting of radio components. The enlargement occurs as the result of the hydrodynamic evolution of the edges of the component. The shape of the component changes because the flow conditions differ upstream and downstream from the injection point of the component. Even in the case of a uniform and straight jet, the two edges of the perturbation will evolve according to the local flow conditions (see Fig. 2.18). The evolution of the two edges of the component is not symmetric, because the component as a whole is boosted by the beam fluid, which moves with a Lorentz factor, $W = 6$ (i.e. 98.6% of the speed of light). The asymmetry even more pronounced when viewed from Earth.

Three dimensional simulations show that the original component eventually splits into two distinct features (backward and forward regions in Fig. 2.18). The backward part moves more slowly than the beam of the jet. One would therefore underestimate the beam velocity using the apparent velocity of this feature, as is conventially done when interpreting observations. On the other side, the forward part of the component moves faster than the beam with a Lorentz factor 9 ($0.994\,c$).

A particularly interesting phenomenon occurs where the helical flow changes from receding to approaching with respect to an observer on Earth. These locations are called the *elbows* of the helix (Fig. 2.19).The radiation emitted by a fluid moving close to the speed of light is beamed into a narrow cone whose opening angle is proportional to the inverse of the Lorentz factor ($\sim 1/W$). If one observes such a fluid at a viewing angle larger than $1/W$, almost no radiation is detected. (Fig. 2.19, case a). However, when the beams turns towards the observer, a sudden increase of the radio flux is detected. (Fig. 2.19, case b)). This triggers the appearance of *phantom* components in front of the original component. Phantom components appear suddenly and do not seem to emerge from the galactic nucleus. Because they are associated with the pattern motion induced by the helical beam, their apparent motions are generally smaller than those of ordinary components (see Fig. 2.17 panels 13 to 44).

Another surprising result is that when the component interacts with the walls of the beam, it does not get brighter. Instead there may be a a rarefaction that causes it to become less luminous . This occurs only when the component impacts the wall of the beam at angles smaller than 30°. Our simulations represent the most detailed investigation of a relativistic jet including time dilation effects. They show that the commonly accepted association of components with a single shock or blob of matter may not be correct. Indeed, it turns out that a single component shape can result in an extraordinarily rich variety of radio features. (Miguel-Angel Aloy, José María Martí, José Luis Gómez, Iván Agudo and Ewald Müller).

2.8 Origin of the X-ray spectrum of accreting black holes

One of the central puzzles in X-ray astronomy is the origin of the hard X-rays in binary stars con-

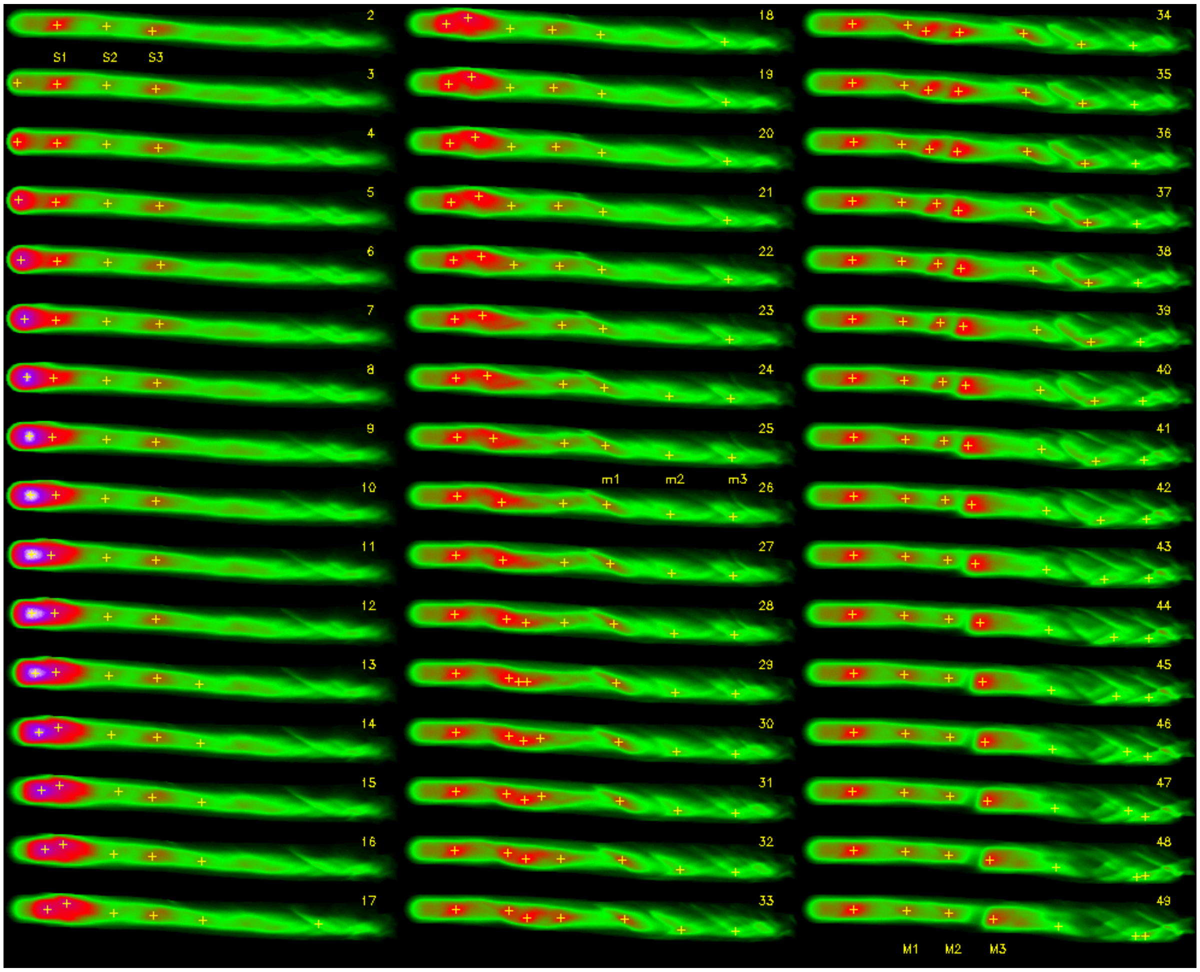

Figure 2.17: Snapshots of the evolution of the radio emission taken in intervals of 0.135 units of time. M1, M2 and M3 refer to the left overs of the component injected (M3 is the backward part of the full perturbation at the end of the evolution). S1, S2 and S3, are steady features that correspond to recollimation shocks. m1, m2 and m3 are the phantom components stimulated by the passage of the forward part of the full component over the elbows of the beam's helix.

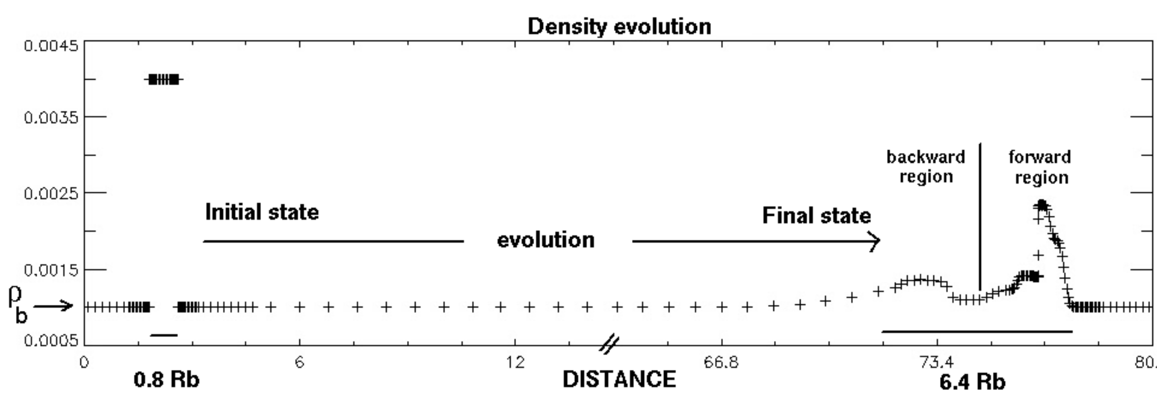

Figure 2.18: Hydrodynamic evolution of a component that has a density and a pressure four times larger than that of the unperturbed medium (ρ_b marks the density of the unperturbed medium). The velocity of both the component and the medium is $v \approx 0.985c$ (the velocity is directed to the right). On the left, one recognizes the initial state with a square shape. On the right, the final state is plotted after $\simeq 80$ units of time when the width of the component has grown by about a factor of five and when it has split into two distinct features.

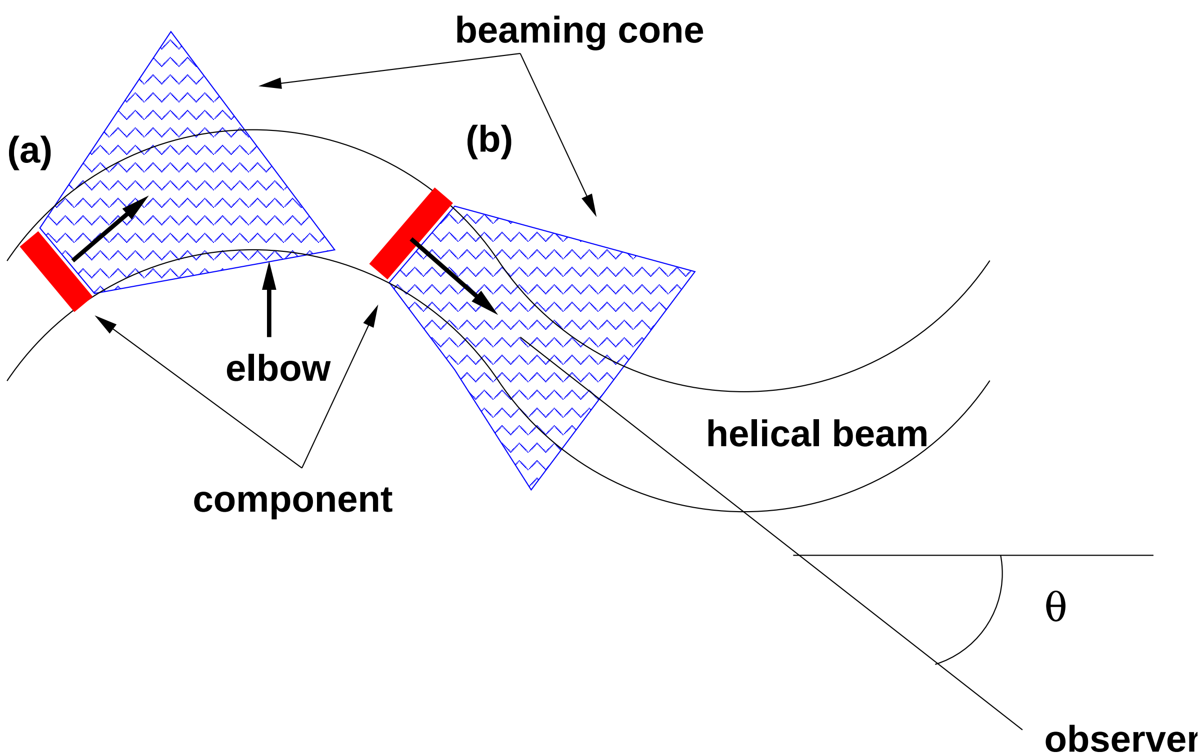

Figure 2.19: Schematic view of the passage of the forward shock of a component through an elbow of a helical jet (projected to the plane of the sky). (a) The forward shock is reaching an elbow of the beam and the observer, that is looking at the jet with a certain viewing angle θ, receives almost no radiation. (b) The forward shock has passed the elbow and moves towards the observer. The observer is now located within the beaming cone of the component and measures much more radiation than in stage (a). Thus, when a component passes an elbow of the helix, a sudden transition from case (a) to case (b) occurs.

taining black holes and neutron stars. It is well established that this radiation is caused by a hot optically thin plasma. But whereas the cool optically thick plasmas sometimes observed are well-understood (they represent the theoretically predicted accretion disks), the origin and the physics of the observed hot plasmas remains elusive.

Various mechanisms for the creation of hot plasma have been proposed in the literature, ranging from thermal instabilities in the surface layer of the disk to solar type coronal loops emerging from the accretion disk's interior. The majority of these proposals are somewhat qualitative and do not have much predictive power. Models of disk evaporation are more concrete and predictive. In these models it is proposed that the hot plasma is created by evaporation of the surface of the disk. The accretion disk does not extend all the way to the last stable orbit of the black hole, but instead makes a transition to a hot optically thin flow. The challenge in these models is to explain how this 'magic' transition takes place.

One such model is the mechanism of evaporation by electron thermal conduction by Meyer & Meyer–Hofmeister, which is similar to the process of evaporation of the Sun's surface that feeds the solar wind. This disk evaporation model works well in regions far away from the hole, but it fails to explain observations of black hole X-ray binaries in which the inner radius of the accretion disk is located much closer to the hole but still away from the last stable orbit. The reason for this is that the evaporation is driven by electrons. Due to their radiative efficiency, electrons lose most of their thermal energy close to the black hole. Ions, on the other hand, radiate much less strongly, and can retain most of the thermal energy they gain due to the accretion process. So one can conclude that, if an evaporation mechanism is to exist close to the black hole, it must be driven by the influx of ions onto the disk's surface.

In order to find out if ions can provide the driving mechanism of evaporation, one needs to consider the non-thermal nature of the hot plasma. Rather than providing a smooth influx of ion energy into the disk's surface layers, the disk is in fact bombarded by individual ions at an energy of a few hundred MeV. As they enter the disk's atmosphere, they gradually lose their energy due to interaction with the local free electrons. The upper layers of the disk heat up, and form a thin comptonizing corona of about 80 KeV on top of the disk (Fig. 2.20). Our self-consistent calculation, which includes the heating due to the ion bombardment and radiative cooling due to bremsstrahlung and comptonization, shows that this layer has a Thompson optical depth of about unity and emits a spectrum that closely resembles typical observed spectra (see Fig. 2.21).

