Max-Planck-Institut
für
Astrophysik

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Contents

1 General Information

1.1 A brief history of the MPA

The Max-Planck-Institut für Astrophysik, usually called MPA for short, was founded in 1958 under the directorship of Ludwig Biermann. It was established as an offshoot of the Max-Planck-Institut für Physik, which at that time had just moved from Göttingen to Munich. In 1979, as part of plans to move the headquarters of the European Southern Observatory from Geneva to Garching, Biermann's successor, Rudolf Kippenhahn, relocated the MPA to its current site. The MPA became fully independent in 1991. Kippenhahn retired shortly thereafter and this led to a period of uncertainty, which ended in 1994 with the appointment of Simon White as director. The subsequent appointments of Rashid Sunyaev (1995) and Wolfgang Hillebrandt (1997) as directors at the institute, together with adoption of new set of statutes in 1997, allowed the MPA to adopt a system of collegial leadership by a Board of Directors. The Managing Directorship rotates every three years, with Eiichiro Komatsu in post for the period 2015-2017.

In 2007 Martin Asplund arrived as a new director but, for personal reasons, decided to return to The Australian National University in 2011. He remains linked to the institute as external Scientific Member, joining the other external Scientific Members: Riccardo Giacconi, Rolf Kudritzki and Werner Tscharnuter. Eiichiro Komatsu arrived in 2012 from the University of Texas to take up a directorship, bringing new impetus to the institute's research into the early universe and the growth of structure. This generational change continued in 2013 when the MPA's own Guinevere Kauffmann was promoted to a directorship, thereby ensuring that the institute will remain a centre for studies of the formation and evolution of galaxies. Finally, two searches are currently underway for two new directors, active in general areas of computational astrophysics, and the areas including, but not limited to, stellar astrophysics, planetary science, and high-energy astrophysics such as accretion disks and compact objects. These new directors are formally the successors of Wolfgang Hillebrandt who retired in 2012 and Simon White who will retire in 2019.

The MPA was originally founded as an institute for theoretical astrophysics, aiming to develop the theoretical concepts and numerical algorithms needed to study the structure and evolution of stars (including the sun), the dynamics and chemistry of the interstellar medium, the interaction of hot, dilute plasmas with magnetic fields and energetic particles, and the calculation of transition probabilities and cross–sections for astrophysical processes in rarefied media. From its inception the MPA has had an internationally-recognized numerical astrophysics program that was long unparalleled by any other institution of similar size.

Over the last 20 years, activities at the MPA have diversified considerably. They now address a much broader range of topics, including a variety of data analysis and even some observing projects, although there is still a major emphasis on theory and numerics. Resources are channeled into directions where new instrumental or computational capabilities are expected to lead to rapid developments. Active areas of current research include stellar evolution, stellar atmospheres, accretion phenomena, nuclear and particle astrophysics, supernova physics, astrophysical fluid dynamics, high-energy astrophysics, radiative processes, the structure, formation and evolution of galaxies, gravitational lensing, the large-scale structure of the Universe, the cosmic microwave background, and physical and early universe cosmology. Several previous research themes (solar system physics, the quantum chemistry of astrophysical molecules, general relativity and gravitational wave astronomy) have been substantially reduced since 1994.

Since 2001 the MPA has been part of the International Max-Planck Research School in Astrophysics, a joint initiative between the Max Planck Society and the Ludwig-Maximilians University of Munich. About 70 PhD students participate in the school at any given time, most of them at the MPE or the MPA. This has subtantially increased and internationalised the graduate student body at MPA over the last decade and has resulted in productive social and professional links between MPA students and those at other local institutions. Currently about 25 students at MPA participate in the

IMPRS.

MPA policy is effectively set by the Wissenschaftliche Institutsrat (WIR) which has met regularly about 6 times a year since 1995 to discuss all academic, social and administrative issues affecting the institute. This consists of all the permanent scientific staff and the Max-Planck Research Group leaders, as well as elected representatives of the postdocs, doctoral students and support staff. It acts as the main formal conduit for discussion and communication within the institute, advising the directorate on all substantive issues. Ad hoc subcommittees of the WIR carry out the annual postdoc and student hiring exercises, monitor student progress, oversee the running of the computer system, and, in recent years, have carried out the searches for new directions and directorial candidates.

Other aspects of the MPA's structure have historical origins. Its administrative staff is shared with the neighboring, but substantially larger MPI für extraterrestrische Physik (MPE). The library in the MPA building also serves the two institutes jointly. All major astronomical books and periodicals are available. The MPA played an important role in founding the Max-Planck Society's Garching Computer Centre (the RZG; the principal supercomputing centre of the Society as a whole). MPA scientists have free access to the RZG and are among the top users of the facilities there. The Max Planck Computing and Data Facility (MPCDF, formerly known as RZG) is a cross-institutional competence centre of the Max Planck Society to support computational and data sciences. It originated as the computing centre of the Max Planck Institute for Plasma Physics (IPP) which was founded 1960 by Werner Heisenberg and the Max Planck Society (MPS). Since January 2015 the MPCDF became an independent institute of the MPG.

1.2 Current MPA facilities

Computational facilities

Theoretical astrophysicists demand a perfect computing and networking infrastructure. Theoreticians, numerical simulators and data analysts have different needs. To satisfy these needs, MPA has its own, strong and capable IT-group, headed by a scientist to efficiently communicate between scientists and computer specialists. In addition, a group of scientists constitutes the "Computer Executive Committee", responsible for the long-term strategy an planning and for balancing the requests of the different groups and users. Our aim is to satisfy the needs by providing both extensive in-house computer power and by ensuring effective access to the supercomputers and the mass storage facilities at the Max Planck Computing and Data Facility (MPCDF) and the Leibniz Computer Centre of the state of Bavaria (LRZ). MPCDF and MPA coordinate their activities and development plans through regular meetings to ensure continuity in the working environment experienced by the users. Scientists at MPA are also very successful obtaining additional supercomputing time, typically of the order of millions of CPU-hours per project at various other supercomputer centres at both national and international level.

The most important resources provided by the MPCDF are parallel supercomputers, PByte mass storage facilities (also for backups), and the gateway to the German high-speed network for science and education. MPA participates actively in discussions of major investments at the MPCDF, and has provided several benchmark codes for the evaluation of the next generation supercomputer options. MPCDF also hosts a few mid-range computers owned by MPA. In 2015, two Linux-clusters (with 756 and over 2600 processor cores, up to 10~TB of core memory and 890~TB disk storage capacity) were located at MPCDF, and are used for moderately parallel codes. The smaller and older one of them was taken out of service at the end of 2015, to be replaced by an equivalent, but much more power-efficient machine now hosted at MPA. In addition, MPA is operating a core node of the Virgo (the Virgo supercomputer consortium) data center at the MPCDF. The node will host the full results from all important Virgo simulations (e.g. Millennium XXL, Eagle) and provide web access to the world-wide community via the Millenium database. This system consists of 2~PB disk storage and a fat-node server with 48 cores and 1~TB RAM for data access and memory-intensive parallel data analysis.

MPA's computer system guarantees that every user has full access to all facilities needed, and that there is no need for users to perform maintenance or system tasks. All desks are equipped with modern PCs, running under one operating system (Linux) and a fully transparent file system, with full data security and integrity guaranteed through multiple backups, firewalls, and the choice of the operating system. With this approach MPA is achieving virtually uninterrupted service. Since desktop PCs are not personalized, hardware failures are quickly repaired by a complete exchange of the computer.

In addition to the desktop systems, which amount to more than 170 fully equipped workplaces, users have access to central number crunchers. This cluster comprises about 15 machines (with up to 32 processor cores and 96 GB memory) plus the latest and largest machine with 480 cores and about 3 TB of core memory, which was added in 2015. The total on-line data capacity at MPA is approaching the Petabyte range; individual users control disk space ranging from a mere GB to several TB, according to scientific need. Energy consumption and cooling has become a crucial aspect of IT-installations. At MPA, we are concentrating on low power-consumption hardware and efficient, environmental-friendly cooling.

All MPA scientists and PhD students may also get a personal laptop for the duration of their presence at the institute. These and private laptops may be connected to the in-house network through a subnet which is separated from crucial system components by a firewall. Apart from the standard wired network (Gb capacity up to floor level, and 100 Mb to the individual machine), access through a protected WLAN is provided. MPA is also a partner in the eduroam-consortium, thus allowing its members unrestricted access to WLAN at all participating institutions.

The basic operating system relies on OpenSource software and developments. The Linux system is a special distribution developed in-house, including the A(dvanced) F(ile) S(ystem), which allows completely transparent access to data and high flexibility for system maintenance. For scientific work, licensed software, e.g. for data reduction and visualization, is in use, too. Special needs requiring Microsoft or Macintosh PCs or software are satisfied by a number of public PCs and through servers and emulations.

The system manager group comprises three full-time and one part-time system administrators; users have no administrative privileges nor duties, which allows them to fully concentrate on their scientific work.

Library

The library is a shared facility of the MPA and the MPE and therefore has to serve the needs of two institutes with differing research emphases – predominantly theoretical astrophysics at MPA and predominantly observational/instrumental astrophysics at MPE. At present the library holds a unique print collection of about 53000 books and journals and about 7300 reports and observatory publications, as well as print subscriptions for about 160 journals and online subscriptions for about 500 periodicals, as well as an ebook collection of about 4000 copies. In addition the library maintains an archive of MPA and MPE publications, two slide collections (one for MPA and one for the MPE), a collection of approximately 800 non print media and it stores copies of the Palomar Observatory Sky Survey (on photographic prints) and of the ESO/SERC Sky Survey (on film). The MPA/MPE library catalogue includes books, conference proceedings, periodicals, doctoral dissertations, and habilitation theses, reports (print and online). Additional technical services such as several PCs and terminals in the library area, copy machines, a colour book-scanner, two laser printers, and a fax machine are available to serve the users' and the librarians' needs. The library is run by two people who share the tasks as follows: Mrs. Bartels (full time; head of the library, administration of books and reports) and Mrs. Blank (full time; "Pure", publication management for both institutes - about 850 publications 2015, and administration of journals)

1.3 2015 at the MPA

New Research group

Simona Vegetti, a former postdoc at MPA, began her independent Max-Planck Research group (MPRG) in October 2015. This is the first time that the MPA hosts an MPRG. The MPRGs are established as smaller, independent research units, often supplementing departments at Max Planck Institutes, such as at MPA. MPRG's funding comes from the central administration of the Max Planck Society, and is separate from the budget of MPA, assuring financial independence of the groups. The MPRGs are highly competitive positions, selected from the international pool of applicants with the success rate of about 40 to 1. The groups offer young junior scientists who hold a doctorate an exceptional opportunity to further qualify themselves on a very high level. Vegetti is appointed for a five-year term (renewable for up to four more years). She is building her research group with two PhD students and two postdocs. Vegetti uses strong gravitational lensing to detect substructures in dark matter halos and test the predictions of the cold dark matter scenario. Using high-resolution images of strong gravitational lenses, she tries to find and constrain the properties of small satellite galaxies in the distant universe. The nature of dark matter and how galaxies form are two major issues of modern Cosmology. Numerical simulations of galaxy formation have shown that the amount of mass substructure in galaxies strongly depends on the assumed nature of dark matter. However, dark matter cannot be directly observed and using luminous matter as a tracer is not always reliable. Therefore, Vegetti uses the gravitational lensing effect. Already during her PhD in Groningen and later as a postdoc at MIT she developed the technique: In strong gravitational lens systems, such as galaxy clusters, individual (small) galaxies can induce small perturbations on the observed lensing features, such as arcs. These perturbations then reveal details about the lensing galaxy, allowing the scientist to measure the mass substructures in gravitational lens galaxies, galaxy-groups and galaxy-clusters. Recently, her technique could be extended to also study in great details high-redshift lensed galaxies observed with new radio interferometers. While her research so far has been confined to fairly massive substructures, the advent of much more sensitive and high resolution data from radio interferometry systems will allow her to study much smaller galaxies, down to about 10^6 solar masses, and a wide range of cosmological epochs.

MPA scientific meetings in 2015

This year's MPA/MPE/ESO/Excellence Cluster conference was on ”Theoretical and Observational Progress on Large-scale Structure of the Universe”, organised by Eiichiro Komatsu with the co-organisers at MPA, MPE, ESO, and Excellence Cluster. It hosted 188 participants in a new ESO Auditorium “Eridanus”. The participants presented the new results and discussed a wide range of topics from the recent observational data on the large-scale structure to the latest developments in theory and numerical simulations. One of the highlights of the conference was the official announcement of the first science results from Dark Energy Survey.