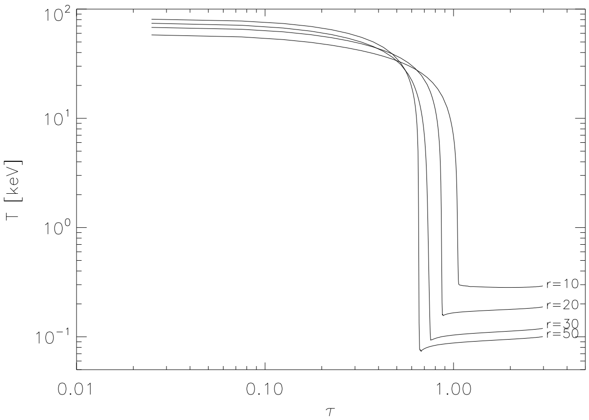

Figure 2.20: The vertical structure of the warm surface layer produced by the ion-bombardment.

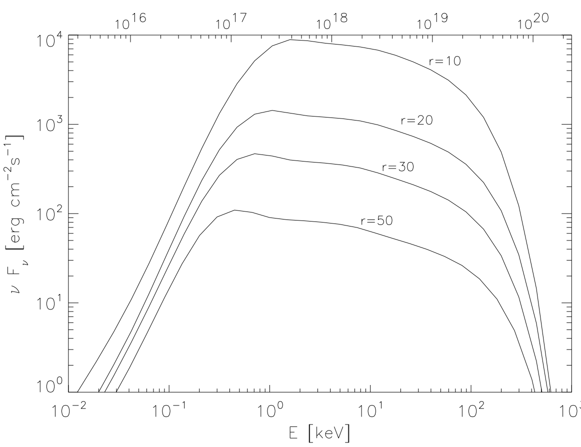

Figure 2.21: Typical spectra produced by the ion-bombarded surface layers of the disk.

Unfortunately, this layer is still not hot enough to evaporate. It is kept relatively cool by abundant low-energy photons emitted from the cool disk under it. Near the inner edge of the cool disk, however, these low energy photons disappear, and the ion-bombarded layer quickly heats up to higher temperatures, around 500 keV. At this temperature, the layer becomes thermally unstable because the ions heat up by internal (viscous) friction. As a result of the peculiar behavior of Coulomb interactions in an ionized plasma, the ions decouple from the electrons and heat up to a new equilibrium around 10-100MeV. Since the ions carry almost all the mass, the layer effectively evaporates,

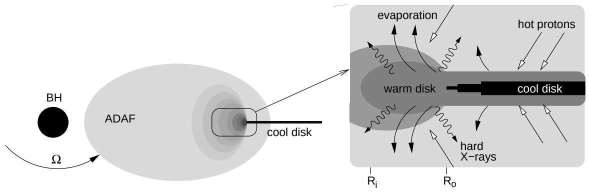

Figure 2.22: A sketch of the geometry of the plasma in the two-stage evaporation mechanism.

forming a so-called ion-supported accretion flow. In effect, we thus have a two-stage evaporation process: matter first evaporates from the cool disk into the warm layer, and then from the warm layer into the ion supported accretion flow (Fig. 2.22).

The two-stage evaporation mechanism described here is a new idea for the explanation of disk evaporation in X-ray binaries, and may explain why under some circumstances we observe accretion disks with inner radii of only a few tens of Schwarzschild radii. Moreover, it is intimately connected to the emission of hard X-rays, not only by the virial temperature plasma, but also by the 80 KeV Comptonizing surface layer.

The physics of the processes involved is well understood and can be applied directly to quantitative models. In this way, detailed predictions of the X-ray spectra of accreting black holes and the time dependence of the accretion flow near the hole can be made. Work on such calculations is in progess at the MPA. (*Bernhard Deufel, Kees Dullemond*)

2.9 V4641Sgr – Super-Eddington source enshrouded by an extended envelope

After its discovery by the BeppoSAX and RXTE observatories in February 1999 V4641 Sgr remained an ordinary, moderately bright source not different from many other Galactic transient sources, until it entered a period of violent activity half a year later (Fig. 2.23). During two days of Sept. 14–15 it produced several powerful and rapid outbursts of X-ray emission the most significant of which lasted for several hours and reached peak flux of ~ 12 Crab. Because of the rapid nature of the events, data on the X-ray behaviour of V4641 Sgr was almost exclusively obtained by the All Sky Monitor aboard RXTE observatory, which measured the source flux approximately once every 1.5 hours. The source had a number of properties that distinguished it from the other X-ray binaries. The most remarkable were strongly variable low energy absorption by a warm or ionized absorber with NH $\gtrsim 10^{23}$ cm^{-2}, a very bright iron K_α line and a rapid final decline of the X-ray emission by ~ 2.5 orders of magnitude within ~ 2 hours.

Radio observations performed at the end of the outburst showed an extended jet-like radio structure with an axis ratio exceeding 10:1. Although no apparent proper motion was observed, its angular size combined with the lower limit to the source distance of $\gtrsim 0.5$ kpc available at that time, implied moderate superluminal motions, assuming that the ejection occurred during the brightest of the X-ray outbursts.

Key information, that dramatically changed the overall picture, came from the optical data. The optical spectroscopic observations of V4641 Sgr performed a year later when the source had returned to the quiescence led to its identification as a high mass black hole binary with orbital period of ≈ 2.81 days and a mass of $9.6 M_\odot$. Most importantly, the optical observations constrained the source distance to 7.4–12.3 kpc thus placing the source much further away than previouslt thought. This new distance measurement dramatically changed our estimates of the source energetics. At this distance the flux of 12 Crab measured by ASM/RXTE near the peak of the brightest outburst implies that the 2-12 keV luminosity at the peak exceeded $\gtrsim 4 \cdot 10^{39}$ erg/s, i.e. was at least 3 times higher than the Eddington luminosity for a $9.6 M_\odot$ black hole ($\sim 1.3 \cdot 10^{39}$ erg/s). The angular size of the extended radio source implies, at the revised distance, an extremely superluminal proper motion with apparent velocity of $\gtrsim 9.5c$.

Another remarkable property of V4641 Sgr was revealed by the optical photometry (Fig. 2.23). The photometric data collected by amateur astronomers in Sept. 1999 and published by the Variable Stars Network showed that the maximal visual magnitude during the outburst exceeded the quiescent level by $\Delta m_V \gtrsim 4.7^{\rm m}$ and reached $m_V \gtrsim 8.8^{\rm m}$. Because of the gap in the data between Sept. 14.8 and 15.3, corresponding to day time in Japan where all observations were made, the optical observations probably missed the peak of the optical outburst.

Although the low mass systems constituting the majority of the black hole transients commonly increase their optical brightness by as much as $\Delta m_V \sim 8 - 10^{\rm m}$ due to emission from the irradiated outer accretion disk and the irradiated side

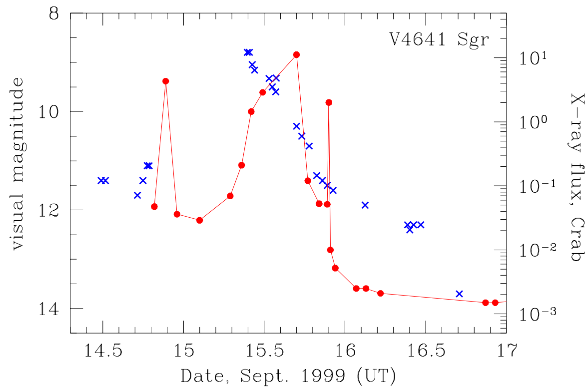

Figure 2.23: The light curves of V4641 Sgr in the optical V-band (crosses) and in X-rays (circles) near the peak of main outburst in Sep. 1999.

of the companion star, the observed brightening of V4641 Sgr by $\Delta m_V \gtrsim 4.7^{\rm m}$ is outstanding for a high mass binary. The reason is that the high mass systems have a bright optical star, which is often intrinsically more luminous that the X-ray source itself. As a result, illumination from the latter cannot increase total optical luminosity of the system significantly. Moreover, the absolute optical magnitude of V4641 Sgr at the peak was so high, that interpreting the increased optical brightness in the same manner as for LMXBs leads to an extremely high luminosity for the system. Indeed, assuming that the peak optical flux is due to optically thick thermal emission of the accretion disk or a companion star, one can estimate the temperature ($T \sim 3{\cdot}10^5$K) and the bolometric luminosity. Even the most conservative estimates give a bolometric luminosity of $\sim$ few $\cdot 10^{41}$ ergs/s, i.e. more than two orders of magnitude greater than the the Eddington critical luminosity for a $10M_\odot$ black hole.

Although there are many ways to produce a luminosity slightly above the Eddington limit, it is very unlikely that a source powered by accretion can exceed the Eddington critical luminosity by 2–3 orders of magnitude. Therefore an alternative scenario is needed.

As was suggested already in 1970s, a supercritical accretion onto a black hole can result in the formation of a wind, or a geometrically thick envelope surrounding the black hole. Such an envelope, under certain circumstances, can absorb the primary X-ray flux and re-emit it in the optical and UV bands. It turns out that the parameters of the envelope are tightly constrained by the observed optical flux and the requirement that (i) the total luminosity does not significantly exceed the Eddington value, (ii) its size does not exceed the orbital size of the binary system. Indeed, if the envelope temperature is too low, $T < 3 \cdot 10^4$ K, then the size of the emitting region required to explain observed optical luminosity exceeds the size of the binary system. If, on the other hand, the temperature is too high, $T > 3 \cdot 10^6$ K the bolometric luminosity exceeds the Eddington value even under assumption of an optically thin emission spectrum.

In order to efficiently absorb and re-emit X-rays from the black hole, the envelope should be optically thick in photo-absorption for X-rays and infrared and optical emission. On the other hand, in order not to exceed the Eddington luminosity the envelope has to be transparent in the UV and soft X-ray bands where the bulk of energy is emitted. These requirements constrain the density of the envelope to $n \sim 10^{12-13}\,{\rm cm}^{-3}$. The total mass of the envelope is then $M_{\rm env} \sim \int n dV \sim 10^{23-24}$ g. Assuming an Eddington mass accretion rate, such an envelope could be accumulated over 10^4–10^5 s.

The relatively smooth behavior of the optical flux (Fig. 2.23) reflects the change of the total intrinsic luminosity of the source and the amount of X–rays absorbed by the reprocessing region. At the maximum of the optical light curve, most of the X–rays are probably absorbed, while later most of the X–rays escape the envelope freely. Rapid changes in X–ray flux might be due to changes of the geometry of the absorbing region (e.g. edge of the torus obscuring line of sight) or thermal instability in the gas that causes fragmentation of the medium into separate clouds. In the course of such changes significant and rapid redistribution of the emitted energy over wavelength (optical, UV, X-rays) may occur, while the bolometric luminosity of the source behaves much more smoothly and reflects the mass accretion rate onto the black hole. The envelope vanishes during the subsequent evolution of the source when the apparent luminosity drops well below the Eddington value. Thus this transient source provides us with direct evidence of dramatic changes in the character of an accretion flow occurring at the mass accretion rates near or above the Eddington value, as predicted a long time ago by theoretical models. (M. Gilfanov, E. Churazov, R. Sunyaev, M. Revnivtsev)

2.10 Lighthouses of the Universe

During August 6-10, 2001 Garching hosted a large astrophysical conference entitled “Lighthouses of the Universe: Most luminous celestial objects and their use for cosmology”. The conference was organized jointly by the Max-Planck-Institut für Astrophysik, Max-Planck-Institut für Extraterrestrische Physik, European Southern Observatory and Universitäts-Sternwarte München.

The name “Lighthouses” was coined from sailor lingo in order to stress that the objects under discussion were among the brightest in the Universe and visible from the most distant parts of it. These objects include supermassive black holes, supermassive stars, gamma-ray bursts and jets of extremely hot and energetic matter.

Two major sets of questions related to these extreme objects were addressed. The first was: When and how were these objects formed, what source of energy powers them and how do these objects die? The second set of questions asked how one could use these objects to learn more about our Universe, in particular about the early stages of its evolution.

The broad theoretical overviews of the nature of “lighthouses” presented during the conference were complemented by astonishing new results from orbital and ground based observatories such as Chandra, XMM, VLT and many others. With such powerful instruments, one can directly see the objects as they were born many billions of years ago when our Universe was young. The discussions were very intense and emotional– not surprising given that the subject is at cutting edge of modern astrophysics.

One area that rapidly evolving into a powerful cosmological tool is the study of distant explosions of supernovae type Ia. These are potential “standard candles” that can be used as distance indicators. The most recent observations have made it possible to verify if the expansion of our Universe accelerates or decelerates and to constrain other important cosmological parameters. Present data favour an accelerating Universe and an important contribution from the so-called Lambda-term, introduced by Einstein in an attempt to build a steady-state Universe, but discarded again after Hubble discovered the Universe was expanding.

Impressive results from the Sloan Digital Sky Survey were reported. This survey will map one-quarter of the entire sky, determining the positions and absolute brightnesses of more than 100 million celestial objects. The survey has already uncovered distant quasars with redshifts greater than 6. At that time, the Universe was 7 times smaller than now. The very first “lighthouses” were in the process of forming. The distribution of these “lighthouses” on the sky was not perfectly uniform. In fact, these lighthouses trace the large-scale structure of our Universe and are formed in regions where gravitational instabilities amplified the background of tiny initial perturbations. The present status of the state-of-the-art simulations of the large-scale structure was reported and comparisons between the predictions of the simulations and the observations were presented.