The Physical Cosmology group organised two focused workshops: “ICM Physics and Modeling” (46 participants) and “The Near Infrared Background II: From Reionization to the Present Epoch” (33 participants) The ICM meeting was held to initiate an active network of collaborations in the topic of galaxy clusters among MPA, Yale, UC Santa Barbara, and the University of Tokyo. The near infrared background workshop was a sequel to the meeting organised by Komatsu at the University of Texas at Austin in 2012. These workshops hosted experts on the subjects in friendly, informal settings, stimulating active discussions. They were organised primarily by the postdocs Xun Shi and Kári Helgason, respectively.

3D Hydro for stars

In April (13th to 16th, 2015) the Stellar Physics group organised a workshop on 3-dimensional modeling of stellar interiors. Members of our group discussed with colleagues from Toulouse, Montpelliere, and Melbourne the current state and the future prospects of 3d-hydro modeling of stars, and how results can be used to improve the treatment of hydrodynamical effects in 1-dimensional stellar evolution models. The workshop ended with a roadmap how this can be achieved, and a plan of cooperation of the participating groups. The workshop was a spin-off of a workshop at the Lorentz-Centre in Leiden, held in 2013, and organized and supported by members of MPA.

Biermann lectures 2015

The topic of the 2015 Biermann Lectures by Professor Isabelle Baraffe from the University of Exeter was exoplanet modelling. The different aspects touched on in the course of the miniseries ranged from an exoplanet's interior structure to its outer atmosphere. Are there other planets like Earth out there? This question has remained unanswered for a long time - only recently the detection of exoplanets has moved into mainstream astronomy. These faint objects, however, are difficult to observe directly; especially as they are often outshone by the stars they are orbiting. It was during Isabelle Baraffe's early career that scientists started discovering planets outside our own solar system with high-precision measurements. The first definite exoplanet 51 Pegasi b was discovered 1995 in the Pegasus constellation. Baraffe has been fascinated by these astrophysical objects ever since. So far, astronomers have observed exoplanets mainly indirectly. There are more than registered exoplanets, but only some 50 have been detected by imaging. Baraffe, however, chose a different approach: she tries to understand extra solar planets from theoretic principles, starting with theoretical physics. By modelling the physical characteristics of exoplanets - their formation, their atmospheric and interior structure, and their evolution - she is trying to better understand these mysterious objects. After her PhD in Astronomy from University of Paris and University of Göttingen in 1990 she worked at MPA and University of Göttingen as a postdoc. In Lyon, she held her first professorships before moving to England where she joined the University of Exeter in 2010. There she is now the Head of Astrophysics and holds the Chair of Astrophysics. In addition to being named Biermann Lecturer 2015, she has received a number of national awards in France, Germany and the UK, such as the Johann–Wempe award in 2004 for her outstanding theoretical work about low–mass stars, brown dwarfs and extrasolar gas planets. Without her evolutionary models of these objects, some of the most exciting recent observations with the Hubble Space Telescope or the Very Large Telescope could not have been interpreted. Moreover, she was awarded an Advanced Grant by the European Research Council in 2012 to work on this area.

Figure 1.1: Isabelle Baraffe is currently Professor at the University of Exeter, U.K. She has been the MPA Biermann Lecturer in 2015)

Prizes and Awards

MPA director Rashid Sunyaev received to distinctions in 2015: The Royal Astronomical Society awarded him with the Eddington Medal, which is awarded for single investigations of outstanding merit in theoretical astrophysics. He was nominated for a series of papers, in which he and Ya. B. Zel'dovich predict the existence of two important milestones in the evolution of the Universe: (1) the last scattering surface of photons and (2) the blackbody photosphere of the universe. In addition, the papers also describe the existence of inevitable distortions of the CMB spectrum from a pure Planck spectrum. Also in 2015, the presidium of the Russian Academy of Sciences (RAS) decided to award Rashid Sunyaev with the Gold Medal named after Ya. B. Zel'dovich for a sequence of the papers about the very early universe, containing calculations about the last scattering of photons and the black body radiation that was later observed as the cosmic microwave background. This is the first time that the RAS honours a scientist with this medal for outstanding work in the field of physics and astrophysics. The award is named in honour of the Soviet physicist and physical chemist Ya B. Zel'dovich, PhD supervisor to Rashid Sunyaev and long-time collaborator.

MPA director Eiichiro Komatsu was also honoured twice: in March, the Astronomical Society of Japan awarded him with the "Chushiro Hayashi Prize" during its annual spring meeting at Osaka University. The prize is awarded to scientists who made major contributions to the fields of astronomy and astrophysics. The Chushiro Hayashi Prize was founded in 1996, using a part of the Kyoto Prize money awarded to Hayashi in 1995. Komatsu is the 19th laureate for this prestigious award, which he received for "Precision Cosmology based on the Cosmic Microwave Background", the left-over radiation from the Big Bang at the beginning of the Universe. Komatsu analysed and interpreted the CMB data that was measured by the WMAP satellite mission, and in particular determined the cosmological parameters as well as testing theories of inflation. Furthermore, in its September meeting, the American Physical Society (APS) elected Eiichiro Komatsu as a Fellow. This distinction is recognition of his outstanding contributions to physics, in particular for his work on the analysis of the cosmic microwave background radiation and the physics of the early universe. Eiichiro Komatsu was recommended by the Division of Astrophysics and nominated by the APS Council of Representatives in its September meeting, for his pioneering use of the bispectrum to study the physics of the early universe and for playing a leading role in the analysis of WMAP data. The European Research Council (ERC) selected Fabian Schmidt as one of the recipients for its highly competitive starting grant in 2015. This will allow Fabian Schmidt to establish his own research group to investigate the very early Universe and probe the general theory of relativity. The goal of the Fabian Schmidt's research funded by the ERC grant is to probe our theory of gravity, general relativity, on cosmological scales. In addition, it aims to shed light on the origin of the initial seed fluctuations out of which all structure in the Universe formed, by constraining the physics and energy scale of inflation. At its biennial Membership Election Meeting in November 2015, the Chinese Academy of Sciences (CAS) elected MPA director Simon White as a Foreign Member in recognition of his scientific achievements and his contributions to promoting the development of science and technology in China. With his election, Simon White becomes the only astrophysicist among the Foreign Members and the third scientist working in Germany (following Klaus von Klitzing and Hartmut Michel). Simon White will be formally admitted to the CAS at its 18th General Assembly in June 2016, along with former MPA-postdoc Yipeng Jing, currently Distinguished Professor at Shanghai Jiao Tong University, who was also elected in November 2015.

Figure 1.2: The Kippenhahn-Award has been awarded to Richard D'Souza and Marco Selig for the best scientific paper written by MPA students. *copyright: Andi Weiss, MPA*

Rudolf-Kippenhahn-Award

Since 2008, the Kippenhahn Prize is awarded for the best scientific publication written by an MPA student; it was donated by the former director of the institute, Prof. Rudolf Kippenhahn. The decision for 2014 was difficult due to the high quality of the submitted publications, so that the committee decided to award the prize jointly to two young researchers: Richard D'Souza for his paper *"Parametrizing the Stellar Haloes of Galaxies"* and Marco Selig for his paper *"D^3PO - Denoising, Deconvolving, and Decomposing Photon Observations"* (See Figure 1.2). The galactic halo is an extended, roughly spherical component of stars, which extends beyond the main, visible component of the galaxy. As these stellar halos can be very faint, Richard D'Souza used deep observations from the SDSS to stack a large number of images of individual galaxies. The stacked images of the galaxies reveal the existence of stellar halos around galaxies of all types, both elliptical and spiral, with masses ranging from that of the Small Magellanic Cloud to those of the most massive ellipticals in the centres of rich clusters. Richard D'Souza led the difficult SDSS imaging analysis from start to finish and wrote up an excellent paper, which has been well received by the community. The paper written by Marco Selig bridges from information theory to next generation astronomical imaging. It develops the *D^3PO* algorithm, which performs several complex data analysis steps in order to process photon count data jointly and self-consistently. The results are two independent sky images, one for the diffuse flux and one for the point-like sources. *D^3PO* has been applied to gamma ray data from the Fermi satellite, producing unique sky maps, a point source catalogue that is competitive with the best one of the Fermi collaboration, and separate maps revealing two diffuse phases of the interstellar medium. As "astro-infonaut", Marco Selig crafted novel and versatile tools to extract signals with high fidelity from complex and noisy data sets which he then applied successfully to astronomical data.

Figure 1.3: The school girls were able to do some research themselves during the Girls'Day. In different experiments they "worked" on several astronomical topics.*(copyright: H.-A. Arnolds, MPA)*

Figure 1.4: Visitors at the poster gallery and public talk during the "Lange Nacht der Wissenschaften" on June 27, 2015 *(copyright: Vanessa Laspe)*

Public Outreach

In 2015, there were three main public outreach events, organised by MPA staff: As in previous years, MPA again participated in the annual Girls'Day. In the portable planetarium dome, junior scientists presented the digital planetarium show "Changing Skies", which not only deals with changes in stars and galaxies but also explains how some of these processes can be understood and modelled in simulations. In a complementary talk, the participants learned about some recent research findings. In addition, the girls were able to do some research themselves: In different experiments they "worked" on several astronomical topics. Throughout the half day, they also had the opportunity to discuss with the scientists at MPA about their work and their career (see Fig. 1.3).

In May, the mobile planetarium was set up outside the institute for the first time, in the General Office of the Max Planck Society, for the MPG kick-off event for the International Year of Light. There, the MPA team organised a number of live presentations in the planetarium for school classes during the day – complemented by talks given in the MPG seminar room – as well as shows for students in the evening. In the very informal setting the students also had a chance to network and ask questions about life and work at the institute. The Open Day in 2015 took the special form of a – Long Night of Science – on the occasion of the 1100th jubilee of Garching. The programme included hourly talks, poster presentations, and Q&A-sessions with scientists. Special attractions proofed to be the digital planetarium as well as visits to the new telescope on the roof of the extension building. In total about 1500 people visited the institute during the Long Night (see Fig. 1.4).

In addition, the public outreach work at MPA involves a broad range of activities with many staff and scientists contributing. The planetarium group also organised a number of visits (7 groups with a total of about 180 people) for school children as well as scientist groups from other disciplines. MPA scientists were also involved in educational programmes for school teachers and gave public talks in and outside the institute. They supervised interns, wrote articles for popular science media and acted as interview partners for journalists.

The public outreach office issued a number of press releases about important scientific results and new projects as well as news about awards and prizes for MPA scientists. These were published on the MPA website as well, complementing the popular monthly scientific highlight series. In 2015, the institute adopted a new Content Managing System for its public website, taking the opportunity for a complete update and restructuring of website contents. This allowed for a more dynamic homepage, concentrating on news and highlights, as well as directly accessible pages about the institute, the research being done at MPA, career opportunities, events and conferences.

2 Scientific Highlights

2.1 Starburst cycles in galaxies

While it is well known that galaxies reside in halos of dark matter, there has been disagreement about the detailed distribution of dark matter between cosmological simulations and observations: the so-called “cuspy halo problem”. Astrophysicists at the MPA have now used spectral features in a number of SDSS galaxies to show that strong starbursts occur frequently enough in low mass galaxies flatten the inner mass profiles of these systems, explaining why the theoretically predicted “cusps” are not observed.

Cosmological simulations of the evolution of cold dark matter (CDM) show that the dark matter in galaxy halos forms cuspy distributions - with inner profiles that are too steep compared with observations. This is commonly referred to as the “cuspy halo problem”. One solution to this problem, that was proposed early on, is as a galaxy loses mass in the form of explosions this can lead to an irreversible expansion of the orbits of stars and dark matter near the centre of the halo. The very dense cusps would then be spread out over a wider area. These conclusions, however, were based on simple analytic arguments and it was not clear whether this mechanism could in fact produce central density profiles in close agreement with observations. Later gas-dynamical simulations of dwarf galaxies indeed demonstrated that repeated gas outflows during bursts of star formation could in principle transfer enough energy to the dark matter component to flatten 'cuspy' central dark matter profiles.

Nevertheless, it has remained unclear whether the energy requirements for flattening cuspy profiles are in line with the actual stellar populations and star formation histories of real low mass galaxies. In order to estimate how frequently starbursts occur as well as the amplitude range in star formation during a burst, it is necessary to analyze a large sample of galaxies that are intrinsically similar.

High quality spectra provide a number of stellar features that are extremely useful as diagnostics of the star formation history of a galaxy. A primary feature is the strong break at 4000 Angstroms, caused by the blanket absorption of high energy

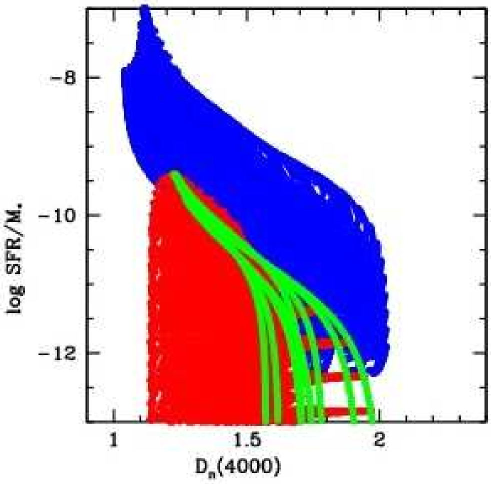

Figure 2.1: The distribution of model galaxies, where the specific star formation rate is plotted versus the strength of the 4000-Angstrom-break. Model galaxies that have experienced continuous star formation histories are coloured in green, those that are currently undergoing bursts are coloured in blue and those that have experienced bursts in the past are coloured in red. One can clearly distinguish the three groups, even if there is some overlap. Plots of the specific star formation rate versus the Balmer absorption or emission line features show a similar picture

radiation from metals in stellar atmospheres. This break becomes strong once young, hot, blue stars have evolved off the Main Sequence. In addition, absorption lines from the Balmer series, which are strongest in stars of spectral type A-F, are a diagnostic of the contribution of stars of intermediate ages to the total luminosity of the galaxy. Finally, Balmer emission lines arise in large, low-density clouds of gas where very recently formed stars emit copious amounts of ultraviolet light that ionize the surrounding gas (predominantly hydrogen).

Used in concert, Kauffmann (2014) found that these spectral features allow one to clearly separate galaxies in three groups: those that are currently undergoing a burst of star formation, those that have formed their stars continuously and those that have experienced a burst in the past (Fig.2.1). Applied to a large sample of galaxies from the Sloan Digital Sky Survey, the scientists were able to constrain the fraction of galaxies that were experiencing current starbursts, the mass of stars typically formed in these bursts, as well the duration of the starbursts. One could then investigate whether the burst frequency depended on the mass of the galaxy and whether starbursts were associated with changes in the internal structure of galaxies.

The analysis showed that the fraction of the total star formation rate in galaxies with ongoing bursts was a strong function of stellar mass, declining from 0.85 for the smallest galaxies in the sample to 0.25 for galaxies with masses close to that of the Milky Way. Also the burst mass fraction, the half-mass formation times and the burst amplitudes and durations could be constrained. Finally, the scientists found that the central stellar densities in bursting low mass galaxies are reduced compared to their quiescent counterparts.

These results are in remarkably good agreement with predictions of some of the recent hydrodynamical simulations and give further credence to the idea that the cuspy halo problem can be solved by energy input from multiple starbursts over the lifetime of the galaxy. (Guinevere Kauffmann)

References:
Kauffmann, G. : Quantitative constraints on starburst cycles in galaxies with stellar masses in the range $10^8 - 10^{10} M_\odot$ Mon. Not. R. Astron. Soc. **441** (3): 2717-2724 (2014).

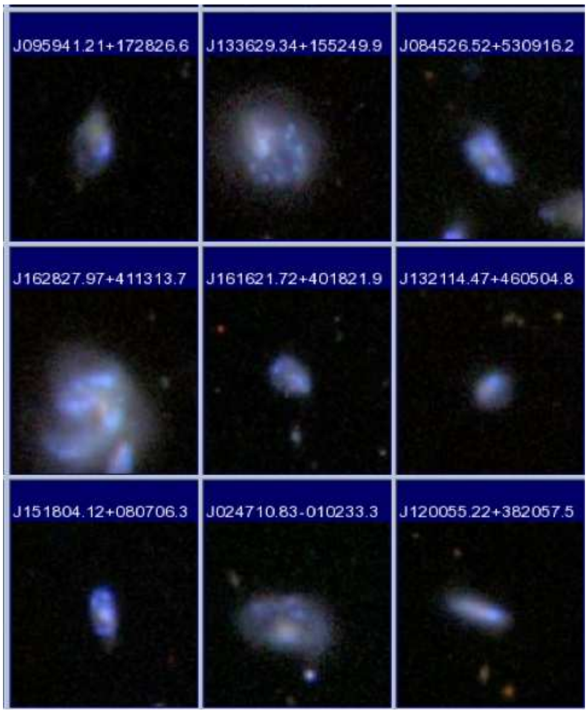

Figure 2.2: Postage stamp images of some of the low mass galaxies in the SDSS that are currently undergoing strong bursts.

2.2 Galactic anatomy with gamma rays

The anatomy of the Milky Way as seen in gamma light is full of mysteries. For example, there are gigantic bubbles of unknown origin above and below the center of the Milky Way that emit a lot of this high-energy radiation. A new method for imaging, developed at the Max Planck Institute for Astrophysics, now divided the Galactic gamma-radiation into three fundamental components: radiation from point sources, radiation from reactions of energetic protons with dense cold gas clouds, and radiation from electrons scattering light in the thin, hot, Galactic gas. The anatomic insights gained unravel some Galactic mysteries. Thus, it appears that the gamma-ray bubbles are simply outflows of ordinary, hot gas from the central region of the Milky Way.

The sky in the light of gamma-radiation shows a variety of objects, structures, and astrophysical processes (Fig. 2.3). It is most prominently illuminated by the Milky Way, which contributes a great part of the point sources as well as the major part of the diffuse gamma-radiation in the sky. The various radiation sources appear superimposed, which complicates their identification and interpretation. Furthermore, our measurement instruments, such as the Fermi satellite, record only individual gamma photons, arriving at random times from random directions. These are highly energetic light particles, whose observation requires complex imaging algorithms in order to reconstruct sky maps. A new method for denoising, deconvolving, and decomposing photon observations, called D^3PO, developed at the Max Planck Institute for Astrophysics, has now created the by far most brilliant gamma-radiation map of the sky from the data of the Fermi satellite (Fig. 2.3).

D^3PO has decomposed the gamma-ray sky into point sources (Fig.2.4c) and diffuse radiation at nine photon energies. From these, a colored image can be generated (Fig.2.4b), which shows the diffuse sky as it would appear to an observer with gamma-eyes. The different astrophysical processes can be recognized therein via their different energy spectra, visible as different colors (Fig. 2.4b). The gamma-bubbles above (and below) the center of the Milky Way appear blue-greenish, which indicates particularly high-energy gamma-radiation. This should have been mainly generated by collisions of electrons that are moving almost with the speed of light with starlight and other photons. The orange-brown areas on the right and left side are primarily caused by collisions of super-fast protons with nuclei in dense, cold gas clouds.

The big surprise was that the central bright Galactic disk, and virtually all other areas of the sky, show essentially just a superposition of these two processes: collisions of protons with nuclei and of electrons with photons. If we decompose the diffuse gamma-radiation into only these two processes (Fig. 2.4d and 2.4e), more than 90% of the radiation is explained – and this at all studied sky locations and energies (Fig. 2.4g). The total diffuse galactic gamma-radiation is thus produced almost exclusively by two typical media: dense, cold gas clouds and the thin, hot gas between them. In fact, gamma-radiation coming from the clouds shows almost the same spatial distribution as the Galactic dust clouds as measured by the Planck satellite in the microwave range (Fig. 2.4f).

The gamma-radiation generated by electrons in the mysterious gamma-ray bubbles does not differ in color from the electron-generated radiation from the Galactic disk. This suggests that we see the same material in both places: hot gas that has been enriched with electrons moving almost at the speed of light by supernova explosions. The gamma-bubbles are therefore simply rising hot gas

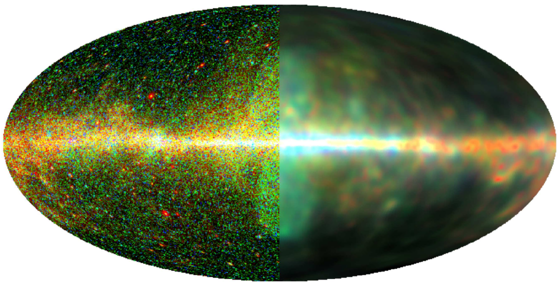

Figure 2.3: Gamma-ray data (left) and diffuse Galactic gamma-radiation calculated by D^3PO (right). The Galactic disk is displayed horizontally, with the Galactic center in the middle of the image.

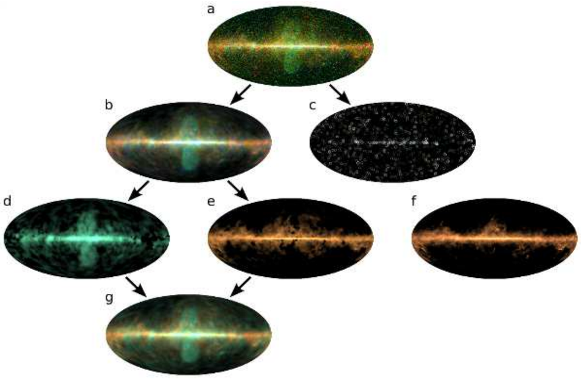

Figure 2.4: The gamma-ray sky at different stages of the data analysis: (a) The data of the Fermi satellite. D^3PO denoised, deconvolved, and decomposed the data into (b) diffuse emission and (c) point sources. A further separation reveals the gamma-rays emitted by (d) hot, dilute clouds of gas and (e) cold, dense gas clouds, which closely resemble (f) the Galactic dust clouds from the Planck mission. (g) The sum of the two gamma components (d and e) explains around 90% of the total diffuse gamma-radiation.

masses, leaving the center of our Milky Way.

In addition to unraveling the gamma-ray bubbles, the D^3PO analysis of the anatomy of Galactic gamma-radiation has delivered a number of other scientific results. It was shown that the cold gas clouds that are illuminated by the gamma-radiation extend up to larger heights above the Galactic plane than the dust clouds measured by the Planck satellite. While this could have been expected due to the higher mass of dust particles in comparison with the gas particles, it is a nice confirmation of the astrophysical correctness of these anatomical dissections of the Galaxy in gamma light. Furthermore, a comprehensive catalog of point sources was generated and searched for gamma-radiation from clusters of galaxies – unfortunately without success.

The D^3PO algorithm that has made all this possible is now freely available and will in the future also provide astronomical images at other wavelengths of light. D^3PO was developed by Marco Selig during his just-completed doctorate with honors at the LMU in Munich (Fig. 2.5). The algorithm was derived within information field theory and implemented using the also freely available NIFTY-software for numerical information field theory. Information field theory deals with the mathematics of imaging complex data sets and is a central focus of the research group of Torsten Enßlin at the Max Planck Institute for Astrophysics. (Marco Selig, Valentina Vacca, Niels Oppermann, Torsten Enßlin).

References:

Marco Selig, Valentina Vacca, Niels Oppermann, Torsten A. Enßlin The Denoised, Deconvolved, and Decomposed Fermi γ -ray Sky - An Application of the Algorithm. Astron.Astrophys. **581**, A126, 1-16 (2015).

2.3 Measuring gas velocities in galaxy clusters with X-ray images

X-ray observations provide us with detailed information on the density and temperature of the hot gas inside galaxy clusters. The other major gas characteristic that still needs to be measured is the gas velocity. While current generation X-ray observatories lack the required energy resolution to measure velocities directly, future observatories such as ASTRO-H and ATHENA will address this limitation. An international team including MPA scientists has shown that the power spectrum of the velocity field can inferred indirectly from existing X-ray images of relaxed clusters. Numerical simulations confirm this simple theoretical idea, opening a way of probing gas velocities using already existing X-ray data.

Figure 2.5: Marco Selig after his doctorate examination, which he passed with honors at the LMU in Munich.