New results from the Chandra and XMM X-ray observatories demonstrated the complexity and beauty of another class of lighthouses – clusters of galaxies – where hot gas sitting in the gravitational potential of the cluster is responsible for the observed X-ray emission. Shocks, cold fronts, bubbles and other complicated features are now clearly seen in these objects. The same observatories are now pushing forward the study of the X-ray background, which is composed primarily of the contributions of distant Active Galactic Nuclei and quasars. With Chandra and XMM, more than 90already been identified with individual sources.

Very interesting numerical and analytical results were reported on the formation of the very first stars. These stars are thought to be responsible for injecting the first heavy elements into the primordial gas, which consisted mostly of hydrogen and helium.

Another extremely interesting session was devoted to the formation of supermassive black holes and the extraction of energy form these objects. These monstrous objects (with masses a billion times that of our Sun) are the most luminous sources in the distant Universe. The same objects are present closer to home (within 10-20 Mpc), but for some reason they are dormant and emit at a much lower level than their analogues at higher redshifts. What powers these objects – accretion of matter or rotation of the supermassive black holes? And why are they so dim in our vicinity? These were very important and nagging questions.

A special session was devoted to the Gamma-Ray Bursts. During the past few years the detection of afterglows in the X-ray, optical and radio energy bands that follow the short outburst of gamma-ray emission, and the identification of the host galaxies proved that the sources of the bursts are at cosmological distances. Various models of these objects were presented and discussed. The possibility to use the GRBs to study the environment of distant galaxies was stressed.

Many other topics were considered at the conference, including gravitational lenses, the physics of jets, the nature of the most powerful objects in various energy bands and so on. The conference was certainly a success and we all learned a lot about new and exciting facts and ideas (Marat Gilfanov, Eugene Churazov, Rashid Sunyaev).

3 Research Activities

3.1 Stellar physics

The Sun and the Solar System. H. Spruit developed a model for the generation of magnetic fields in stably stratified stellar interriors. This dynamo process operates directly on differential rotation, without the involvement of convective velocity fields. This model was incorporated into a stellar evolution code in a collaboration with A. Heger and S. Woosley (University of California, Santa Cruz). The torques exerted by the magnetic field extract angular momentum from the evolving core of the star. In supernova progenitor models computed in this way, there was enough angular momentum left in the core to explain the rotation of pulsars, but not enough to produce 'collapsar'-tori.

In collaboration with P. Foukal (CRI, Cambridge, Mass.), H. Spruit revisited the interpretation of solar irradiance variations and their possible effect on the Earth's climate. They concluded that the observed effects are almost entirely explainable by the simple superposition of dark and bright structures caused by magnetic fields on the Sun's surface. The known physical mechanisms of luminosity variation of the Sun, including these 'surface effects' are too small to have an effect on the Earth's climate on human time scales. With this work they hope to put to rest a continuing controversy about the possible significance of solar effects for global warming.

On May 1, 1996 the Ulysses spacecraft detected cometary ions, most probably from comet Hyakutake whose nucleus was 3.5 AU away. At the same time, an unusual magnetic field structure was detected by the spacecraft's magnetometer. R. Wegmann performed MHD model calculations showing that a noticeable disturbance of the solar wind velocity and of the interplanetary magnetic field by a comet occurs only up to distances well below 1 AU. Nevertheless, cometary ions can survive in the solar wind flow to larger distances.

U. Anzer and P. Heinzel (Ondrejov, Czech Rep.) developed an iterative scheme to calculate the magnetostatic equilibrium and the non-LTE radiation field self-consistently and they applied it to their models for vertical prominence threads. In addition they studied the properties of prominence-corona transition regions both along the magnetic field lines and accross them and calculated the resulting line profiles. They also discussed the problem of extended EUV filament channels.

Single Stars. Research in the field of stellar evolution has focused on old low-mass stars, both in globular clusters and in the galactic halo. Questions addressed were the effect of sedimentation on age determinations and the lithium abundance (Weiss and Salaris, Liverpool), nucleosynthesis in the helium-flash of Population III red giants (Schlattl and Salaris, Liverpool, Cassisi, Teramo, and Weiss), and abundance anomalies in red giants (Denissenkov, St. Petersburg, and Weiss). In the last area, an interesting result was obtained that observed Al abundances could be explained by the already established "deep mixing"-scenario if the observed aluminum is in fact the nuclear unstable ^{26}Al-isotope. If this could be verified, it would immediately prove the evolutionary scenanrio and the assumed mixing timescales.

Flaskamp, Weiss and Tsytovich (Moscow) demonstrated that the Sun could be used to put limits on the amount of electron screening in nuclear reactions. It appears that the standard Salpeter formula for week screening provides the best models and may not be modified by more than 5%, before becoming inconsistent with helioseismological results.

As part of an extendend collaboration, Marigo, Girardi (both Padua), Groenewegen (ESO) and Weiss have developed the most refined model for synthetic post-AGB and Planetary Nebulae populations. The method andthe first comparisons with properties of galactic Planetary Nebulae have been published. The applications, in particular the development of a purely theoretical Planetary Nebulae Luminosity Function, await further effort.

As part of his Diploma Thesis, F. Linke, supervised by J.A. Font, H.-Th. Janka, E. Müller and P. Papadopoulos (School of Computer Science and Mathematics, Portsmouth), performed general relativistic hydrodynamical simulations of the spherical collapse of supermassive stars. Using a physical equation of state, it was possible to calculate the neutrino emission during the collapse. The detailed models do not support the suggestion that collapsing supermassive stars can be sources of cosmic gamma-ray bursts.

Binary Systems. Low–mass stars, brown dwarfs and giant planets have recently become the focus of numerous theoretical and observational studies. Computing the internal structure and evolution of such objects is still a non–trivial task because of numerous problems associated with the equation of state, opacities, and stellar atmospheres. Using the most up to date input physics, evolutionary models for cool methane brown dwarfs with masses down to $10^{-3}M_\odot$ which take into account the formation of dust in the cool atmospheric layers were calculated by I. Baraffe together with F. Allard, G. Chabrier (Ecole Normale Supérieure de Lyon), and P. Hauschildt (University of Georgia, Athens)

Compact binaries, i.e. binary systems in which at least one of the two components is a compact star (white dwarf, neutron star, black hole), are of considerable astrophysical interest. One of the ongoing activities in the theory of stellar structure and evolution concerns the formation and evolution of such objects.

One topic of research focuses on the formation of long–period pulsar binaries. In particular the absence of millisecond pulsars in binary systems with orbital periods longer than about 200 days can be understood as a consequence of episodic disc accretion if the duration of the quiescence is longer than $\approx$ 100 yr. In this context H. Ritter and A. King (University of Leicester) have derived an empirical lower limit for the duration of the quiescence of such systems based on observed pulsar data. The result is that in the progenitors of long-period pulsar binaries the duration of the quiescence is likely to be $\gtrsim$ 1500 yr.

Population synthesis calculations for the formation of the recently discovered high–velocity white dwarfs in the Galactic halo have been carried out by H. Ritter in cooperation with M. Davies and A. King (both University of Leicester). The calculations are based on a model in which these white dwarfs are the descendants of intermediate mass secondary stars which are ejected from the progenitor binary system when it is broken up by the supernova explosion of the more massive primary star.

In the context of cataclysmic variables, i.e. binaries in which a white dwarf accretes from an unevolved companion star, I. Barafffe, V. Renvoizé (both Ecole Normale Supérieure de Lyon), U. Kolb (Open University, Milton Keynes) and H. Ritter have addressed the problem of whether the discrepancy between the observed minimum orbital period of cataclysmic binaries and the one predicted by theoretical calculations can be accounted for by the fact that the latter use spherically symmetric models. Based on results of earlier 3D SPH calculations, in which a lobe–filling star is slightly more distended than a spherical star, a simple analytical and numerical scheme was developed to take into account the effects of the altered thermal relaxation. It was found that the theoretical value of the minimum period still falls short of the observed one by $\sim$ 6–8 min.

A. Buening, together with H. Ritter, adapted the MPA stellar evolution code for computing mass transfer in close binary systems implicitly, including the reaction of the donor star to irradiation from a compact, accreting companion. The aim was to study the long–term evolution of cataclysmic variables and low-mass X–ray binaries taking into account the effect of irradiation on a nuclear evolved donor star.

In the context of cataclysmic variables, H. Ritter and U. Kolb (Open University, Milton Keynes) have continued compiling data for the web-based living version of the Catalog and Atlas of Cataclysmic Variables, maintained in collaboration with R. Downes (Space Telescope Science Intitute, Baltimore), R. Webbink (Univeriesty of Illinois, Urbana), M. Shara (American Museum of Natural History, New York), and H. Duerbeck (Free University Brussels, Brussels).

3.2 Nuclear and Neutrino Astrophysics

Results of 2- and 3-dimensional numerical simulations of thermonuclear (type Ia) supernovae, produced by M. Reinecke, W. Hillebrandt and J. Niemeyer, are now used as input into computations of synthetic spectra and lightcurves. In a first attempt, Daniel Sauer used the photospheric approximation was used to calculate near-maximum spectra as part of his PhD thesis supervised by P. Mazzali (Trieste), A. Pauldrach (U. Munich) and W. Hillebrandt. The work will be extended to other phases and to more sophisticated radiation transport schemes. First lightcurves for 3-dimensional explosion models were calculated by K. Maeda (U.

Tokyo) and P. Mazzali during their visit to MPA. In another thesis, M. Stehle is analyzing data of observed nearby Type Ia supernovae in order to link them to physical properties of the models. This work will become part of a Research Training Network (RTN) coordinated by W. Hillebrandt aimed at a better understanding of Type Ia supernovae. The netowrk combinres the theoretical and observational efforts of nine European institutes.

R. Buras, H.-Th. Janka and M. Rampp continued simulations of the core collapse and post-bounce evolution of massive stars with their new Boltzmann solver for neutrino transport. In collaboration with C.J. Horowitz (Indiana Univ., Bloomington) and K. Takahashi the neutrino-nucleon interaction rates were updated to include weak magnetism terms and to take into account the detailed reaction kinematics, nucleon phase space blocking, and an approximate treatment of nucleon-nucleon correlations in the neutron star medium. The simulations yield significantly higher neutrino luminosities (particularly in the general relativistic case) than calculations with a standard description of neutrino interactions. In the spherically symmetric case, explosions could not be obtained, but the models develop layers of convective instability. Two-dimensional simulations are therefore in progress. In collaborative work with G. Raffelt (MPI Physics, Freimann), the effects of a non-conservation of lepton-number in neutrino-matter interactions were investigated. Laboratory measurements do not provide strong limits on such processes, which are allowed in the standard model of electro-weak interactions. In the simulations the supernova evolution exhibits an astonishing insensitivity to such drastic changes of the microphysics.

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

3.3 Numerical Hydrodynamics

Work continued on modeling thermonuclear combustion fronts and type Ia supernova explosions. The group, consisting of W. Hillebrandt, J.C. Niemeyer and M. Reinecke, and PhD students M. Lisewski, F. Röpke and W. Schmidt, investigated questions concerning the nature of subsonic turbulent burning fronts in the flamelet and in the distributed burning regime. They also studied hydrodynamic and flame instabilities and explored numerical methods to model them. The level set method used by the group in the flamelet regime was extended by F. Röpke to allow for full reconstruction of thermodynamic quantities in grid zones cut by the front. The new code was used to study the Landau-Darrieus-instability in the non-linear regime. W. Schmidt investigated various sub-grid models to include the physics on numerically unresolved scales in the codes.

Following up on their earlier work, M. Reinecke, W. Hillebrandt and J.C. Niemeyer presented an improved set of numerical models for simulations of white dwarfs exploding as type Ia supernovae. Two-dimensional simulations were used to test the reliability and numerical robustness of their algorithms. The results indicate that integral quantities like the total energy release are insensitive to changes of the grid resolution (above a certain threshold). This was not the case for their former code. The models were further enhanced to allow fully three-dimensional simulations of SNe Ia. A direct comparison of a 2D and a 3D calculation with identical initial conditions showed that the explosion was considerably more energetic in three dimensions. This is most likely caused by the assumption of axisymmetry in 2D, which inhibits the growth of flame instabilities in the azimuthal direction and thereby decreases the flame surface. The new models give results comparable to observed SN Ia in terms of released energy and production of ^{56}Ni. The numerical models are currently being extended in order to simulate the exploding star for a longer period of time. This will, in turn, allow more detailed comparisons with observed lightcurves and spectra.

In collaboration with W. Hillebrandt, E. Müller and J. Niemeyer, M. Brüggen performed hydrodynamical simulations of nuclear flames in white dwarfs. The group used the FLASH code, a parallel 3D AMR code that includes nuclear burning. It was developed by the Center for Thermonuclear Flashes at the University of Chicago, The MPA group collaborates closely with the Center, both on code development and on validation. Certain test problems are under investigation by both groups. These include comparisons of direct numerical simulations based on the FLASH AMR-code with the MPA flame models, implemented and extended by F. Röpke.

Using the results of recent work in shear instabilities in stratified fluids, R. Rosner, A. Alexakis, Y.-N. Young, J. W. Truran (all U. Chicago), and W. Hillebrandt showed that the resonant interaction between large-scale flows in the accreted H/He envelope of white dwarf stars and interfacial gravity waves can mix the star's envelope with the white dwarf's surface material, leading to the enhancement of the envelope's C/O abundance to levels required by extant models for nova outbursts.

Numerical simulations of relativistic astrophysical systems using the so-called characteristic formulation of general relativity have been carried through at the MPA by a subset of the hydrodynamics group (J.A. Font, E. Müller, F. Siebel), in close collaboration with P. Papadopoulos (University of Portsmouth). F. Siebal, J.A. Font and P. Papadopoulos have studied the interaction of massless scalar fields with relativistic stars by means of fully dynamic numerical simulations of the Einstein-Klein-Gordon perfect fluid system. Their investigation showed that, depending on the compactness of the stellar model, the scalar wave either forces the star to oscillate in its radial modes of pulsation or to undergo gravitational collapse to a black hole on a dynamical timescale.

As part of a Ph.D. supervised by E. Müller, J.A. Font and P. Papadopoulos, F. Siebel has finished the development of an axisymmetric hydrodynamic code based on the Bondi metric, by which the entire spacetime is foliated with a family of outgoing light cones. The code has successfully passed a number of stringent tests involving relativistic stars and gravitational radiation. It has also been applied to the study of axisymmetric relativistic stars, whose mode-frequencies have been extracted in fully relativistic simulations of the Einstein-perfect fluid system. Current research is focused on the computation of the gravitational waveforms emitted in axisymmetric core collapse events.

In collaboration with N. Stergioulas (University of Thessaloniki), J.A. Font continued working on the (gravitational wave-driven) r-mode instability in isentropic, rapidly-rotating relativistic stars. Their most recent work, which extends the parameter space of previous published simulations, provides further insight into the expected amplitude values at which the instability saturates, and presents a kinematical mechanism which explains the final outcome and eventual saturation of these modes. Their investigation shows that gravitational radiation reaction can drive unstable r-modes to a large amplitude, making them a detectable source of gravitational radiation.

J.A. Font continued an ongoing collaboration with the Numerical Relativity group at the Albert Einstein Institute (Golm). Using a family of new formulations of the standard 3+1 formulation of the Einstein equations, Font studied the long-term dynamics of relativistic stars by means of a three-dimensional numerical relativity code (called `cactus`). A comprehensive number of simulations were performed, involving single non-rotating stars in stable equilibrium, non-rotating stars undergoing radial and quadrupolar oscillations, non-rotating stars on the unstable branch of the equilibrium configurations migrating to the stable branch, non-rotating stars undergoing gravitational collapse to a black hole, and rapidly rotating stars in stable equilibrium undergoing quasi-radial oscillations. This investigation provided the first eigenfrequencies of rotating stars in full general relativity and rapid rotation.

In collaboration with F. Daigne, J.A. Font began a research project aimed at studying the runaway instability of thick discs around black holes. This instability is an important issue for most models of cosmic gamma-ray bursts. The first results, limited to the case of a Schwarzschild black hole and a constant angular momentum disc, are ready to be submitted for publication. The simulations show that for disc-to-hole mass ratios between 1 and 0.05, the runaway instability appears on a dynamical timescale of a few orbital periods (< 0.5s). These results are in agreement with previous studies based on stationary models. Extension of this work to rotating black holes and non-constant angular momentum discs are currently underway.

H. Dimmelmeier finished his Ph.D. (supervised by E. Müller and J.A. Font) devoted to the study of general relativistic, axisymmetric, rotational core collapse using the Wilson approximation to General Relativity (conformally flat gauge condition). The simulations demonstrated that relativistic effects can change the collapse dynamics qualitatively. A direct comparison with previous Newtonian simulations showed that the three different types of collapse and waveforms identified in Newtonian models are also present in relativistic rotational core collapse, but that multiple bounces only occur for a much narrower range of parameters. In most cases, the gravitational wave signal is weaker than in the Newtonian simulations and its spectrum exhibits higher average frequencies, because the newly born proto-neutron star has larger compactness in the deeper relativistic gravitational potential. The results imply that the prospects for detection of gravitational wave signals from supernova core collapse are not improved by including relativistic effects.

V. Springel derived a novel formulation of smoothed particle hydrodynamics (SPH) which manifestly conserves both entropy and energy under conditions of variable smoothing lengths (with L. Hernquist of CfA-Harvard). The standard methods of SPH employed so far do not have this desirable property. V. Springel implemented the method in his parallel SPH-code GADGET and showed that the new methodology provides significantly improved numerical results for flows modelled with SPH. These improvements turned out to be very important for accurate simulations of astrophysical cooling flows and the thermal structure of the IGM.

PhD student J. Braithwaite (supervised by H. Spruit) started a study of the stability of magnetic fields in stable stratified stellar interiors with a series of 3D numerical magnetohydrodynamic simulations, using a code developed by Å. Nordlund (Copenhagen Observatory).

M.A. Aloy and E. Müller continued their work on collapsar progenitors of gamma–ray bursts. They demonstrated that a relativistic jet can be formed and propagate through the mantle and envelope of a Wolf–Rayet star as a consequence of an assumed energy deposition. Additional simulations are being done in order to cover the appropriate parameter space and to investigate the occurence of Kelvin–Helmholtz instabilities in the surface layer of the jet. If strong Kelvin–Helmholtz instabilities do occur, collapsars may be ruled out as progenitors of gamma-ray bursts because of the baryonic contamination of the jet as a result of mass entrainment. Because of the high resolution needed in these simulations, the relativistic hydrodynamics code GENESIS was coupled to the adaptive mesh refinement code AMRA. This work was done in collaboration with T. Plewa at the ASCI Flash Center (University of Chicago).

M.A. Aloy and E. Müller in collaboration with J.M. Martí and J.M. Ibáñez (University of Valencia) and J.L. Gómez (Instituto de Astrofísica de Andalucía) performed numerical simulations of relativistic jets in order to disentangle the effects of helical motion and time delay on the properties of parsec scale jets. They proposed a slowly precessing relativistic jet that interacts with a uniform ambient medium to account for the *flashing* of radio components seen in detailed VLBA observations of 3C120 by J.L. Gómez and coworkers. They also found evidence that due to relativistic time dilation, observed components in parsec scale jets may have a much more complex morphology than previously anticipated. A single radio component propagating downstream can be responsible for a large number of apparently disconnected radio–features.

PhD student Tobias Leismann (supervised by M.A. Aloy and E. Müller) started to develop a special relativistic ideal magnetohydrodynamics (RMHD) code to simulate relativistic magnetized jets. The code is based upon an approximate special relativistic MHD Riemann solver and contains special measures to guarantee that the divergence of the magnetic field remains zero.

In collaboration with Markus Rampp, Konstantinos Kifonidis has developed a parallelized matrix solver for block–tridiagonal matrices arising in the description of neutrino transport in core collapse supernovae. The solver is based on a cyclic reduction algorithm and performs very well on machines with shared memory architecture. The parallelization is, however, achieved at three times higher computational cost.

3.4 High Energy Astrophysics

Clusters of galaxies. The radiative cooling time of gas in the central parts of rich galaxy clusters is much shorter than the Hubble time and without an external energy source, the gas must cool below X–ray temperatures forming a so-called "cooling flows". One of the long standing problems in X-ray astronomy is the conflict between the large mass deposition rate predicted by a cooling flow model and lack of observational evidence for a massive enough repository of cold gas. E. Churazov, W. Forman (CfA), H. Böhringer (MPE) and R. Sunyaev studied the dissipation of the mechanical energy injected into the cluster gas by the AGN. They showed that the efficiency of conversion of AGN mechanical power into gas heating can be high, even in the absence of strong shocks. Motivated by this conclusion, a simple quasi-stationary cooling flow model with a very small net mass deposition has been proposed.

The predicted observational appearance of a cooling flow heated by mechanical energy of an

AGN has been calculated by M. Brüggen (IoA), C. Kaiser (Southampton) and T. Enßlin. The latest 3D hydrodynamical simulations broadly confirm earlier 2D results: large buoyant bubbles are formed due to AGN activity which rise through the cooling flow region and exchange energy with the cooling gas. This picture of a cooling flow heated by buoyant bubbles is now being tested by the Chandra and XMM-Newton observations.

Extended regions of radio emission surround some clusters of galaxies, but cannot be associated with active radio galaxies. These 'cluster radio relics' are usually found in merging clusters of galaxies, which suggests that they result from dissipative processes in the Intra Cluster Medium (ICM). T. Enßlin (MPA) and M. Brüggen (MPA/IoA Cambridge) performed 3-D MHD simulations of a bubble of fossil radio plasma (a former radio lobe/cocoon) which crosses a shock wave produced in a cosmological simulation of structure formation. Polarization radio maps of the synchrotron emission of the aging and compressionally revived relativistic electron population show filamentary structures and tori, very similar to those observed in 'cluster radio relics'. This supports the cluster radio relic formation scenario proposed by Enßlin & Gopal-Krishna (2001), and suggests that future high resolution observations of these sources will allow us to study the properties of large-scale structure shock waves. Emission by fast particles produced by shock waves also provides a good explanation for other intergalactic radio structures, such as emission around filaments of galaxies, and an unusual feature at the head of the radio galaxy 3C 129.

As is known, resonant scattering can distort the surface-brightness profiles of clusters of galaxies in X-ray lines. S. Sazonov, E. Churazov and R. Sunyaev have studied the polarization properties of the scattered line emission. They have shown that the expected degree of polarization is of the order of 10% for the richest regular clusters (e.g. Coma) and clusters whose X-ray emission is dominated by a central cooling flow (e.g. Perseus or M87/Virgo). This will be detectable with X-ray polarimeters in the near future. Spectrally-resolved mapping of a galaxy cluster in polarized X-rays could provide valuable independent information on the physical conditions in the cluster, in particular on element abundances and on the characteristic velocity of small-scale turbulent motions in the intracluster gas.

AGNs and microquasars. Only a small fraction of galaxies are active at present. S. Sazonov, C. Cramphorn and R.Sunyaev suggested a method for obtaining information on the past activity of supermassive black holes residing in the centers of clusters or large elliptical galaxies. The hot intergalactic gas scatters part of the emission from the central source, allowing us to receive the scattered X-ray radiation a few $\times 10^5$ years after the source turned off. Resonant scattering in X-ray lines is of particular importance.

Microquasars, the Galactic equivalent of powerful AGN jets, are a recent addition to the zoo of compact object phenomenology. They are morphologically very similar to their AGN counterparts, which suggests that a detailed comparison between AGN jets and microquasars can yield important clues about the nature of jets in general. Using generic scaling models, S. Heinz & R. Sunyaev showed how the measured non-linear relations between black hole mass and radio flux and between accretion rate and radio flux can be used to constrain the geometry of the jet and the topology of the magnetic field. S. Heinz and R. Sunyaev also investigated the impact of microquasars on the Galactic cosmic ray spectrum. They showed that microquasars have a high efficiency of converting kinetic energy flux into cosmic rays and that microquasars are likely to produce measurable, relatively narrow features in the low energy (1 - 10 GeV) range of the cosmic ray proton spectrum.

In collaboration with Demos Kazanas of NASA/GSFC, Maryland, Sergei Nayakshin carried out calculations of time variability of fluorescent Fe Kα lines from photo-ionized accretion disks. The results have significant implications for the planned NASA mission Constellation-X.

Neutron stars. SAX J1808.4–3658 is the only accretion powered millisecond X-ray pulsar known so far. Due to the small size (10-15 km) and the short rotational period (2.5 msec) of the neutron star, general and special relativistic effects play an important role in formation of the light curve of the pulsed emission. M. Gilfanov and M. Revnivtsev performed full general relativistic modelling of the emission from the polar cap of a rapidly rotating neutron star. They showed that the pulse profile of the source can be understood as a superposition of thermal emission from the polar cap and Comptonized emission from the radiation dominated shock near the surface of the star. By comparing the RXTE data with the model, they constrained the radius and the mass of the neutron star and its equation of state.

Gamma-ray bursts (GRB). Magnetically powered gamma-ray burst models were developed by G. Drenkhahn, H. Spruit and F. Daigne. A new and very practical formalism for calculating steady general relativistic MHD flows was developed and applied to GRB models. A major new result is that part of the Poynting flux can be dissipated internally in the flow by magnetic reconnection processes, and that this dissipation simultaneously provides most of the acceleration of the relativistic flow. For typical GRB parameters, this dissipation mostly takes place outside the photosphere of the flow, and appears as nonthermal emission. This turns out to be a much more efficient process for generating the prompt emission than the standard internal shock process. For somewhat larger baryon loading, the dissipation takes place inside the photosphere, and an X-ray flash with a bulk Lorentz factor of 30–100 is produced instead of a GRB.

X-ray binaries. An optical spectroscopy of an unusual fast transient V4641 Sgr constrained its mass to 8.7–11.7 $M_\odot$ and the distance to 7.4–12.3 kpc. At this distance the peak flux observed during its Sept. 1999 outburst implies an X-ray luminosity exceeding the Eddington limit for a $\approx 10 M_\odot$ black hole. The visual magnitude at the peak of the optical outburst was $\Delta m_V \geq 4.7^{\rm m}$ above the quiescent level. If the optical emission were due to irradiated surface of an accretion disk or a companion star, the bolometric luminosity of the system would exceed $\geq 3 \cdot 10^{41}$ erg/s $\sim 300 L_{\rm Edd}$. M. Revnivtsev, M. Gilfanov, E. Churazov and R. Sunyaev showed that the data suggest the presence of an extended envelope surrounding the source which absorbs the primary X–ray flux and reemits it in optical and UV. This envelope is the result of a near- or super-Eddington rate of mass accretion onto the black hole. It vanishes when the apparent luminosity drops well below the Eddington value.

H. Spruit and G. Kanbach (MPE) have analyzed data obtained with simultaneous X-Ray (RXTE) and optical (OPTIMA) observations of the black hole candidate XTE J1118+480 (= KV UMa). The X-ray/optical cross correlation shows unexpected properties, including a very steep rise of the visible light (within 30 ms after the X-rays) and a pronounced dip 1–5 s *before the X-rays.* These results are not compatible with X-ray reprocessing as the source of visible light. A model has been developed that explains the visible light as due to cyclo-synchrotron emission in a relatively slow, magnetically driven outflow from a region close to the hole.