Galaxy clusters are the largest gravitationally bound structures in the present Universe. Hot gas (with temperatures of 10 to 100 million Kelvin) fills their gravitational potential wells and shines in the X-ray band, making the clusters an easy target for orbital X-ray observatories. Both the density and the temperature of the gas in clusters is routinely measured using X-ray data, while it is notoriously difficult to directly measure the turbulent motion of the gas via the Doppler shift of X-ray lines. Since the information on the turbulent gas velocities would have profound implications for the mass determination of clusters and for determining the plasma microphysics, new approaches have been developed to indirectly measure the gas velocities using existing X-ray data. One of these approaches is based on the analysis of small-scale fluctuations in X-ray images as described below.

In relaxed clusters the gas approaches the state of hydrostatic equilibrium, when all thermodynamic properties are aligned along surfaces with equal gravitational potential, making X-ray images smooth and round (Fig. 2.6). These stratified and stable atmospheres of cluster gas bear much similarity to the Earth's atmosphere or to water in the oceans where cold and dense material tends to be below hotter and lighter material due to the combined action of gravity and buoyancy. Slow subsonic perturbations of such atmospheres can be represented as a combination of internal (gravity) waves, very much like waves in the ocean (bottom panel of Fig. 2.6). In oceans there is a simple relation: the larger the amplitude of the waves, the higher the velocityof water. Is the same true for gas in galaxy clusters? Both theoretical analysis and numerical simulations have shown that this is indeed the case.

The main idea is that gas is disturbed on large scales and that this results in a cascade of waves. In clusters these waves are creating perturbations in the gas density that are visible in X-ray images as small-scale fluctuations of the surface brightness relative to a smooth global model. Our analysis shows that there is a simple linear relation between the gas velocities and density perturbations. Moreover, this relation holds for a broad range of scales: on large scales, where buoyancy effects dominate (internal waves), as well as on small scales where the isotropic turbulent cascade usually develops. At these small scales, the entropy of the gas acts as a passive scalar advected by the velocity field and makes the gas displacement visible in X-rays.

Based on these arguments one can expect that in relaxed clusters (i.e. clusters which are only slightly disturbed) the power spectrum of the velocity field can simply be recovered from the power spectrum of density fluctuations. The latter can be straightforwardly estimated from X-ray images.

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Numerical simulations (cosmological simulations of cluster formation and pure hydrodynamic simulations with turbulence) confirm this conclusion and open an interesting possibility to use gas density power spectra as a proxy for the velocity power spectra in relaxed clusters.

Once the gas velocities can be measured directly with future X-ray observatories, it will be possible to push this analysis further and search for differences between the density and velocity power spectra. Strong departures of the two power spectra from the universal behavior described above can then be used to constrain physical effects such as conductivity or viscosity in the gas. (Eugene Churazov, Massimo Gaspari, Irina Zhuravleva (Stan-

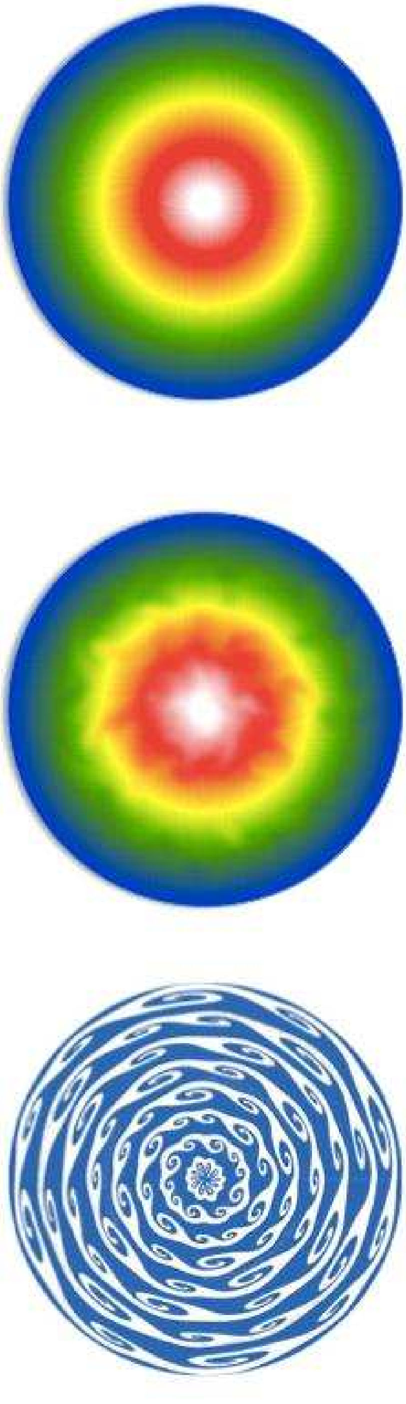

Figure 2.6: Schematic illustration of gas density distribution in a spherically symmetric cluster in perfect hydrostatic equilibrium ($v = 0$, top) and in a slightly disturbed cluster ($v \neq 0$, middle). Slow large-scale perturbations in a stratified cluster atmosphere can be interpreted as internal waves (as illustrated in the bottom panel), similar to waves in the ocean, where the velocity of water and the amplitude of waves are linked. In clusters, similar perturbations are caused by a variety of reasons, including minor mergers or the activity of the central supermassive black holes.

ford), Alex Schekochihin (Oxford), Rashid Sunyaev)

References:

Zhuravleva I., Churazov E., A. Schekochihin et al.: The Relation between Gas Density and Velocity Power Spectra in Galaxy Clusters: Qualitative Treatment and Cosmological Simulations, Astrophys. J. Lett. **788**, 13 (2014).

Gaspari M., Churazov E., Nagai D., et al.: The relation between gas density and velocity power spectra in galaxy clusters: high-resolution hydrodynamic simulations and the role of conduction, Astron. Astrophys. **569A**, 67 (2014).

Gaspari M., Churazov E., Constraining turbulence and conduction in the hot ICM through density perturbations, Astron. Astrophys. **559A**, 78 (2013.

Churazov E., Vikhlinin A. et al. (incl. R. Sunyaev): X-ray surface brightness and gas density fluctuations in the Coma cluster, 2012, Mon. Not. R. Astron. Soc. **421**, 1123 (2014).

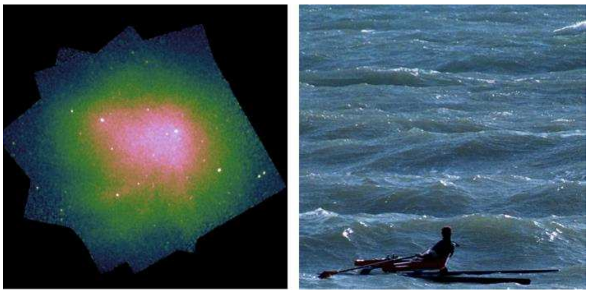

Figure 2.7: X-ray image of the Coma cluster as seen with Chandra observatory. The substructure seen in the image implies that the X-ray emitting gas is not at rest. Right: High waves in the sea can be linked to the large fluid velocity. The conjecture is that in clusters one can similarly infer the velocity of gas motions from the amplitude of density perturbations.

2.4 Computer simulation confirms supernova mechanism in three dimensions

Massive stars explode as supernovae at the end of their lives, but how exactly does the explosion begin and what is the role of different physical processes? For the first time, scientists at the Max Planck Institute for Astrophysics have been able to simulate such a stellar explosion in all three dimensions with detailed physical input. The results show that the energetic neutrinos radiated by the newly formed neutron star indeed trigger the explosion by heating the stellar matter. Turbulent flows support this process and lead to an even more energetic explosion.

During their lifetimes, stars “burn” light elements such as hydrogen into heavier ones by nuclear fusion. This process produces energy until, at the end, an iron core is formed. Since iron has the largest binding energy of all nuclei, no heavier elements can be produced in fusion reactions and nuclear burning ceases. However, the iron core continues to grow by fusion processes at its surface. At this stage, gravity is balanced by the quantum mechanical pressure of the electrons. Similar to a white dwarf star, there is a critical mass above which the iron core can no longer resist the pull of gravity and collapses. Under appropriate conditions, this results in a powerful stellar explosion: a supernova.

Already in the middle of the past century, first theories proposed the origin of the supernova energy: Because of the extreme gravitational force, the core collapses within fractions of a second to produce a neutron star. Gravitational binding energy is released and transported outwards by a shock front, but gets quickly absorbed by the outer layers of the iron core. To actually trigger the explosion, an additional effect is required: heating by neutrinos (see Highlight 2001). These elementary particles are generated in vast numbers in the new-born neutron star and propagate outwards relatively freely, once they are outside the neutron star’s surface. Therefore they can extract energy from the so-called “cooling layer” and deposit this energy at greater distances from the neutron star where they are re-absorbed and thus heat the plasma in the so-called “heating layer” behind the shock wave. If the amount of deposited energy is large enough, the shock is pushed outwards, which eventually disrupts the star in a supernova. At least that is how the theory goes.

The process to confirm this paradigm in detailed physical models, however, has been long: In the 1980s, the first star “exploded” in a computer, but only in spherically symmetric (i.e. one-dimensional) models and with some special assumptions to simplify the description of the physics involved. But the observation of supernova 1987A showed that multi-dimensional effects play an important role during the explosion. The shells surrounding the neutron star are mixed by convection, which further supports neutrino heating. After a few decades, scientists could confirm the ba-

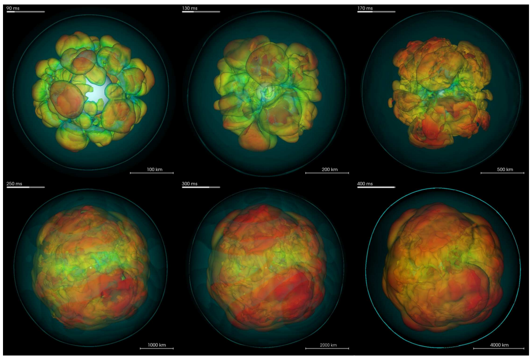

Figure 2.8: History of the explosion in the stellar interior: within fractions of a second, the core inflates to many times its volume. The snapshots impressively show that the explosion is far from symmetric and that convective buoyancy and turbulence play an important role. The colour code indicates the speed of the ejected material. The thin bluish line shows the position of the shock front.

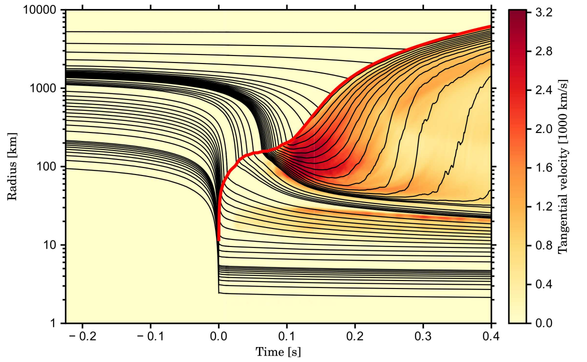

Figure 2.9: This diagram shows the progression of the stellar explosion; the thick red line traces the position of the shock front. The shock forms when a neutron star is born in the center, begins to first move outwards rapidly, and then stalls before it is revived by neutrino heating. The red areas indicate regions with strong turbulent motions of the stellar matter.

sic functioning of the neutrino mechanism with two-dimensional models (see Press Release 2009). Still, the forced rotational symmetry about an arbitrary axis severely restricts motions of the stellar plasma. In addition, turbulent flows behave differently under these symmetry assumptions compared to three dimensions. It is therefore necessary to perform three-dimensional calculations to model all processes during the supernova correctly.

So far, simulations have not yielded successful explosions in three dimensions (Press Release 2013 und Highlight 2014). But now, the scientists obtained their long desired result: the first successful, neutrino-driven explosion of a star with an initial mass of 9.6 solar masses in a three-dimensional, self-consistent simulation (see Fig. 2.8 and 2.9). The challenge was to describe the neutrinos as correctly as possible, so that the resulting complex calculation kept even supercomputers busy for a few months. The new method provides the currently most complete description of how neutrinos interact with matter in a supernova calculation. In particular, there is an open, controversial question whether three-dimensional turbulence in the neutrino heated plasma helps or hinders the explosion.

In this case, the answer is definitely yes: three-dimensional turbulence leads to about 10% higher explosion energy. Turbulent effects in the heating layer change the flow of stellar material into the cooling layer, which means that the temperature in this region remains lower. As the cooling by neutrinos strongly depends on temperature, the energy loss by neutrino emission decreases at lower temperature and the explosion gets stronger. However, it is difficult to predict whether this phenomenon could play an equally important role for even more massive stars. To answer this question, the scientists need further simulations. They also plan to calculate the explosion with even higher resolution to better resolve turbulence and investigate it on smaller scales. Another important question is whether the star might have been asymmetric before collapse and how this would affect the explosion. So even with this significant milestone, the astrophysicists still have some way to go. (Tobias Melson, Hans-Thomas Janka)

References:

T. Melson, H.-T. Janka, and A. Marek: Neutrino-driven supernova of a low-mass iron-core progenitor boosted by three-dimensional turbulent convection, Astrophys. J. Lett. **801**, L24 (2015).