The long term evolution of several X-ray binaries was studied based on the data of MIR-KVANT/TTM and RXTE orbital observatories by M. Revnivtsev and R. Sunyaev. They found long term flares on time scales of ∼years in the light curves of several sources and considered various mechanism which can result in such long term events: influence of a third field star in the globular cluster, a gravitational microlensing event or accretion disk instabilities. On shorter time scales, they discovered coherent variability of the source X-ray flux from KS 1731-260 with a period of 38 days. Using archival CHANDRA data they improved the localization of a number of LMXBs in the galactic globular clusters to arcsec accuracy.

Recent advances in the study of microlensing events suggested that several of them might be due to black holes with masses higher than $2-3 M_\odot$. Using the archival RXTE data M.Revnivtsev and R.Sunyaev searched for an X-ray emission from one of the black hole candidate identified by the microlensing studies and obtained stringent upper limits on it's X-ray luminosity.

H.-J. Grimm, M. Gilfanov and R. Sunyaev studied the spatial distribution and X-ray luminosity function of bright X-ray binaries in the Milky Way. In agreement with theoretical expectations and earlier results, they found that the volume density of LMXB sources peaks strongly at the Galactic Bulge, whereas HMXBs tend to avoid the inner part of the Galaxy and show clear signatures of the spiral structure in their spatial distribution. The integrated 2-10 keV luminosity of X-ray binaries is $\sim 2-3 \cdot 10^{39}$. HMXBs contribute only $\sim 10\%$ to this. Because of the shallow slope of the luminosity function, the integrated emission of X-ray binaries is dominated by the $\sim$ 5–10 most luminous sources. These determine how the Milky Way would appear to an outside observer in the standard X-ray band. Variability of individual sources or an outburst of a bright transient source can increase the integrated luminosity of the Milky Way by as much as a factor of ~ 2. Although the average LMXB luminosity function shows a break near the Eddington luminosity for a 1.4 $M_\odot$ neutron star, at least 11 sources exhibited episodes of super-Eddington luminosity during ASM observations.

3.5 Accretion

A small delay of hard X-ray photons with respect to the soft ones (so-called time lag) in the light curves of accreting galactic black hole candidates is a well established, but poorly understood phenomenon. E.Churazov, M. Gilfanov and O. Kotov (IKI) have shown that the observed energy dependence of the time lags is inconsistent with assumption that they are caused by reflection of the X-rays from the accretion disk. In this interpretation, the delay would be due to the finite light crossing time of the disk. They suggested instead a simple model in which time lags naturally appear due to inward propagation of perturbations in the accretion flow.

Theoretical work on accretion onto black holes is receiving new impetus with the very detailed X-ray observations being obtained with the new generation of satellites, Chandra and XMM-Newton. In most sources, accretion in the outer regions occurs via a thin optically thick disk and further in in the form of a coronal flow where advective energy transport dominates. F. Meyer and E. Meyer-Hofmeister (partly in collaboration with Liu Bifang, Kyoto University) continued their investigation of the transition from one form to the other. These results were applied to stellar black holes in X-ray binaries and to accretion onto supermassive black holes in AGN. One recent result concerns the coexistence of a thin disk and a coronal flow in the innermost regions of luminous narrow-line Seyfert 1 galaxies. Another result in this context is an explanation of the apparent dichotomy in thin disk truncation in low-luminosity AGN in terms of disk dynamo action. E. Meyer-Hofmeister showed the strong dependence of the disk-corona interplay on the viscosity in the coronal gas.

The study of dusty disks surrounding young stars is one of the key methods of gaining insight into the formation of our own solar system. Modern observing facilities such as the VLT are beginning to reach the necessary resolution and sensitivity to probe these disks down to the relevant scales of planet formation. But with sub-AU multi-baseline imaging still a few years ahead, a good theoretical understanding of these disks is crucial in order to interpret current observations. At the MPA, work along these lines is undertaken by C.P. Dullemond, who focuses on the effects of irradiation of the central (T-Tauri or Herbig Ae) star on the circumstellar disk. This work is done in collaboration with A. Natta from Arcetri, Firenze, and C. Dominik and L. Waters from the Anton Pannekoek Institute, Amstedam. This year they developed a self-consistent disk model for Herbig Ae stars, the intermediate-mass counterparts of T-Tauri stars. The model can explain the spectral energy distribution of most of these stars, and also fits available near-infrared interferometry data. This work has made it possible to place the various classes of Herbig Ae stars in an evolutionary scenario. The model has been worked out in more detail (both theoretically, and in application) in collaboration with several PhD students from both Amsterdam and Leiden (e.g. G-J. van Zadelhoff, J. Bouwman), and an undergraduate student from the LMU (S. Walch).

The suggestion that many cataclysmic variables are surrounded by circumbinary disks (or CBs, see highlight in Annual report 2000) was developed further by H. Spruit, in collaboration with R. Taam (Northwestern University) and G. Dubus (Caltech). Detailed time-dependent calculations of the evolution of such disks and their expected spectral energy distributions were made. These show that 'S-curve' type instability is possible, but only for rather massive CB disks. A first attempt to detect CB disks in the infrared light curves of eclipsing Novalike variables was made by Spruit and T. Augusteijn (ING, La Palma) with the infrared camera on the William Herschel telescope (data still in the reduction process).

The stability of magnetically driven outflows from an accretion disk was studied analytically by X.-W. Cao (Shanghai Observatory) and H. Spruit. The coupling between the disk and the outflow is found to be highly unstable. The conclusion is that disk-generated winds are likely to be highly episodic. This may be relevant to the episodic nature of outflows in AGN and young stellar objects as indicated by observations.

Circumbinary disks in X-ray transients can affect the accretion from the standard disk around the black hole (F. Meyer, E. Meyer-Hofmeister). This establishes the very long outburst cycles lasting decades makes it possible to understand why very few systems with short cycles are observed.

Friedrich Meyer together with E. Meyer-Hofmeister and Y. Osaki (Nagasaki University) suggested a model for the repetitive rebrightening of the dwarf nova EG Cancri at the end of the superoutburst. These features can be understood as the result of the gradual decay of magnetic viscosity from its initially high value created by dynamo action during the outburst. F. Meyer and Y. Osaki also showed that the "early-hump" phenomenon in outbursts of WZ Sagittae stars originates from a strong 2:1 resonance between the Kepler and the orbital period in these very low mass ratio systems. This led to a new subdivision of the dwarf nova classification scheme.

U. Anzer, G. Börner, I. Kryukov (Moscow) and N. Pogorelov (Moscow) continued their numerical investigation of wind accretion flows. They implemented the equation for the energy balance into their numerical code and considered effects of different heating and cooling processes in these flows. They also worked on constructing a consistent model for the magnetosphere that results from such accretion flows.

The relativistic precession model interprets frequencies of quasi-periodic oscillations in terms of nodal precession and periastron rotation of Keplerian orbits. N.A.Sibgatullin (Moscow State University) considered low-eccentricity orbits inclined randomly to the equatorial plane around a Kerr black hole and a rapidly rotating neutron star (taking account the rotation induced quadrupole momentum). He showed that the orbit inclination can change the Keplerian, nodal precession and periastron rotation frequencies significantly. He alsoderived formulae for these frequencies and obtained convenient asymptotic formulae for the metric coefficients around rapidly rotating neutron stars taking into account the rotation induced by quadrupole momentum.

3.6 Interaction of radiation with matter

this paragraph slightly straightened out. The Sgr B2 giant molecular cloud is claimed to be an "X-ray reflection nebula" - the reprocessing site of a powerful flare of the Sgr A* source that occurred few hundred years ago. The shape of the X-ray spectrum and the strength of the iron fluorescent line support this hypothesis. Previous work at MPA work has shown how these observations can probe the past history of activity of the supermassive black hole at the center of our Galaxy. Recent progress in the development of X–ray polarimeters for space missions makes the Sgr B2 cloud a natural target for polarimetric studies. E.Churazov, R.Sunyaev and S.Sazonov have shown that continuum emission of an "X-ray reflection nebula" must be strongly polarized, while emission in the fluorescent lines should be unpolarized. A detection of polarized emission from Sgr B2 would be the most clean test of the origin of X-rays from this object.

B. Deufel finished his PhD thesis (supervised by H. Spruit) on the origin of the hard X-rays in X-ray binaries. This is a classical unsolved problem in X-ray astronomy: the observed spectra usually peak at a photon energy of around 100 keV instead of at the expected accretion disk temperature of 100 ev–1 keV. Deufel's work shows that such spectra are a natural consequence of the interaction of a cool accretion disk with a hot so-called ion-supported flow. Spruit, Deufel and Dullemond also showed that this interaction will lead to 'evaporation' of the inner edge of the cool disk to virial temperatures, providing a natural transition from a cool disk to an ion supported flow. Together, these results provide for the first time a firm theoretical basis for the 'disk around ion-supported flow' picture, which so far was suggested primarily by a range of observational clues.

A second process that can produce hard photons is Compton scattering in the rotating, sub-relativistic flow close to a black hole ('orbital Comptonization'). With detailed Monte Carlo simulations P. Reig, N. Kylafis (FORTH, Heraklion) and HṠpruit showed that this process may explain at least a part of the excess of hard photons seen in the so-called soft states, if the sources are accreting near and above the Eddington value.

3.7 Galaxy Evolution and the Intergalactic Medium

Nearby galaxies. In 2001 the MPA joined the SDSS collaboration and as a result, much effort has been devoted to developing new methods for interpreting very large galaxy surveys. Among other topics, SDSS research at MPA has focused on developing new ways of extracting the physical parameters of galaxies from their observed spectra. G. Kauffmann and S. Charlot, in collaboration with M. Balogh of the University of Durham, demonstrated that the distribution of the Balmer absorption line equivalent widths and the 4000 Å break strengths of a population of galaxies could be used to determine whether galaxies have undergone continuous or episodic star formation over the past few Gigayears. G. Kauffmann and S. Charlot have also been collaborating with Tim Heckman and C. Tremonti of John Hopkins University to interpret galaxy spectra in the SDSS survey. They have developed a new way of estimating the stellar mass-to-light ratios of galaxies and have applied this to study trends in the physical properties of galaxies as a function of mass. They have shown that correlation between galaxy metallicity and mass is substantially tighter than the correlation between metallicity and luminosity. Moreover, at stellar masses greater than $10^{10} M_{\odot}$, the metallicity-mass relation flattens. The metallicities of galaxies apear to saturate at a value close to solar. This is the first time this flattening has been seen (previous samples did not contain enough high mass galaxies) and is a significant result, because it has long been one of the key predictions of galactic wind models. The MPA/JHU collaboration has also studied how the recent star formation histories of galaxies vary with stellar mass. Galaxies with masses less than $10^{10} M_{\odot}$ appear to have had star formation histories characterized by bursts, whereas galaxies more massive than this have experienced more continuous star formation.

F. van den Bosch constructed new models for the formation of disk galaxies. These were used to investigate which observably accessible parameters are best suited as indicators of total virial mass, to explore the impact that cooling and feedback have on the structural properties of disk galaxies, and to study the origin of the exponental density distribution of disks. Together with A. Burkert (MPIA, Heidelberg) and R. Swaters (DTM, Washington DC.) F. van den Bosch computed the angular momentum distribution of low mass disk galaxies. Compared to dark matter halos, these disks lack predominantly low angular momentum material. In a more detailed study along similar lines, F. van den Bosch, T. Abel (Cambridge), R. Croft (CfA), L. Hernquist (CfA) and S. White (MPA) used numerical simulations of structure formation, including non-radiative gas, to compute and compare the angular momentum distributions of the gas and dark matter in CDM halos.

F. van den Bosch, A. Rest (UW, Seattle), W. Jaffe (Leiden Observatory) H. Tran, H. Ford, Z. Tsvetanov, J. Davies, and J. Schafer (all JHU, Baltimore) obtained HST R-band images of 67 early-type galaxies as part of an HST snap-shot survey. This roughly doubled the number of early-type galaxies that have now been imaged at HST resolution. These images have been used to investigate the surface brightness profiles, isophotal shapes and dust properties of early-type galaxies. F. van den Bosch, together with M. Milosavljević and D. Merritt (both Rutgers University) and A. Rest (UW, Seattle) used the surface brightness profiles of these early-type galaxies to compute the three-dimensional density distributions. The masses of the central cusps were compared to those of the nuclear black holes to test the hypothesis that central cores are created by binary black holes.

Galaxy formation. V. Springel has worked on hybrid multi-phase models for the interstellar medium which are suitable for inclusion in numerical simulations of galaxy formation on cosmological scales (with L. Hernquist of CfA-Harvard). These models describe mass and energy exchange processes between the different phases of the ISM in a simplified way, with the goal to arrive at a physically plausible model for the effects of star formation and feedback on larger scales. Several variants of such models have been implemented by V. Springel in a tree-SPH code for structure formation, which he then used to numerically study the self-regulation of star formation in galaxies, the star formation history of the universe, and the enrichment and heating of the IGM by winds driven from starforming galaxies.

S. Shen and H.J. Mo, in collaboration with C. Shu (Shanghai) used the current theory of galaxy formation to study the fundamental-plane type of relations for disk galaxies, and found that such relations can provide important constraints on theoretical models. Based on such models, H. J. Mo, together with S. Mao (Manchester) and C. Shu (Shanghai) used the observed luminosity and size functions of Lyman-break galaxies to understand the physical properties of these galaxies and their dark haloes.

In related work, H.J. Mo, in collaboration with S. Mao (Manchester), analyzed the effects of preheating of the intergalactic medium on subsequent galaxy formation.

F. van den Bosch used a new method, based on extended Press-Schechter theory, to compute the mass accretion histories of cold dark matter halos. This new method yields MAHs that are in better agreement with numerical simulations than some previously used methods. It is shown that the average MAH of CDM halos follow a Universal profile.

As part of a large project within the international Virgo consortium for cosmological simulations, S.D.M. White and V. Springel have studied the numerical requirements to obtain accurate simulations of the inner structure of dark matter haloes. This is currently a topic of considerable interest and also considerable controversy, since the standard structure formation paradigm appears to predict dark haloes with more massive central cusps than can be accommodated by observations of the rotation curves of dwarf galaxies. The Virgo consortium project demonstrated that extreme care is needed to get reliable results on this issue, and fully converged simulations of a few systems suggest that earlier work may have overestimated the degree of central concentration expected in a Λ CDM cosmology. The project is continuing in order to improve their library of systems with reliable, fully converged simulations.

G. Kauffmann and M. Haehnelt (IoA, Cambridge) continued to develop their "unified" models of quasar and galaxy evolution. They studied the cross-correlation between quasars and galaxies by embedding models for the formation and evolution of the two populations in cosmological N-body simulations and showed that future measurements would place strong constraints on both quasar lifetimes and the physical processes responsible for fuelling supermassive black holes.

H.C. Arp is compiling a Catalog of Discordant Redshift Associations which identifies regions in the sky where families of related objects of different redshift appear. E. M Burbidge in the U. S. A. , Y. Chu in China and G. Rupprecht and F. Patat in ESO (Garching) are collaborating with spectroscopic measures and direct images of optically identified objects in these associations. Data on the empirical evolutionary processes are being interpreted in terms of basic physics in collaboration with J. V. Narlikar and his collaborators at the Inter University Center for Astrophysics and Astronomy in Pune India and G. R. Burbidge at the Center for Astrophysics and Space Sciences at the Univ. of California, San Diego.

The high redshift of Intergalactic Medium. H.J. Mo, in collaboration with M. Viel, S. Matarrese (both from Padova), M. Haehnelt and T. Theuns (both from Cambridge), studied the possibility of using the spectra of QSOs in multiple lines of sight to recover the linear spectrum of the cosmic density field. W.P. Lin (a student from Beijing Observatory supported by the CAS-MPG exchange program) has finished his PhD thesis with G. Börner and H.J. Mo on 'The origin of the QSO absorption line systems associated with galaxies'.

Using a novel multi-resolution analysis method, T. Theuns (IoA Cambridge), S. Zaroubi (MPA), T.-S. Kim (ESO), P. Tzanavaris (IoA), and R.F. Carswell (IoA) have studied the thermal evolution of the intergalactic medium from the observed Lyman-α forest and found strong evidence of a marked jump in the temperature, with 99% significance, at the mean density, T_0, of 60 per cent around a redshift z = 3.3, which has been attributed to reionization of Helium II. They have also found that $T_0 = 12000K$ at z > 3.6. Such a high temperature suggests that Hydrogen reionization occurred relatively recently.

The application of the Gunn-Peterson test to QSO absorption spectra suggests that the IGM is completely reionized by $z \sim 6$. As the known population of quasars and galaxies provides ~ 10 times fewer ionizing photons than are necessary to maintain the observed IGM ionization level, additional sources of ionizing photons are required at high redshift, the most promising being early galaxies and quasars. B. Ciardi, F. Stöhr and S. White are presently studying the reionization process produced by an early population of pregalactic stellar objects. This is obtained combining the high-resolution simulations run at the MPA, for the galaxy distribution and emission properties, with the code CRASH, for the radiative transfer of photons.

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

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

Detecting the first luminous objects in the universe, responsible for the reionization and metal enrichment of the IGM will be the primary goal of several future space- and ground-based telescopes. Due to the low mass of these primordial objects, the stellar feedback from massive stars is able to blow away their gas content and collect it into a cooling shell where H_2 rapidly forms and IR roto-vibrational lines (as for example the restframe 2.12 μm) carry away a large fraction of the explosion energy, which can be observed, redshifted in the Mid-IR. B. Ciardi and A. Ferrara (OAA, Florence) have studied the observability of these lines with the planned telescope NGST.

Intracluster gas. K. Dolag continued to simulate and analyze the evolution of magnetic fields in the intergalactic gas in galaxy clusters. Together with L. Feretti and F. Govoni (Istituto di Radioastronomia CNR, Bologna) and S. Schindler (John Moores University, Liverpool) they compared the behavior of magnetic field in real galaxy clusters with simulations. Using the correlation of x-ray surface brightness and Faraday rotation they found that the magnetic field in galaxy clusters follows the gas density, as predicted by the simulations. Together with M. Bartelmann and H. Lesch (Uninversity-Observatory Munich) K. Dolag analyzed the structure and the evolution of the magnetic fields within simulated galaxy clusters in more detail. They showed that the principal structure of the magnetic field, like the reversal length or the shape of the radial profile within clusters, does not depend on the details of the initial magnetic seed field.

The energy input by radio galaxies can have a significant effect on their environment, though the extent to which the IGM can be heated and whether the thermodynamics of the gas in the centers of galaxy clusters can be affected significantly is still unclear. Using 2-D hydrodynamic simulations of radio jets interacting with their environment, S. Heinz, C. Reynolds (UMD) and M. Begelman (CU Boulder) showed that a large fraction of the energy released by the AGN can in principle be injected into the central regions. Limits on the energy supply by radio galaxies can be derived from X-ray observations of such interacting systems, such as the galaxy cluster Abell 4059. High resolution Chandra X-ray Observatory images (S. Heinz, Y.-Y. Choi, CU Boulder, C. Reynolds, UMD, and M. Begelman, CU Boulder) demonstrate that this violent interaction does take place and that the central radio source PKS 2354–35 was likely an order of magnitude more powerful in the past than its current radio power suggests. T. Ensslin and S. Heinz used analytic models of the evolution of such bubbles to derive observational diagnostic tools to interpret the ubiquitous X-ray cavities found by Chandra and the associated radio bubbles.

F. Miniati brought to completion some work related to non thermal activity in clusters of galaxies. In particular he finalized a numerical code that follows the acceleration and subsequent energy losses and spatial transport of shock accelerated cosmic-rays in the intra-cluster medium. In collaboration with T. Jones (University of Minnesota, USA), D. Ryu (Chungnam University, KR) and H. Kang (Pusan University, KR) the code was implemented in a hydro/N-body code for large scale structure simulations. They showed that a substantial fraction of the total pressure inside clusters of galaxies could be borne by cosmic-ray protons accelerated at shocks that form in the process of non-linear structure formation. In addition their simulations show that the synchrotron radiation generated by the electrons accelerated at the same shocks reproduces many features observed in a class of radio sources associated with clusters of galaxies and referred to as “radio relics”. Similarly, they showed that synchrotron radiation of secondary electrons produced by the abovementioned cosmic-ray protons in p-p inelastic collisions off thermal nuclei, provides a remarkable model for radio emission associated with “radio halos”.

Structure of the the Milky Way. In collaboration with V. Springel and S. White, A. Helmi studied the phase-space structure of a dark-matter halo formed in a high resolution simulation of a ΛCDM cosmology. Their goal was to quantify how much substructure is leftover from the different merger events, and how it may affect direct detection experiments aimed at determining the nature of dark-matter. They find that the velocity ellipsoid in the Solar neighbourhood deviates only slightly from a multivariate Gaussian. They suggest that the most promising way of determining the nature of dark-matter will be through experiments which are sensitive to directions of motion of the highest energy dark-matter particles. The expected signal for the fastest moving particles is highly anisotropic, and could be eventually be used, not just to determine the nature of the dark-matter, but also to recover at least partially the merging history of our galaxy.

A. Helmi, in collaboration with the Spaghetti Project Survey Team (H.L. Morrison (CWRU), M. Mateo (Michigan), E. Olszewski (Arizona), R.C.

Dohm-Palmer (Michigan), P. Harding (CWRU), J.E. Norris (Mount Stromlo Observatory), K.C. Freeman (Mount Stromlo Observatory) & S.A. Shectman (Carnegie Observatories), have detected a concentration of giant stars in the Galactic Halo, at $l \sim 350$deg, $b \sim 50$deg $\sim 50kpc$ from the Sun, which matches that of the northern overdensity detected by the Sloan Digital Sky Survey. They find additional evidence for structure at ~ 80 kpc in the same direction. The radial velocities obtained for the stars in these structures are in excellent agreement with models of the dynamical evolution of the Sagittarius dwarf tidal debris developed by A. Helmi & S. White, strongly suggesting a common origin.

3.8 Cosmic Structure from $z = 0$ to the Big Bang

Large scale structure. The existence of large empty regions, so-called voids, has been one of the most striking results of large-scale structure surveys. It has been emphasised by Peebles that all types of galaxies, even small dwarfs appear to respect these voids and to lie along the large structures which bound them. H. Mathis and S.D.M. White have used high resolution cosmological N-body simulations, constrained to match the observed large-scale structure of the nearby Universe, and including a detailed treatment treatment of galaxy formation based on the semi-analytic techniques developed at MPA by G. Kauffmann and V. Springel, to study whether the properties of voids highlighted by Peebles can be reproduced in the current standard ΛCDM cosmology. They find that no population of simulated galaxy can be considered to fill the voids, and that all inhabit the structures defined by bright normal galaxies. Nevertheless, it remains unclear whether the simulated universe is as “voidy” as that observed.

With S.D.M. White, M. Bartelmann investigated to what redshift clusters will be detectable in the Sloan Digital Sky Survey (SDSS), using a novel technique based on surface-brightness enhancements in smoothed images. Summing data in the three to four red-most SDSS filter bands, it should be possible to find massive clusters to $z \sim 1.3$. Redshift determinations will be possible out to $z \sim 1$ using photometric redshifts or magnitudes of brightest cluster members. The so-defined SDSS cluster sample will contain $\sim 98\%$ of the clusters detectable for Planck in the SDSS sky area.

H.J. Mo, as part of team in the SDSS collaboration, used galaxies in the survey to analyze the two-point correlation function, pair-wise peculiar velocity dispersion, and other statistical measures of the galaxy distribution. The higher order correlations of the galaxy distribution were analysed by G. Börner and Y.P. Jing (of the partner group of the MPA at Shanghai observatory) based on the PSCz and 2dF Redshift catalogues. R. Casas-Miranda, H.J. Mo, G. Börner, together with R. Sheth (Fermilab) studied the distribution function of dark halos and its relation to the galaxy distribution.

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

Together with L.N. da Costa and his collaborators, S. Zaroubi (MPA) has estimated the mass density fluctuations power spectrum (PS) on large scales by applying a maximum likelihood technique to the peculiar-velocity data of the recently completed redshift-distance survey of early-type galaxies (ENEAR). The general results are in agreement with the high amplitude power spectra found from similar analysis of other independent all-sky catalogs of peculiar velocity data such as MARK III and SFI. For Lambda & Open CDM COBE normalized PS models, the best-fit parameters are confined by a contour approximately defined by $\Omega h^{1.3} = 0.377 \pm 0.08$ and $\Omega h^{0.88} = 0.517 \pm 0.083$, respectively.

X- L. M. Griffiths (Oxford), J. Silk (Oxford) and S. Zaroubi (MPA) have considered a primordial power spectrum which incorporates a bump, arbitrarily placed at $k_{\rm b}$, and characterized by a Gaussian in log k of standard deviation $\sigma_{\rm b}$ and amplitude $A_{\rm b}$, that is superimposed onto a scale-invariant power spectrum and compared it with the *COBE* DMR data and the recently published BOOMERanG and MAXIMA data.

Early Universe studies. D. Sauer under supervision of K. Jedamzik performed numerical simulations of HII-regions in order to investigate the significance of potential systematic uncertainties in the determination of the primordial ^{4}He abundance. K. Jedamzik in collaboration with J. B. Rehm performed comprehensive investigations of the influence of small-scale baryonic inhomogeneities as well as antimatter domains on the light-element synthesis during the Big Bang nucleosynthesis process. K. Jedamzik also analyzed possible production of deuterium in local astrophysical sites.

The paradigm of cosmological inflation provides a mechanism for the generation of large scale structure from the gravitational collapse of primordial quantum fluctuations. Jens Niemeyer and Renaud Parentani (Univ. Tours) showed that this framework is robust with respect to nonlinearities of the dispersion relation of the relevant quantum modes (introduced, e.g., by quantum gravity) under rather general assumptions. In collaboration with Achim Kempf (Univ. Waterloo), Jens Niemeyer analyzed the effects of a short-distance cutoff, implemented by means of a string-inspired modified Heisenberg algebra, on the predictions of inflation. They showed that such effects are negligibly small if the vacuum of the quantum field is the standard one very close to the string scale. This assumption, however, need not be satisfied. Ongoing work examines possible alternative initial vacua. In related work, Jens Niemeyer showed that the same type of cutoff gives rise to a natural framework for varying speed of light cosmology, which was proposed several years ago as an alternative to inflation.

3.9 Gravitational Lensing

M. Bartelmann studied what part of the galaxy cluster population will be detectable for the Planck satellite through the thermal Sunyaev-Zel'dovich effect, what fraction of those will be significant gravitational lenses and thus allow mass determination, and what can be learned from combining thermal-SZ and gravitational-lensing data. Planck will detect of order 10^4 clusters, 70% of which will be significant lenses. The mass function of those clusters is predicted to show a pronounced peak near $5 \times 10^{14}\, h^{-1}\, M_\odot$. The location and height of this peak depends on cosmological parameters, the baryon fraction, and the thermal evolution of the clusters.

S. Zaroubi (MPA), G. Squires (CalTech), G. de Gasperis (Roma), A. Evrard (Ann-Arbor), Y. Hoffman (Jerusalem), J. Silk (Oxford) have applied a general method of deprojecting two-dimensional galaxy cluster images to reconstruct the three dimensional structure of the projected object – specifically X-ray, Sunyaev-Zel'dovich (SZ) and gravitational lensing maps of rich clusters of galaxies – assuming axial symmetry. The applicability of the method for realistic, numerically simulated galaxy clusters, viewed from three orthogonal projections at various redshift outputs.