2.5 Understanding X-ray emission from galaxies and galaxy clusters

By combining data for more than 250,000 individual objects, an MPA-based team has for the first time been able to measure X-ray emission in a uniform manner for objects with masses ranging from that of the Milky Way up to that of rich galaxy clusters. The results are surprisingly simple and give insight into how ordinary matter is distributed in today's universe, and how this distribution has been affected by energy input from galactic nuclei.

While galaxies, with their billions of stars, may seem unfathomably large, the Universe contains even bigger objects. Clusters of galaxies are the largest known equilibrium structures. They can contain many hundreds of galaxies and a total mass thousands of times that of the Milky Way system. Galaxies and clusters appear very different when viewed in optical light (see Fig. **??**), but computer simulations such as the Millennium Simulation suggest that their dark matter distributions should look very similar. The technical term for this is 'self-similarity', which in this context means that the dark matter halos of galaxy clusters are more or less just scaled-up versions of those which surround galaxies.

Both galaxies and galaxy clusters (and their dark matter halos) are expected to be suffused with hot gas as well. This gas, which is heated to temperatures of millions of Kelvin, emits high-energy radiation and can be studied with X-ray telescopes like ROSAT and XMM-Newton. Studies of dozens of galaxy clusters show that the X-ray luminosity of the hot gas increases with the total mass of the cluster. Independently, studies of dozens of elliptical galaxies have shown that the X-ray luminosity of their hot gas increases with the stellar mass of the galaxy. These two correlations connect X-ray luminosity to two different quantities (total mass for clusters, stellar mass for galaxies), and have typically been measured in different ways for the different types of object.

A team at MPA has now combined these two relations using an archived X-ray map of the whole sky. They analysed emission around a sample of 250,000 galaxies in the ROSAT All-Sky Survey - more than a thousand times the number used in any previous galaxy study - and carefully combined the X-ray emission from several thousand similar mass galaxies into a set of average images in a process known as "stacking". Example stacked im-

Figure 2.10: Images of a galaxy (NGC 1132, left) and a galaxy cluster (Abell 1689, right) taken with the ESA/NASA Hubble Space Telescope. Observed in optical light, these systems look very different, as a galaxy cluster may contain hundreds or even thousands of galaxies. On the other hand, the X-ray emission from these systems looks remarkably similar.

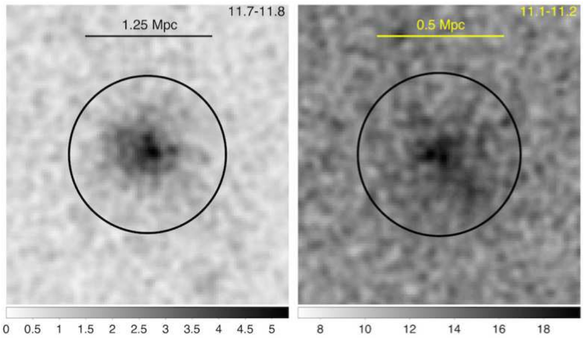

Figure 2.11: Stacked X-ray images of the emission around the central galaxies of rich galaxy clusters (left) and lower mass galaxy groups (right). These are two of the twenty produced in this study. In both images, the black circle indicates the radius "R500", which roughly matches the size of the dark matter halo. The X-ray emission is centrally concentrated but clearly extends out to a significant fraction of this radius. The numbers in the top right of each image denote the stellar mass of the central galaxies (log $M_\star$; see Fig.2.10) which were stacked. As the rulers show, R500 is about 2.5 times larger (and the mass about 15 times larger) for the clusters than for the groups. However the radial distribution of emission is similar in the two images.

ages are shown in Fig. 2.11 for two different stellar masses. By eye, the distribution of the hot gas in galaxy clusters looks just like a scaled-up version of that around much smaller galaxies. The full results are shown in Fig. 2.11, which shows the relation between mean X-ray luminosity and stellar mass. This relation follows a straight line all the way from the individual galaxy regime (small masses) up to the rich cluster regime.

However, a more detailed analysis shows that the slope of this line is steeper than would be expected if the hot gas were perfectly self-similar. This is probably due to a combination of effects, with a major contribution coming from heating by supermassive black holes at the centres of galaxies. As gas falls into a supermassive black hole, it loses large amounts of energy which are pumped into the hot gas atmosphere surrounding the galaxy. This is known "active galactic nucleus (AGN) feedback" and is thought to be important in the formation of both galaxies and galaxy clusters. AGN feedback has a bigger effect on less massive systems, lowering the X-ray luminosity of galaxies much more than that of clusters.

This effect makes the relation in Figure 2.12 steeper than it would be if the hot gas were perfectly self-similar. The new measurements of X-ray luminosity over a broad range of masses gives a powerful clue to help understand AGN feedback. Comparing these measurements against predictions from numerical simulations, the MPA team showed that gentle, 'self-regulated' AGN feedback is preferred over more violent input of energy.

Detailed comparison with previous measurements show that the new results are perfectly consistent with previously measured scaling relations for galaxies, as well as with scaling relations measured for optically selected samples of galaxy clusters. This suggests that a single relation can indeed describe both types of object. Studies of scaling relations for galaxy clusters selected by their X-ray properties have typically shown a similar slope but a systematically higher mean brightness at given total mass. This is most likely a reflection of the diversity of X-ray properties among clusters of a given total mass, which may have been underestimated in earlier work.

Finally, this work complements a similar analysis performed for the same galaxies and galaxy clusters using data from the Planck satellite. That analysis used the shadows which hot gas atmospheres cast on the cosmic microwave background to measure the total thermal energy of the hot gas, as opposed to its X-ray luminosity, finding this to scale with mass self-similarly. Combining these two results implies that a large reservoir of hot gas surrounds galaxies, but is too rarefied as a result of AGN feedback to emit strongly in X-rays. This would resolve the long-standing problem of the location of the baryons which "should" be associated with the galaxies but had not previously been detected directly. (Mike Anderson, Massimo Gaspari, Simon White.)

References:

Anderson, M., M. Gaspari, S. White, W. Wang, X.Y. Dai: X-ray scaling relations from galaxies to clusters, Mon. Not. R. Astron. Soc. **449**, 3806-3826 (2015).

Planck Collaboration Planck intermediate results. XI. The gas content of dark matter halos: the Sunyaev-Zeldovich-stellar mass relation for locally brightest galaxies, Astron. Astrophys. **557**, id.A52, (2013).

2.6 A new observable of the large-scale structure: the position-dependent two-point correlation function

Observations of the large-scale structure, such as galaxy surveys, are one of the most important tools to study our universe. In particular, how the growth of structure is affected by the large-scale environment can be used to test our understanding of gravity, as well as the physics of inflation. A research group at MPA has recently developed a new technique to extract this signal more efficiently from real observations. Specifically, we divide a galaxy survey into sub-volumes, quantify the structure and the environment in each sub-volume, and measure the correlation between these two quantities. This technique thus opens a new avenue to critically test fundamental physics from real observations.

The large-scale structure is one of the most important observables in modern astronomy to probe the properties of our universe. Large galaxy survey programmes such as the 2dF Galaxy Redshift Survey and the Sloan Digital Sky Survey (SDSS) measure the angular positions on the sky and the distance (redshift) of millions of galaxies, currently out to 6.4 billion years ago. Scientists then use these data to construct a three-dimensional map of our universe, as shown in Fig. 2.13.

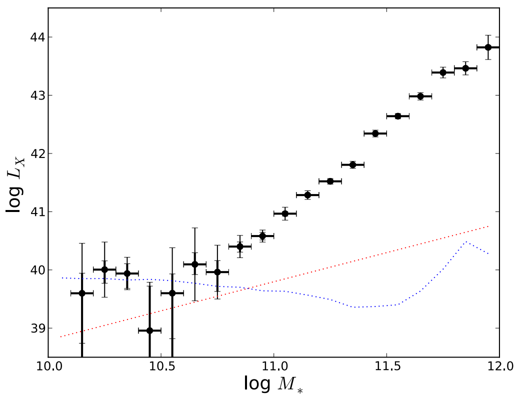

Figure 2.12: Average X-ray luminosity for each of the 20 stacked images as a function of the stellar mass of the central galaxy. At higher masses the relation between the two is a power law (a straight line in this plot). For the seven data points at lowest mass, the X-ray emission from the hot gas is too faint to measure reliably, and the X-ray signal is also contaminated by emission from X-ray binaries in these galaxies - their estimated luminosity is shown with the blue and red dotted lines, corresponding to high-mass X-ray binaries and low-mass X-ray binaries respectively.

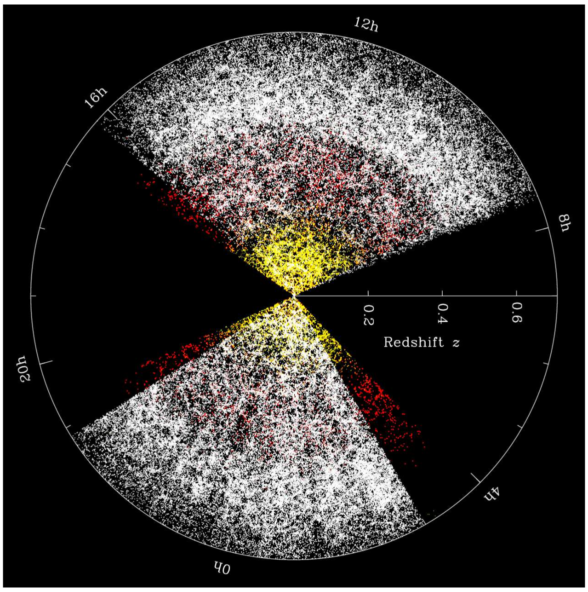

Figure 2.13: Projected slice of the galaxies observed in the SDSS with distances (redshifts). (The position on the sky is measured in observation coordinates: RA labelled in hours, with DEC being projected onto the plane.) The yellow, red, and white points are the main galaxy sample, the red luminous galaxies, and the BOSS CMASS sample, respectively. *Credit: Michael Blanton and SDSS collaboration*

As the visual rendering in Fig. 2.13 shows, one can clearly see filamentary structures as well as relatively empty regions. This is how our universe looks like. To quantify these structures of our universe, scientists use in particular the so-called "two-point correlation function," which measures how likely it is to find galaxies in pairs with some given separation. For example: if we choose a separation of 150 Mpc (which corresponds to 490 million light-years or 4.6 sextillion kilometres), we then count the number of galaxy pairs that we can find with a distance of 150 Mpc between them. Once we are done with this separation, we move on to the next separation we are interested in. As we keep doing this counting, we get the two-point correlation as a function of separation.

The orange data points in Fig. 2.14 show the measurement of the two-point correlation function from the galaxies observed in the SDSS. At a separation of roughly 150 Mpc we find a small bump. This means that it is more likely to find galaxy pairs with this separation compared to smaller or larger distances. This bump was imprinted only 400,000 years after the Big Bang by sound waves in the plasma filling the (then ionized) universe.

While the two-point correlation function is the most common statistic to quantify structures in our universe, the observed galaxies contain more information. One interesting question, in particular, is if and how the structures depend on their large-scale environment. More specifically, we want to study whether or not there will be more structure in a relatively over-dense region compared to an under-dense region.

This question can be addressed by the "three-point correlation function", i.e. looking for three galaxies with given separations. However, these measurements rely on finding galaxy triplets, which is computationally challenging due to the large number of observed galaxies.