With a group of scientists from Trieste (F. Perrotta, C. Baccigalupi) and Padova (G. De Zotti, G.L. Granato), M. Bartelmann investigated the gravitational lensing magnification by dark-matter haloes of different mass profiles on extended, high-redshift sources. While image-splitting properties of NFW haloes differ strongly from those of isothermal spheres, their magnification cross sections turn out to be very similar. The resulting lens model was applied by the same group and M. Magliocchetti, L. Silva and L. Danese (Trieste) to a model for the number counts of sub-mm galaxies at high redshifts. It was shown that up to 40% of the bright sources detectable for the Planck satellite at high frequencies could be gravitationally lensed.

M. Meneghetti (Padova and MPA) and M. Bartelmann continued investigating the strong-lensing properties of galaxy clusters. It was shown that it is impossible using analytic cluster models to deduce any reliable constraints on cosmological models from arc statistics. The main reason is that arc cross sections depend in a highly nonlinear way on cluster asymmetry and substructure.

M. Bartelmann showed together with L. King and P. Schneider (Bonn) that the number of dark-matter haloes detectable with weak-lensing techniques depends sensitively on the halo density profile. The expected number counts are higher by an order of magnitude for NFW haloes than for singular isothermal spheres.

A. Maller, T.S. Kolatt (Jerusalem), M. Bartelmann and G. Blumenthal (Santa Cruz) devised a method based on gravitational lensing to determine the mass-to-neutral-gas fraction in Lyman-limit systems. They showed that this fraction can be reasonably constrained using the Sloan Digital Sky Survey data.

T. Hamana (Tokyo) studied light propagation in large simulations of the dark-matter distribution in the Universe. Among other things, he tested and confirmed the reliability of various common assumptions in weak-lensing theory, and constructed gravitational lensing templates to be used for studying lensing of the cosmic microwave background (CMB). These templates were used by C. Pfrommer and M. Bartelmann to study density reconstruction from CMB lensing.

3.10 Cosmic Microwave Background Studies

The broad-band synchrotron self-Comptonization and CMB-inverse Compton spectrum of objects containing low energy relativistic electron populations, like aged radio galaxies and clusters of galaxies, was investigated by T. Enßlin and R. A. Sunyaev.

With L. Moscardini, S. Matarrese and P. Andreani (Padova), M. Bartelmann studied the clustering properties of the galaxy clusters detectable for the Planck satellite, in particular their dependence on cosmological parameters, cluster evolution, and the baryon fraction. Due to the extended redshift range of the Planck clusters, it will be possible to constrain cluster formation out to $z \sim 1$.

Work has continued on methods to investigate and quantify non-Gaussian signals present in CMB data. Together with E. Komatsu, B. D. Wandelt, D. N. Spergel (Princeton, USA) and K. M. Górski (ESO, Garching) A.J. Banday have developed a method to compute all possible values of the bispectrum. This was subsequently applied to the COBE-DMR data, revealing no new evidence for non-Gaussian signals. A. J. Banday in collaboration with M. Kunz, P. G. Castro, P. G. Ferreira (Oxford, UK) and K. M. Górski (ESO, Garching) extended the range of higher order statistics available to study such signals with a method to compute the angular trispectrum. Analysis of the COBE-DMR data on large angular scales revealed no evidence of non-Gaussian behaviour beyond that previously ascribed to a systematic artifact present in the data. An alternative method based on spherical Mexican Hat wavelets also failed to reveal any behaviour in the COBE-DMR data inconsistent with the hypothesis that the observed temperature fluctuations are cosmological in origin and Gaussian in nature.

A. J. Banday in collaboration with K. M. Górski (ESO, Garching), G. Giardino K. Bennett, J. Tauber (ESTEC, Nordwijk) and J. Jonas (HRAO, South Africa) continued to study the nature of the Galactic radio continuum emission and in particular, based on analysis of polarisation data and the corresponding power spectra, estimated the likely foreground contamination of the polarised CMB signal to be measured by Planck. Simulations of this polarised foreground emission at high resolution were made available as part of the Planck data simulation efforts coordinated at MPA. This work is a natural extension of earlier research (published this year) on the nature of the 2.3 GHz radio continuum, and is relevant to foreground contamination of the CMB temperature signal to be measured by MAP or Planck.

A method for component separation based on the Fast Independent Component Algorithm (FastICA) was developed and applied to simulated Planck resolution simulations by a group comprising A. J. Banday in collaboration with D. Maino, A. Farusi, C. Baccigalupi, F. Perrotta, L. Bedini, C. Burigana, G. De Zotti, E. Salerno (all Padova) and K. M. Górski (ESO, Garching), with promising results. In particular, the CMB component is recovered to percent accuracy on all scales down to the beam resolution of the instrument. Currently, extension of this work is related to application of the method to the DMR data.

M. Bartelmann and the Planck group at MPA (A.J. Banday, F. Dannemann, K. Dolag, R. Hell, W. Hovest, F. Matthai and T. Riller) continued contributing to the Planck project. The main activities were the simulation of realistic data streams for the entire Planck mission, the construction of a prototype data archive, and the development of the software infrastructure for data simulation and analysis.

A. J. Banday in collaboration with K. M. Górski (ESO, Garching), E. Hivon (NASA-JPL, USA) and M. Bartelmann continued to maintain and develop the HEALPix software package for the simulation and analysis of CMB anisotropy maps. Version 1.2 will be released shortly.

3.11 Quantum Mechanics of Atoms and Molecules, Astrochemisty

After the successful predictions and re-assignments of rotational-vibrational energy levels or transitions in triatomic molecular species with so-called Renner-Teller degenerate interacting electronic states using a recently developed new computational approach (P. Jensen, Bergische Universität, Wuppertal), a number of other molecular systems were investigated within this scheme. In collaboration with P.R. Bunker (NRC Canada, Ottawa) it was possible to provide theoretical interpretations of so far unexplained features in the spectra of the CH_2^+ and CD_2^+ ions and the NH_2 radical. Previous studies by Kraemer and Jensen of the silicon containing hydrides SiH_2 and SiH_2^+ were extended to include newly available experimental results. Calculations were also started to study the series of halogen containing compounds HCX with X = F, Cl, Br where theoretical assistence is needed for the interpretation of experimental findings.

Long-term efforts to study the reactive behavior of general triatomic molecular species in a detailed state-to-state description were continued. The energy positions and lifetimes of the low-lying rotational-vibrational resonance states of the model system HeH_2^+ were calculated (V. Špirko and M. Šindelka, Academy of Sciences, Prague). Phase shifts of these resonances (L. Ixaru, Institute of Physics and Nuclear Ingeneering, Bucharest) and their eigenfunctions (F. Mrugala, Nicolaus Copernicus University, Torun) were also obtained and carefully tested. With these tools at hand, F. Mrugala was able for the first time to determine on the basis of *ab initio* calculated state-to-state transition data the temperature dependent rate coefficient function for the radiative association reaction of a triatomic reaction complex, namely for the single-state (X-state) reaction $He(^1S) + H_2^+(^2\Sigma_g^+) \rightarrow HeH_2^+(X^2\Sigma^+) + h\nu$. This was was found to be very small, of the order of $\sim 10^{-20}\ cm^3\ s^{-1}$ in the low-temperature interval of $10 \leq T \leq 100$ K. Similar calculations have now begun for the corresponding A-state reaction $He^+(^2S)+H_2(^1\Sigma_g^+) \rightarrow HeH_2^+(A^2\Sigma^+)+h\nu$. The calculations will be extended to evaluate the rate coefficient function for the two-states *radiative charge exchange* process $He^+(^2S) + H_2(^1\Sigma_g^+) \rightarrow He(^1S) + H_2^+(^2\Sigma_g^+) + h\nu$ for which much larger rates have previously been estimated.

Recent advances in semiconductor technology have allowed the construction of new quantum systems, sometimes referred to as *artificial atoms*, also known as a *quantum dot*. An artifitial atom is essentially a number of electrons confined in a potential well. Similar systems may be obtained by confinig an atom, a molecule or several such objects. Another area where spatial confinement leads to new properties of quantum systems is the embedding of atoms and molecules in nano-cavities, for example in fullerenes, in zeolite cages, in helium droplets, and in nano-bubbles formed around foreign objects in the environment of liquid helium. The development of new technologies and experimental techniques has triggered intensive theoretical studies on modelling spatially confined quantum systems. The atoms He, Li, Be, B, and Ne, and the molecules H_2, LiH and Li_2 have been studied in a Yakawa-type potential (under Debye shielding) and in spherical and non-spherical power series potentials in center and off-center positions in the framework of the self- consistent-field (SCF), configuration Interaction (CI) and coupled-cluster (CC) methods. Methodologically, the novelty of this investigation consists of using methods of modern quantum chemistry rather than model-specific methods designed in other areas of physics to study properties of confined systems. The current results promise to reveal a wealth of information about the spectral and response properties of electrons, atoms and molecules confined in different neutral environments, such as liquid helium, zeolites and micelles.

Motivated by the experimental search for the van der Waals system H_2-CO via its Rydberg states, theoretical work was started to study the properties of Rydberg molecules involving at least one diatomic molecule, as for example: $He-CO, He-N_2, Rg-NH_3, Rg-C_6H_6, H_2-CO$ and H_2-N_2 (Rg=Rare gas). Following the guidelines developed in previous studies on Rydberg molecules the stability and electronic structure of the corresponding Rydberg molecular anions was investigated. For selected systems that are energetically stable as anion, the spectroscopic properties of the low lying electronic states were investigated in order to provide information for the spectroscopic search for Rydberg molecules.

4 Publications and Invited Talks

4.1 Publications in Journals

4.1.1 Publications that appeared in 2001

Agudo, I., J.L. Gómez, J.Mª. Martí, J.Mª. Ibáñez, M.A. Aloy and P.E. Hardee: Jet stability and the generation of superluminal and stationary components. Astrophys. J., Lett. **549**, 183–186 (2001).

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Stoehr, F.S. and S.D.M. White: Ballett der Galaxien. In: SuW-Special 6 - Gravitation Spektrum der Wissenschaft Verlagsgesellschaft mbH, Heidelberg 2001, 84-94.

Zhao, G., J.J. Wang, H.M. Qiu and G. Börner (Eds.): The 5th Sino–German workshop , Astrophysics: China Science and Technology Press, Beijing 2001, 204 pages.

4.4 Invited talks

M. Bartelmann: “Galaxies: Formation and Evolution” (Shanghai, 23.5.–25.5.).

M. Bartelmann: Physikalisches Kolloquium (Oldenburg, 18.6.).

M. Bartelmann: Physikalisches Kolloquium (Karlsruhe, 22.6.).

M. Bartelmann: Astronomisches Kolloquium (Heidelberg, 3.7.).

M. Bartelmann: IAU Symposium 208 “Astrophysical Supercomputing using Particle Simulations” (Tokyo, 10.7.–13.7.).

M. Bartelmann: Physikalisches Kolloquium (Tübingen, 21.11.).

S. Charlot: Oort Conference on “Galaxy Formation” (Leiden, Netherlands, 9.5.–11.5.).

E. Churazov: Workshop “High Energy Astrophysics 2001”, Moscow, Russia (24.12.–26.12.).

T.A. Enßlin: “LOFAR Scientific and Technical Workshop” (MIT Haystack Observatory, USA, 15.10-19.10).

M. Gilfanov: ”X-Ray Emission from Accretion onto Black Holes” (Baltimore, JHU, 24.6.–28.6.).

M. Gilfanov: ”New Visions of the X-ray Universe in the XMM-Newton and Chandra Era” (Noordwijk, ESTEC, 26.11.–30.11.).

M. Gilfanov: ”High Energy Astrophysics 2001” (Moscow, 23.12.–25.12).

W. Hillebrandt: 3rd Int. Conf. on ”Exotic Nuclei and Atomic Masses” (ENAM 2001) (Hämeenlinna, Finland, 2.7.–7.7.).

W. Hillebrandt: EuroConference on ”Frontiers in Particle Astrophysics and Cosmology: Neutrinos in the Universe” (Lenggries, Germany, 29.9.–4.10.).

W. Hillebrandt: EuroConference on ” The Evolution of Galaxies. II. Basic Building Blocks” (Ile de la Reunion, France, 16.10.–21.10.).

H.-Th. Janka: Kolloquium der Münchner Physiker (München, 29.1.).

H.-Th. Janka: Nuclear Physics Colloquium of the Munich Universities (Garching, 9.2.).

H.-Th. Janka: Seminar Talk at the Technical University Munich (Garching, 9.5.).

H.-Th. Janka: Graduiertenkolleg Basel-Tübingen (Tübingen, 8.6.).

H.-Th. Janka: Computer Time Committee of the John von Neumann Institute for Computing (Jülich, 13.6.).

H.-Th. Janka: MPA/ESO/MPE/USM Joint Astronomy Conference “Lighthouses of the Universe:” (Garching, 6.8.–10.8.).

H.-Th. Janka: EuroConference on “Frontiers in Particle Physics and Cosmology: Neutrinos in the Universe” (Lenggries, 29.9.–4.10.).

H.-Th. Janka: Relativity Seminar at the University of Tübingen (Tübingen, 6.12.).

K. Jedamzik: Deuterium in the Universe ”Cosmological Deuterium Production in Non-Standard Scenarios” (Meudon, 25.06. – 27.06.).

K. Jedamzik: The Early Universe and Cosmological Observations: a Critical Review ”From (P)reheating to Nucleosynthesis” (Cape Town, 23. 07. – 25. 07.).

G. Kauffmann: “Astrophysical Ages and Timescales” (Hilo, 5.2.–9.2.).

E. Müller: International Symposium on ”AFD” (Tübingen, 1.4.–3.4.)

E. Müller: International Symposium on ”Nuclear Astrophysics” (GSI Darmstadt, 3.4.–4.5.).

E. Müller: UK Astrophysical Fluids Facility ”UKAFF1” (Leicester, UK, 3.9.–7.9.).

J. Niemeyer: XIIIemes rencontres de Blois ”Frontiers of the universe” (Blois, 17.6.–23.6.).

Revnivtsev M. “Short-term X-ray variability of neutron stars: current status and perspectives ” Physics of the neutron stars. St. Petersburg, Russia, June 2001.

Revnivtsev M. “Different faces of X-ray variability of compact objects: what we learn from those”, Harvard-Smithsonian Center for Astrophysics, (Cambridge, USA, 4.12.).

Revnivtsev M. “Different faces of X-ray variability of compact objects: what we learn from those”, Massachusets Institute of Technology, (Cambridge, USA, 5.12.).

Revnivtsev M. “Short term variability of X-ray sources”, High Energy Astrophysics: today and tomorrow (HEA-2001), (Moscow, Russia, ?? Dec.)

V. Springel: IAU Symposium 208 “Astrophysical Supercomputing using Particle Simulations” (Tokyo, 10.7.–13.7.)

V. Springel: Colloquium at the University of Illinois; “Numerical and semi-analytic models for galaxy formation in CDM universes(Urbana-Champaign, 23.10.).

H. C. Spruit: Workshop ”Physical mechanisms of solar variability” (Joint SSPD/AGU Meeting, Boston, 29.5–2.6.)

H. C. Spruit: Jan van Paradijs Memorial Symposium, Amsterdam (2.6.–6.6.)

H. C. Spruit: 6th Sino-German workshop on astrophysics, Ringberg castle (16.7.–20.7.).

R. Sunyaev: Jan van Paradijs Memorial Symposium, Amsterdam (2.6 - 6.6).

R. Sunyaev: Workshop ”X-Ray Emission from accretion on to black holes”, Johns Hopkins University, Baltimore (20.6.–23.6).

R. Sunyaev: International Workshop on ”Galaxies: Formation and Evolution” at Shanghai Observatory (23.5.–25.5.).

R. Sunyaev: Lecture on ”Microwave background and hot gas in clusters of galaxies” Bejing University, (May 2001).

R. Sunyaev: Lecture on “Resonance scattering of X-Ray lines in clusters of galaxies: line intensities, profile and polarisation”, Bejing Observatory, (May 2001).

R. Sunyaev: Institute of Theoretical Physics, UCSB, Santa Barbara (19.12.).

A. Weiss: 1st Eddington Workshop “Stellar Structure and Habitable Planet Finding” (Cordoba, 11.6.–15.6.)

S. White: Marseille workshop on Where’s the Matter?, (Paris, 24.6.–30.6.).

S. White: Oort workshop on Galaxy formation (Netherlands, 9.5.–11.5.).

S. White: Princeton workshop on the Structure of Dark Halos (Princeton, USA 20.5.–1.6.).

S. White: IAU Symposium 208, (Tokyo 11.7.–14.7.).

S. White: Durham conference on A New Era in Cosmology (Newcastle, U.K. 10.9.–14.9.).

S. Zaroubi: Rencontres de Blois - Frontiers of the Universe “Progress in Mapping the Large Scale Structure of the Universe” (Blois, 17.6.–23.6.).

5 Personnel

5.1 Scientific staff members

Directors

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

Scientific Member

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

External Scientific Members

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

Staff

U. Anzer, A.J. Banday, M. Bartelmann, G. Börner, M. Brüggen (till Aug. 31), St. Charlot (till Aug. 31), E. Churazov, F. Daigne (till Sept. 30), G.H.F. Diercksen (till March 31), H. Dimmelmeier (since Nov. 1), K. Dolag, K. Dullemond (since April 1), T. Enßlin, J.A. Font–Roda (till Aug. 31), M. Gilfanov, S. Heinz, A. Helmi (since Jan. 15), H.–T. Janka, K. Jedamzik (till Nov. 15), G. Kauffmann, K. Kifonidis W.P. Kraemer, H.J. Mo, E. Müller, J.C. Niemeyer, P. Popowski (since Aug. 15), M. Rampp, M. Reinecke (since June 1), H. Ritter, G. Rudnick (since Nov. 15), H. Schlattl (till March 31), V. Springel (since May 15), H.C. Spruit, H.–C. Thomas (till May 31), C. Travaglio (since Oct. 1), F. van den Bosch, A. Weiß, S. Zaroubi.

Emeriti

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

Scientists associate:

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

Sofja Kovalevskaja Programm

J. Brinchmann (since Oct. 1), S. Charlot (awardee, since Sept. 1) C. Möller (since Oct. 1),

Alexander von Humboldt fellowships

Xu Kong (USTC, China) since Nov. 1.

DAAD–fellowships

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

EC–fellowships

A-M. Aloy, S. Bertone (since Sept. 3), S. Bianchi, B. Ciardi, K. Dullemond, L. King, M. Francesco, C. Hernandez-Monteagudo (since Dec. 1),

Ph.D. Students

R. Banerjee, J. Braithwaite, A. Büning, R. Buras (since Jan. 1), R. Casas (till Oct. 30), C. Cramphorn (till Aug. 31.), B. Deufel (till July 31.), H. Dimmelmeier (till Oct. 31), G. Drenkhahn, M. Flaskamp, H.-J. Grimm, H. Hämmerle, F. Hansen, T. Leismann, S. Marri, H. Mathis, B. Menard, A. Nickel, M. Reinecke (till May 31), F. Röpke, D. Sauer (since Febr. 1), L. Scheck, M. Schirmer (since Jan. 1), W. Schmidt (since July 1), F. Siebel, M. Stehle (since Oct. 1), F. Stoehr,

IMPRS Ph.D. Students

K. Basu (since Sept. 1), J. Chluba (since Oct. 10), G. DeLucia (since Jan. 1), L. Gao, P. Mimica (since Sept. 1),L. Tasca (since July 1), C. Vogt (since Sept. 1), S. Zibetti (since Sept. 1).

Diploma students

T. Behrens (since July 15), C. Haydn (since June 20), M. Jubelgas (since Oct. 1), A. Mitchell (Fulbright, since Sept. 1), C. Pfrommer (since May 16), J. Sommer (since June 1).

5.1.1 Staff news

G. Börner: Honoray Professorship, Shanghai Astronomical Observatory, Chinese Academy of Sciences.

S. Charlot: Sofja Kovalevskaja-Award of the Alexander von Humboldt Foundation

A. Helmi: C.J.Kok prize for the year 2000, University of Leiden.

H. Mo: Key-Projects Advisor, the Chinese Academy of Sciences

H. Mo: Outstanding Overseas Young Scientist, the Chinese Academy of Sciences

J. Niemeyer: Erteilung der Lehrbefähigung für theoretische Physik an der Technischen Universität München.

M.Rampp: Otto Hahn Medal of the Max-Planck Society.

A. Weiss: Erteilung der Lehrbefugnis für Astronomie an der Ludwig-Maximilans-Universität München.

5.1.2 Ph.D. theses 2001

Ph.D. theses:

G. Contardo: “Analysis of Light Curves of Type Ia Supernovae”, Technical University; Munich.

B. Deufel: “Origin of the hard X-ray spectra of accreting black holes and neutron stars”, Ludwig-Maximilians-Universität; Munich.

H. Dimmelmeier: “General relativistic collapse of rotating stellar cores in axisymmetry”, Technical University; Munich.

K. Kifonidis: “Nucleosynthesis and Instabilities in Supernova Envelopes”, Technical University; Munich..

M. Reinecke: “Modeling and simulation of turbulent combustion in Type Ia supernovae”, Technical University; Munich.

N. Yoshida: "Numerical simulations of the formation of large-scale structure of the Universe", Ludwig-Maximilians-Universität; Munich.

Habilitation thesis:

J. Niemeyer: "Fluid Dynamics of Thermonuclear White Dwarf Explosions and Primordial Black Hole Collapse" Technical University Munich (4.7.2001).

5.2 Visiting scientists

Name	home institution	Duration of stay at MPA
I. Baraffe	(Lyon, France)	1.10.–30.12.
S. Blinnikov	(ITEP Moscow, Russia)	1.10.–27.10.
M. Brüggen	(Inst. for Astrophys., Cambridge)	4.7–4.9.
S. Canuto	(Sao Paulo, Brasil)	5.7.–5.8.
F.J. Castander	(Santiago, Chile)	30.5.–1.7.
I. Cenusak	(Bratislava, Slovak Republic)	8.10.–2.11.
E. Clementi	(Como, Italy)	26.9.–26.10.,
S. Cora	(La Plata, Argentina)	since 1.11.
K. Coutinho	(Sao Paulo, Brasil)	8.7.–6.8.
P. Denissenkov	(St. Petersburg, Russia)	14.3.–13.5.
Z.G. Deng	(Beijing, China)	7.7.–7.10.
W. Duch	(Torun, Polen)	15.8.–6.9.,
N. Dunina-Barkovskaya	(ITEP, Moscow, Russia)	1.3.–30.4.
J. Dursi	(Chicago, USA)	29.3.–28.4.
S.M. Fall	(Baltimore, USA)	1.6.–30.6.
B.A. Fryxell	(Chicago, USA)	28.3–12.4. (?)
L. Girardi	(Padua, Italy)	10.01.–10.02.
		15.04.–27.05.
K. Grabczewski	(Torun, Polen)	1.9.–28.9.
S.A. Grebenev	(Moskau, Rußland)	4.7.–10.8.
T. Hamana	(Tokyo, Japan)	5.1.–31.3.
		1.8.–31.10.
M. Hähnelt	(Cambridge, U.K.)	26.3.–26.4.
P. Heinzel	(Ondrejov, Czech Rep.)	23.4-12.5.,
		6.6.-14.6.
		7.11-6.12.
J.M. Ibáñez	(Valencia, Spanien)	30.7.–12.8.
J. Ibáñez-Cabanel	(Valencia, Spanien)	1.8.–31.8.
Z. Ivecic	(Princeton, U.S.A.)	1.6.–30.6.
L. Ixaru	(Bukarest, Rumania)	10.12.–21.12.
N. Jankowski	(Torun, Polen)	1.9.–28.9.
P. Jensen	(Wuppertal)	15. 7.–31. 7.
M. Karelson	(Tartu, Estland)	26.2.–10.3.
		3.12.–16.12.
V. Kellö	(Bratislava, Slovak Republic)	8.10.–2.11.
M. Kieninger	(Montevideo, Uruguay)	3.12.–31.1.
I. Kryukov	(Academy of Science, Moscow)	1.6.-31.7.
W. Lin	(Shanghai, China)	5.8.–4.11.
R. Lindh	(Lund, Sweden)	1. 6.–15. 6.
K. Maeda	(Tokyo, Japan)	1.11.–30.11.
S. Mao	(Manchester, UK)	till 13.1.
P. Marigo	(Padua, Italy)	10.1.–9.2.
		17.4.–2.6.
J.M. Martí	(Valencia, Spanien)	23.7.–22.8.
L. Mashonkina	(Kazan, Russia)	since 1.12.

Name	home institution	Duration of stay at MPA
P. Mazzali	(Trieste, Italy)	19.4.–18.7.
R.M. Mendez	(SRON Utrecht, Netherlands)	15.1.–14.4.
M. Meneghetti	(Padova, Italy)	1.4.–30.6.
		1.10.–31.12.
F. Mrugala	(Torun, Poland)	1. 7.–31. 7.
P.K. Mukherjee	(Calcutta, India)	13.8.–13.10.
D. Nadyozhin	(ITEP Moscow, Russia)	1.2.–31.3.
S. Nayakshin	(Washington, U.S.A.)	12.7.–20.8.
I. Panov	(ITEP Moscow, Russia)	1.4.–31.5.
N. Pogorelov	(Academy of Science, Moscow)	1.6.–31.7.
K. Postnov	(Sternberg Inst., Moscow)	1.11–31.12.
A.R. Prasanna	(Ahmedabad, India(	1.5.–28.6.
M.G. Revnivtsev	(Moskau, Rußland)	15.2.–15.4.
		since 15.7.
P. Ricker	(Chicago, USA)	8.4.–25.4. (?)
M. Ruffert	(Edinburgh, Scotland)	10.4.–21.4.
		10.9.–22.9.
P. Ruiz-Lapuente	(Barcelona, Spain)	30.7.–29.9.
T. Sako	(Tokyo, Japan)	1.2.–31.1.
M. Salaris	(Liverpool, UK)	25.6.–31.7.
S.Y. Sazonov	(Moskau, Rußland)	16.2.– 30.3.
		2.5.–16.7.
H. Schlattl	(Liverpool, UK)	01.7.–14.7.
N.I. Shakura	(Moscow, Russia)	1.11–31.12.
C. Shu	(Shanghai, China)	till 31.5.
S. Shen	(Shanghai, China)	since 1.3.
N.R. Sibgatullin	(IKI Moscow, Russia)	12.1.–11.2.
		24.6.–15.8.
S. Sild	(Tartu, Estland)	26.2.–24.3.
		3.12.–21.12.
M. Sindelka	(Prague, Czech Rep.)	1. 5.–31. 7.
		21.11.–21.12.
E. Sorokina	(Sternberg Inst. Moscow)	1.10.–31.10.
V. Spirko	(Prague, Czech Rep.)	5.6.–13.7.
R. E. Taam	(Evanston)	1.9.-15.9.
C.A. Tremonti	(Baltimore, USA)	2.7.–2.8.
J. Truran	(Chicago, U.S.A)	29.5.–28.6.
O. Ventura	(Montevideo, Uruguay)	3.12.–31.1.
M. Viel	(Padova, Italy)	1.3.–1.9.
B. Wybourne	(Torun, Polen)	1.9.–30.9.
X.Y. Xia	(Tianjin, China)	7.7.–7.10.
X. Yang	(Hefei, China)	since 15.7.
G.J. van Zadelhoff	(Leiden, The Netherlands)	11.7.–13.7.
D. Zhao	(Shanghai, China)	since 13.3.
M. Zingale	(Chicago, USA)	29.3.–28.4.