Recently, a research group at MPA has developed a new method, the position-dependent two-point correlation function, to address the question of how structure depends on the environment and capture this particular signal from the observed galaxies. Specifically, for a given galaxy survey, we divide the entire survey volume into small sub-volumes (Fig. 2.15). We then measure the mean over-density (with respect to the entire survey) and the two-point correlation function in each sub-volume, to get a position-dependent two-point correlation function. Finally, we measure the correlation between these two quantities. If we find a positive correlation, this means that it is more likely to find more structures in the over-dense background, and vice versa. In mathematical terms, this cor-

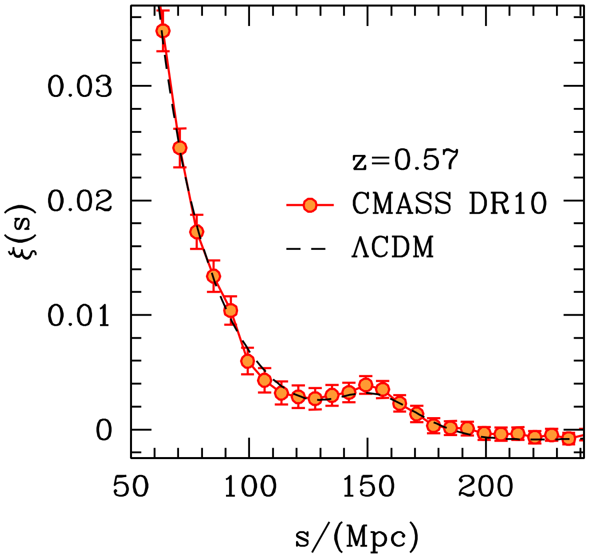

Figure 2.14: The two-point correlation function of the BOSS DR10 CMASS sample. The orange data points are the measurements for the observed galaxies, the dashed line denotes the expectation from the currently accepted cosmological model. *Credit: Ariel G. Sánchez and SDSS collaboration*

relation measures an integral over the three-point function; therefore we call it the integrated three-point function. Since this new method requires only the counting of galaxy pairs, the computational problems with the three-point function are largely alleviated.

We apply this new technique to "real" and "mock" data of a sample of SDSS galaxies, the BOSS DR10 CMASS sample. The real data contain positions and distances (redshifts) for about 0.4 million observed galaxies, while the 600 mock catalogues were generated by simulations to match the properties of the real data for data analysis. The first measurement of the integrated three-point function for the BOSS DR10 CMASS sample is shown in figure 2.16. We find that even though the integrated three-point function of the observed galaxies does not agree perfectly with the mean of the mock realisations, it is within the scatter of the simulated results. Moreover, both the measurements for the real data and the mean mock results are above zero for all separations, meaning that in our universe the structures do grow more strongly if they are in an over-dense environment.

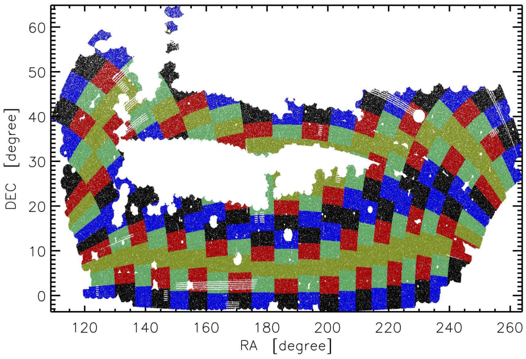

Figure 2.15: The division of the BOSS DR10 CMASS sample into sub-volumes on the sky. Each coloured block extends over the whole redshift range. *Credit: MPA*

The coupling between small-scale structures and their environment or background plays a fundamental role in cosmology. This correlation arises because of gravitational evolution, and possibly from inflationary physics. This new observable, the position-dependent two-point correlation function, therefore allows us to test our understanding of gravity and the physics of inflation. Combining our first measurement with other probes such as the global two-point correlation function and the weak lensing signal, we are able to constrain how galaxies trace the underlying dark matter density. In the future, with better data, we shall utilise this technique to study the properties of inflation, which is one of the biggest mysteries in physics and at the same time provided the seeds for all present-day structures. (Chi-Ting Chiang)

Reference:

Chiang, C.T., C. Wagner, G.A. Sánchez, F. Schmidt, and E. Komatsu: Position-dependent correlation function from the SDSS-III Baryon Oscillation Spectroscopic Survey Data Release 10 CMASS Sample, *http://arxiv.org/abs/1504.03322*

2.7 Understanding how stars form from molecular gas

The star formation rate in galaxies varies greatly both across different galaxy types and over galactic time scales. MPA astronomers have been trying to gain insight into how the interstellar medium may change in different galaxies by studying molecular gas in a wide variety of galaxies, ranging from gas-poor, massive ellipticals to strongly star-forming irregulars, and in environments ranging from inner bulges to outer disks. They find that the gas depletion time depends both on the strength of the local gravitational forces and the star formation activity inside the galaxy.

Molecular clouds are clouds in galaxies consist-

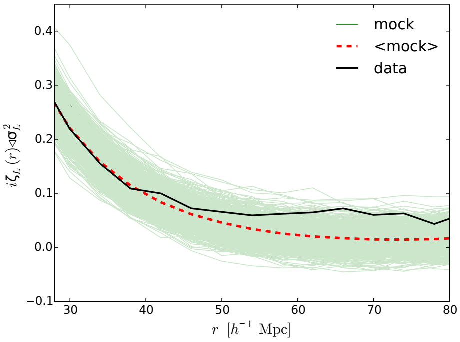

Figure 2.16: First measurement of the integrated three-point function from the BOSS DR10 CMASS sample. The thick black solid line shows the measurement for real data, the thin green lines show the results for each of the 600 mock realisations, while the thick red dashed line shows the mean of the mock realisations. *(c)MPA*

ing predominantly of molecular hydrogen. They are stellar nurseries where the gas reaches high enough densities to form new stars and planetary systems. Molecular clouds are highly complex structures. Fig. 2.17 shows a Hubble Space Telescope image of the Eagle Nebula, a nearby molecular cloud with a highly filamentary and irregular structure.

In the neighbourhood of our Sun, molecular clouds make up only 1 % of the total volume of the interstellar medium and form stars at modest rates of a few solar masses per year. In the early Universe, however, there is mounting evidence that galaxies contain much more molecular gas and therefore they can form stars at rates up to a thousand times higher than in our Milky Way. The densities and pressures in the interstellar media of these early galaxies are also orders of magnitude higher than in the solar neighbourhood, and it is unlikely that molecular clouds in these systems are the same as the very well-studied Eagle nebula.

In recent work, the MPA group studied variations in the relation between the local density of molecular gas and newly formed stars. They used this as a diagnostic of changing conditions within the interstellar medium. According to standard theory, molecular clouds exist in a balance between gravitational forces, which work to collapse the cloud, and pressure forces (primarily from the gas), which work to keep the cloud from collapsing. When these forces fall out of balance, such as can happen in a supernova shock wave, the cloud begins to collapse and fragment into smaller and smaller pieces. The smallest of these fragments begin contracting and become proto-stars.

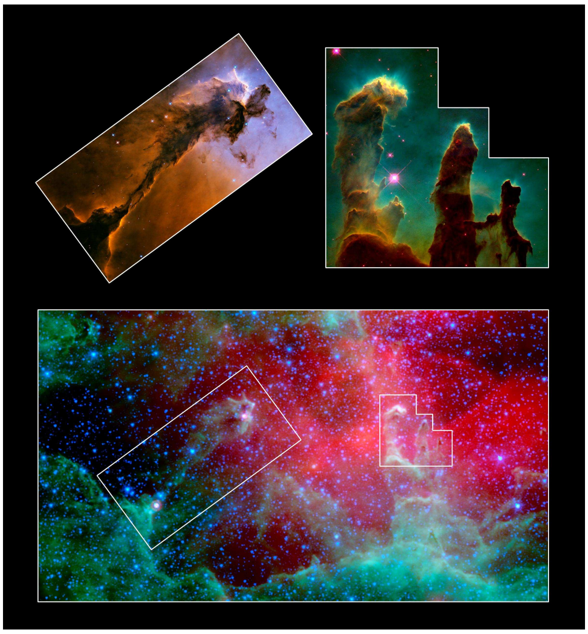

Figure 2.17: Eagle Nebula imaged by Hubble Space Telescope. *Credit: NASA, ESA/Hubble and the Hubble Heritage Team (STScI/AURA)*

Gravitational forces vary significantly from one galaxy to the next, as well as in different regions of the same galaxy. At the centre of a giant elliptical galaxy, gravity is much higher than in the outskirts of a small dwarf irregular. Likewise, the incidence of supernova explosions can differ drastically between different galaxies and between different locations within the same galaxy. Variations in the ratio of the density of molecular gas to young stars (commonly referred to as the depletion time of the molecular gas) may thus be expected as a consequence of these changing conditions.

The main result (see Figure 2.18) from the MPA group's analysis is that the rate at which molecular gas forms new stars is set BOTH by gravity (as measured by the local surface density of stars in the galaxy) and by the local star formation activity level in the galaxy, which in turn will determine the incidence of supernova-driven shock waves in the interstellar medium. Molecular gas depletion times are shortest in regions where gravity is strong and where the star formation activity is high, particularly in galaxy bulges with gas and ongoing star formation.

Reaching this conclusion required very careful analysis of a variety of data sets at different wavelengths. In particular, star formation rates derived from the combination of infrared images that trace young stars embedded inside dusty clouds and far-

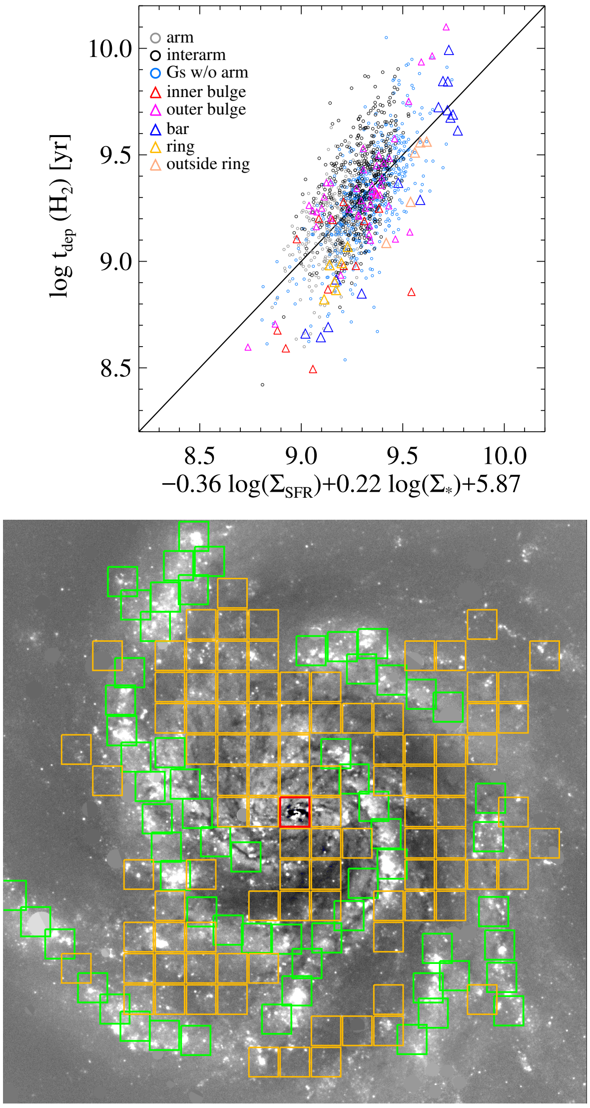

Figure 2.18: Top: This plot is linking the depletion time and a specific combination of star formation rate (SFR) and stellar surface densities. Each data point represents a grid cell of $1kpc \times 1kpc$ size within different structures of the galaxies analysed. Bottom: The optical image of one of the galaxies in the sample, NGC 5457. Coloured squares show grids cells, with 1 kpc on a side, in the arm (green), interarm (yellow) and bulge (red) regions. *Credit: MPA*

ultraviolet images that trace stars that have migrated outside these clouds, are crucial for pinpointing these relations as accurately as possible. In future, new state-of-the-art interferometric radio telescopes, in particular the Atacama Large Millimeter/submillimeter Array (ALMA), will allow us to understand the detailed structure of molecular clouds in regions of high gravity in much more detail. (Guinevere Kauffmann and Mei-Ling Huang)

References:

Huang M.-L., Kauffmann G.: The variation in molecular gas depletion time among nearby galaxies: what are the main parameter dependences? Mon. Not. R. Astron. Soc. **443** 1329-1338, (2014).

Huang M.-L., Kauffmann G.: The variation in molecular gas depletion time among nearby galaxies âĂŞ II. The impact of galaxy internal structures. Mon. Not. R. Astron. Soc. **450** 1375-1387 (2015).

2.8 Three-dimensional computer simulations support neutrinos as cause of supernova explosions

Latest three-dimensional computer simulations are closing in on the solution of an decades-old problem: how do massive stars die in gigantic supernova explosions? Since the mid-1960s, astronomers thought that neutrinos, elementary particles that are radiated in huge numbers by the newly formed neutron star, could be the ones to energize the blast wave that disrupts the star. However, only now the power of modern supercomputers has made it possible to actually demonstrate the viability of this neutrino-driven mechanism.

Supernovae are among the brightest and most violent explosive events in the Universe. They are not only the birth sites of neutron stars and black holes; they also produce and disseminate heavy chemical elements up to iron and possibly even nuclear species heavier than iron, which could be forged during the explosion. Understanding the explosion mechanism of massive stars is therefore of fundamental importance to better define the role of supernovae in the cosmic cycle of matter.

Stars with more than about eight times the mass of our sun evolve by “burning” nuclear fuel to successively heavier chemical elements, thus converting hydrogen to helium, carbon, oxygen, sulfur and silicon, until a dense, degenerate core mostly made of iron builds up in the center. At this stage no further energy gain by nuclear fusion is possible, because neutrons and protons in iron nuclei possess the highest nuclear binding energies.

Lacking its central energy source, the stellar iron core cannot escape gravitational instability when its mass grows to a critical limit by ongoing silicon burning in a surrounding shell. A catastrophic collapse sets in and stops abruptly only when the stellar matter reaches densities higher than in atomic nuclei. At this moment repulsive forces between the neutrons and protons resist further compression and the central region bounces back to send a strong shock wave into the overlying, still infalling matter of the iron core.

For more than 30 years there had been hope that ever more improved computer models would finally be able to demonstrate that this "core-bounce shock" is able to trigger a successful supernova explosion by reversing the infall of the outer stellar layers. However, the opposite turned out to be the case: Better models showed that the energy losses of the bounce shock are so dramatic that its outward propagation comes to a halt still well inside of the iron core. It became clear that something has to help reviving the stalled shock. Some mechanism has to supply the shock with fresh energy so that it reaccelerates and expels the stellar mantle and envelope in the supernova blast.

Already in the 1960's it was speculated (in a seminal publication by Stirling Colgate and Richard White) that neutrinos might be involved. Myriads of these high-energy elementary particles are radiated by the extremely hot, newly formed neutron star. If less than one percent of them gets absorbed in the matter behind the stalled shock, a healthy supernova explosion will be the consequence (see MPA research highlight 2001). This was shown, in principle, already in the mid 1980's with first sufficiently detailed numerical simulations by Jim Wilson and interpretative work by Wilson and Hans Bethe.


Figure 2.19: SuperMUC supercomputer of the Leibniz Computing Center (LRZ). *Credit: LRZ 2012*

However, many aspects of the involved physics were still too crude and too approximate to be realistic. In particular, with the observation of Supernova 1987A it became clear that stellar explosions are highly asymmetric phenomena and nonspherical plasma flows must play an important role already at the very beginning of the explosion. Early multi-dimensional computer models — mostly still in two dimensions, i.e., assuming rotational symmetry around a chosen axis for reasons of computational efficiency— indeed showed that convection and non-radial mass motions provide crucial support to the neutrino-heating mechanism and enhance the energy deposition by neutrinos. Thus explosions could be obtained although spherical models did not find shock revival and did not lead to explosions (see MPA press release 2009).

Nature, however, has three spatial dimensions and therefore these early successful models were critisized to be unrealistic and not reliable. In fact, not only the assumed axial symmetry is artificial, also the physics of turbulent flows differs in two dimensions compared to the 3D case.

Only very recently the increasing power of modern supercomputers has now made it possible to perform supernova simulations without artificial constraints of the symmetry. A new level of realism in such simulations is thus reached and brings us closer to the solution of a 50 year old problem.

The stellar collapse group at the Max Planck Institute for Astrophysics (MPA) plays a leading role in the worldwide race for such models. With all relevant physics included, in particular using a highly complex treatment of neutrino transport and interactions, such computations are at the very limit of what is currently feasible on the biggest available computers. The model simulations are performed on 16,000 cores (equivalent to a similar number of the fastest existing PCs) in parallel, which is the largest share of SuperMUC at the Leibniz-Rechenzentrum (LRZ) in Garching (Fig. 2.19) and of MareNostrum at the Barcelona Supercomputing Center (BSC; Fig. 2.20) that the MPA team is granted access to. Nevertheless, one full supernova run, conducted over an evolution time of typically half a second, consumes up to 50 million core hours and takes more than 1/2 year of project time to be completed.

The enormous effort has payed off! The

Figure 2.20: MareNostrum supercomputer of the Barcelona Supercomputing Center (BSC). *Credit: BSC 2013*

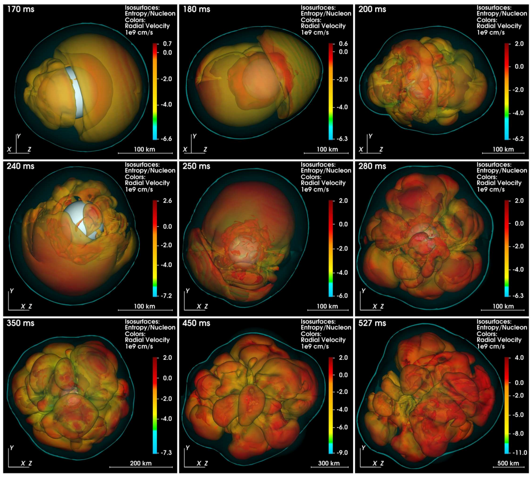

Figure 2.21: Sequence of volume-rendering images that show the violent non-spherical mass motions that drive the evolution of the collapsing 20 solar-mass star towards the onset of a neutrino-powered explosion. The whitish central sphere indicates the newly formed neutron star, the enveloping bluish surface marks the supernova shock. *(Visualization: Elena Erastova and Markus Rampp, Max Planck Computing and Data Facility (MPCDF); Credit: (2015) by American Astronomical Society).*

MPA team has recently been able to report a first successful 3D explosion for a 9.6 solar-mass star (see MPA research highlight 2015; Movie of the 3D explosion of a star with 9.6 solar masses by Aaron Döring) *http://www.mpa-garching.mpg.de/208528/hl201508* and has now also obtained a 3D explosion of a 20 solar-mass progenitor (Fig. 2.21), Based on the presently most advanced description of the neutrino physics in collapsing stellar cores worldwide, these results are a true milestone in supernova modeling. They confirm the viability of the neutrino-heating mechanism in principle, applying our currently best knowledge of all processes that play a role in the center of dying stars, whose extreme conditions in temperature and density are hardly accessible by laboratory experiments on Earth. Since not all aspects of the complex neutrino reactions in the newly formed neutron star are finally understood, the 3D models demonstrate that within existing uncertainties neutrinos can indeed transfer enough energy to revive the stalled shock. As known from previous models in two dimensions, violent non-radial fluid flows must provide crucial support to relaunch the blast wave and will function as seeds of the later, large-scale asymmetries that are observed in supernova explosions.

Further work on the theoretical models is necessary. So far the successful 3D simulations could only be done with rather coarse resolution, because bigger computers would be needed to perform more refined supernova calculations. Moreover, a wider range of stellar masses must be investigated, varying the initial conditions in the precollapse cores. A final confirmation of our theoretical picture of the explosion mechanism and the role of neutrinos, however, can only come from observations. On the one hand this demands a closer link of the explosion models to observable supernova properties, on the other hand much hope rests on a next supernova that will occur in our Milky Way galaxy. Such a nearby event will flood the Earth with 1030 neutrinos, of which several thousand to tens of thousands will be captured in huge underground experiments like Super-Kamiokande in Japan and IceCube at the South Pole. Neutrinos (besides gravitational waves) will thus serve as unique messengers: since they escape from the center of the supernova they will bring us information directly from the very heart of the explosion. (Hans-Thomas Janka)

References:

Melson, T., H.-T. Janka, and A. Marek: Neutrino-driven supernova of a low-mass iron-core progenitor boosted by three-dimensional turbulent convection. Astrophys. J. Lett. **801**, L24 (2015).

Melson, T., H.-T. Janka, R. Bollig, et al.: Neutrino-driven explosion of a 20 solar-mass star in three dimensions enabled by strange-quark contributions to neutrino-nucleon scattering. Astrophys. J. Lett. **808**, L42 (2015).

2.9 New limits on the spectral distortions of the Cosmic Microwave Background

New data from the Planck satellite and the South Pole Telescope on the Cosmic Microwave Background (CMB) combined with a new component separation algorithm developed at MPA give much tighter limits on two parameters measuring the deviation of the CMB from a blackbody radiation. These results can be used to constrain new physics in the very early universe and to study the correlations between the primordial fluctuations on very small and very large angular scales.

The spectrum of the Cosmic Microwave Background (CMB), the relic radiation from the early Universe, is an almost perfect blackbody. The CMB spectrum was measured with high precision about 25 years ago by the FIRAS experiment on the COBE satellite. The FIRAS experiment could not detect any deviations from a Planck or blackbody spectrum and placed upper limits on the spectral distortions, i.e. the deviation from a Planck spectrum as parameterized by two parameters y and ν.

The y-type distortion is created by Compton scattering of CMB photons by free electrons which are at higher temperatures such as those in the hot intracluster medium (ICM) in the clusters of galaxies. In particular, the y-type distortion is the solution when the energy exchange between the electrons and the photons is very inefficient. For example, in clusters of galaxies only a very negligible fraction of electron energy is transferred to the CMB. But since the electron temperature is many orders of magnitude higher than that of the CMB (1 to 10 million degrees Kelvin vs few degrees Kelvin) the effect on the CMB spectrum is non-negligible and observable.

If the energy exchange from electrons to photons and vice versa in Compton scattering is efficient a new equilibrium can be reached. This new equilibrium solution is not a Planck spectrum any longer, since it was created by adding energy to it; it is a more general Bose-Einstein spectrum which differs from the Planck spectrum by the presence of a non-zero chemical potential. The μ parameter is just the magnitude of this chemical potential divided by temperature, both with units of energy, making it dimensionless.

Such conditions, where the energy exchange between electrons and photons is efficient, happen in the early Universe when the density is much higher and the temperature of both photons and electrons is much higher than the CMB temperature today. Both these distortions were predicted by Sunyaev and Zeldovich already in 1969 and 1970. FIRAS put limits on the average values of these parameters in the Universe to be $y < 10^{-5}$, $\mu < 10^{-4}$.

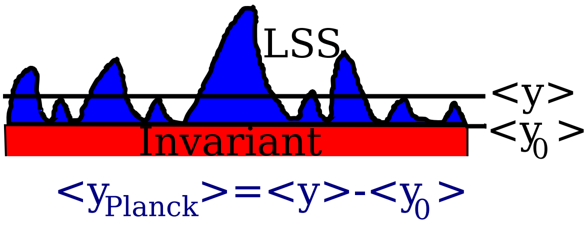

Figure 2.22: New map of the y parameter across the whole sky. The area at the centre of the image, with the plane of our Milky Way galaxy was not analysed. The annotations show a number of large galaxy clusters.

Now 25 years later, the scientists at MPA decided to take another look at these limits in the light of new data available from the Planck satellite and the South Pole Telescope (SPT), both of which have much higher sensitivity than FIRAS but a much smaller number of frequency channels. Unlike FIRAS, Planck and SPT are not sensitive to the absolute intensity of the radiation but measure the variation in intensity as the telescope scans the sky.

Planck and SPT can therefore only give information about the amplitude of the fluctuating part of the spectral distortions with the constant contribution cancelling out. However, this is not a problem, as in the standard cosmological picture, this fluctuating part gives the dominant contribution to the average y parameter. In addition, the μ parameter can fluctuate if there is some new physics which injects energy inhomogeneously in the early Universe at very high redshifts ($z > 5 \times 10^4$). One important scenario is the dissipation of primordial sound waves in the presence of primordial non-Gaussianity, which was first suggested by Pajer and Zaldarriaga.

Digging deep into the publicly available Planck maps, Rishi Khatri and Rashid Sunyaev at the MPA were able to put a new, very conservative limit on the average y parameter (from fluctuating portion of y) of $y < 2.2\times^{-6}$ which is a factor of 7 stronger than the COBE-FIRAS limit. This limit was achieved using a new (almost) all sky map of y-distortion calculated with a new component separation algorithm called LIL developed at the MPA by one of the authors (RK). In addition, by combining the y signal detected by the Planck and SPT teams from confirmed clusters of galaxies in both samples, the team was also able to place an absolute lower bound on the average y distortion of $y < 5.4 \times 10^{-8}$ for the first time.

Using the same algorithm LIL they also created a map of the chemical potential or Îij parameter placing a upper bound at 10 arcmin resolution of $\mu < 6.4 \times 10^{-6}$ a factor of 14 stronger than the COBE-FIRAS limit. By cross correlating the μ map with the CMB temperature map provided by the Planck team they were able to constrain the non-Gaussianity to be no larger than of order unity. The particular configuration of non-Gaussianity that is constrained quantifies the correlation between the primordial density fluctuations on extremely small scales, on the order of 1000 parsec, with the very large scales of 1 to 10 giga parsec. The largest scale we can observe is limited by the size of our cosmological horizon. The Îij distortion is one of the very few methods which can constrain non-Gaussianity on such a broad range of scales. (Rishi Khatri and Rashid Sunyaev).

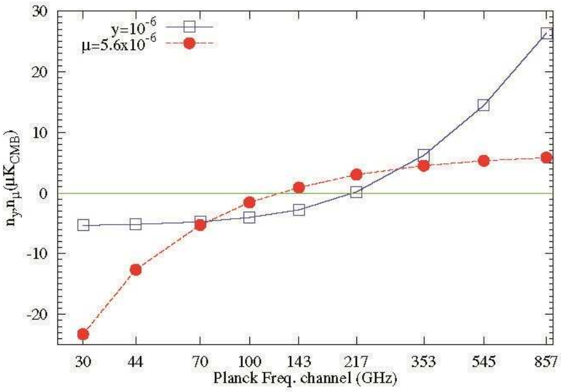

Figure 2.23: Comparison of the two types of spectral distortions y-type and μ-type, characterizing the deviation of the cosmic background radiation from a Planck spectrum.

References:

R. Khatri: An alternative validation strategy for the Planck cluster catalog and y-distortion maps. arXiv:1505.00778.

Khatri, R., and R. Sunyaev: Limits on the fluctuating part of y-type distortion monopole from Planck and SPT results. JCAP 08, 013 (2015).

Khatri, R., and R. Sunyaev: Constraints on Îij-distortion fluctuations and primordial non-Gaussianity from Planck data. accepted in JCAP

2.10 Solving the hydrostatic mass bias problem in cosmology with galaxy clusters

Booming observations of galaxy clusters provide great opportunities for exploring the nature of Dark Energy. At the same time, they post great challenges to scientists. The “hydrostatic mass bias” problem, which leads to a systematic error in estimating the mass of galaxy clusters, is one big limitation when doing precision cosmology with galaxy clusters. Now researchers at MPA have developed a method to correct for it.

Dark Energy is the most dominant energy component in the present-day universe, but its physical nature remains unknown. Dark Energy leaves unique signatures in the universe: it accelerates the expansion of the universe and slows down the growth of structure. As the largest gravitationally-

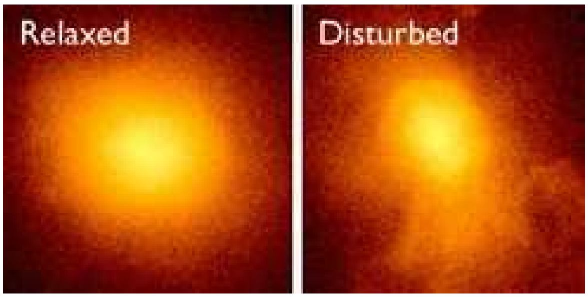

Figure 2.24: Two mock images of galaxy clusters in X-rays, as examples for a relaxed and a disturbed cluster (spatially well-resolved).

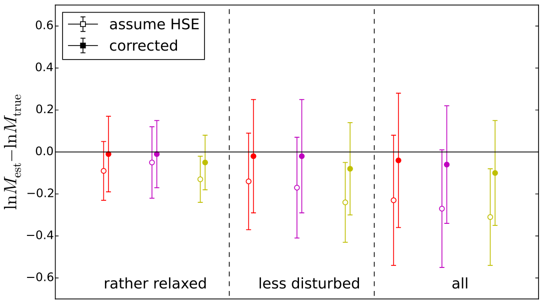

Figure 2.25: This plot shows the hydrostatic mass bias for galaxy clusters, i.e. the difference between the true mass and the estimated mass (with different models). Open symbols give the estimated mass without correction, the filled symbols the results when applying the new method. The three areas of the figure show simulated clusters in different dynamical stages, namely, the top 20% (rather relaxed), 50% (less disturbed) and 100% (all) clusters according how dynamically relaxed they are. The new method works well for all types of clusters and irrespective of the detailed procedures used in estimating the masses (indicated by different colors).

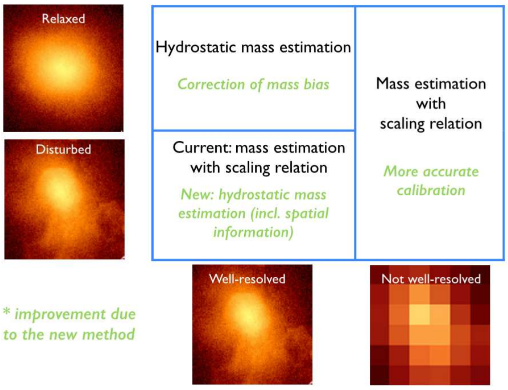

Figure 2.26: Different methods are used to determine the mass of a galaxy cluster depending on both the dynamical relaxation state of the cluster (relaxed/ disturbed, evident from its X-ray image) and the spatial resolution of the observed image (well-resolved or not). With our solution to the hydrostatic mass bias problem, we can improve the accuracy of mass estimation for clusters belonging to all these categories. We will also be able to take advantage of the spatial information in the observations for the well-resolved, dynamically disturbed clusters.

bound structures in the universe, galaxy clusters are a sensitive tracer to these signatures. Thus, researchers can constrain the properties of Dark Energy by counting the numbers of clusters as a function of their masses at various cosmic times.

An accurate measurement of the masses of galaxy clusters is crucial for the success of this method. Although galaxy clusters get their name from observations of galaxies in optical light, the most precise way to estimate their masses - the so-called “hydrostatic mass estimation method” - comes from observations at X-ray wavelengths. X-ray images of galaxy clusters reveal the diffuse hot gas in galaxy clusters that accounts for 90% of their ordinary matter (see mock X-ray images in Fig. 2.24). In spite of its high temperature - which means high thermal velocities - this hot gas is trapped deep inside the galaxy cluster. This is because of the enormous gravitational attraction from the dark matter component, which makes up about 85% of the total mass of a cluster. (Ordinary matter accounts for only about 15% of the mass.)

The hydrostatic mass estimation method assumes that the hot gas is in hydrostatic equilibrium, i.e. its thermal pressure balances the gravitational pull. However, the hot gas in a galaxy cluster is never fully thermalized because it is continuously fed by mass accretion. The residue motions of the infalling gas leads to a non-thermal pressure support, together with possible contributions from magnetic fields and cosmic rays. This breaks the assumption of hydrostatic equilibrium and causes a bias of typically 5-30% to the mass estimation.

This hydrostatic mass bias problem calls for a better description of the underlying physics in galaxy clusters. Researchers at MPA have therefore developed a new analytical model for the non-thermal pressure, which captures the growth and dissipation of the random motions in the hot gas. Adding this contribution to the hydrostatic balance, they were able to correct for the mass estimations when testing with state-of-the-art cosmological hydrodynamics simulations (see Fig. 2.25), where the random motions are the dominating contribution to the hydrostatic mass bias. Remarkably, this correction method works for samples of galaxy clusters with various dynamical states (horizontal axis of Fig. 2.25).

Aided by this correction, the application of the precise hydrostatic mass estimation method can be extended to dynamically disturbed galaxy clusters as long as spatially well-resolved observations are available. With advances in the observation of the Sunyaev-Zeldovich (SZ) effect which directly probes the thermal pressure of the hot gas, spatially well-resolved data will be much easier to obtain, as researchers will no longer rely on the time-consuming X-ray temperature measurements. Already in the last few years, the Planck satellite, the South Pole Telescope and the Atacama Cosmology Telescope have detected more than a thousand galaxy clusters, most of them dynamically disturbed, via their SZ signal. Some of the data already have good spatial resolution.

Still, much more galaxy clusters will be detected without immediate spatially-resolved data. However the newly developed method is also useful for them. For example, the eROSITA survey will measure the X-ray emission of more than 50,000 galaxy clusters and their progenitors. Most of them will not be spatially well-resolved. Masses for these objects will be obtained by scaling relations between the mass and spatially-averaged observables, such as the mean X-ray luminosity, temperature, or their combination. Correcting the hydrostatic mass bias will lead to a more accurate calibration of the scaling relations, and thus allow researchers to better exploit the huge number of galaxy clusters to explore the nature of Dark Energy. (Xun Shi and Eiichiro Komatsu).

References:

X. Shi and E. Komatsu: Mon. Not. R. Astron. Soc., **442**, 512 (2014).

X. Shi, E. Komatsu, K. Nelson and D. Nagai: Mon. Not. R. Astron. Soc., **448**, 1020 (2015).

X. Shi, E. Komatsu, D. Nagai and E. T. Lau, arXiv:1507.04338

K. Nelson, E. T. Lau, D. Nagai, D. H. Rudd, and L. Yu Astrophys. J. **782**, 107 (2014).

2.11 The Distribution of Atomic Hydrogen in Simulated Galaxies

The distribution of atomic hydrogen in simulated galaxies from the hydrodynamical cosmological 'EAGLE' simulation agrees with observations in unprecedented detail. This success means that EAGLE can aid astrophysicists to better understand the processes shaping real galaxies, such as the origin of their atomic hydrogen. EAGLE is not quite perfect, however: the study also found that some simulated galaxies contain unphysically large holes in their atomic hydrogen discs, meaning further work for simulators to improve the models underlying the treatment of supernova explosions and the interstellar matter.

Atomic hydrogen (abbreviated as 'H I') is an important component of galaxies: it is believed to feed the dense interstellar matter from which stars can form. Although invisible to optical telescopes, astronomers have been able to make ever more accurate observations of this gas component using radio telescopes. This has revealed, for instance, that galaxies with the same stellar mass can differ in their H I content by more than an order of magnitude. By combining several radio antennas into one 'supertelescope' with the aid of interferometry, it has also become possible to create high resolution maps showing the distribution of atomic hydrogen within individual galaxies (for an example, see Fig. 2.27).

But despite this wealth of observational data, astronomers are still puzzled by the question of why some galaxies contain so much more H I than others, and especially why 'normal' and 'H I-rich' galaxies still appear to follow common relations, as shown recently by the MPA-led Bluedisk project. A fundamental problem is that galaxies only evolve over periods of many millions of years, so that it is impossible to directly observe how the H I reservoir is built up. Instead, astronomers have to try and answer this question with the aid of models and simulations.

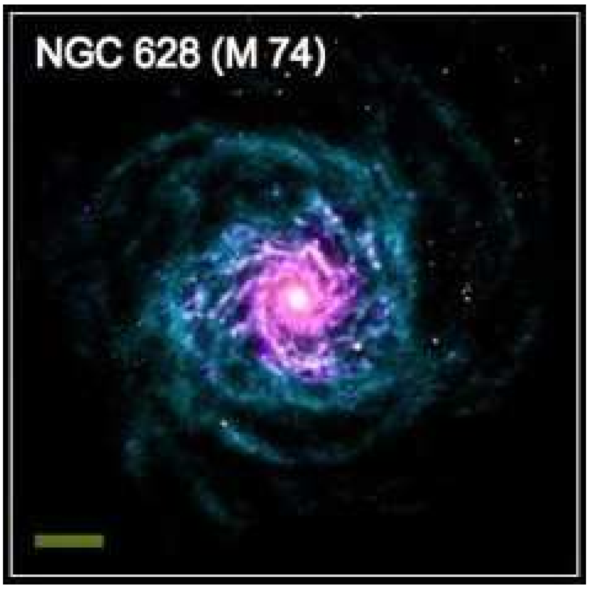

Figure 2.27: Observed distribution of atomic hydrogen (blue) in the nearby galaxy M74. Also shown are old stars (red) and UV radiation emitted by newborn stars (purple) - both of these are more strongly concentrated towards the galaxy's centre than the atomic hydrogen. The green bar shows a length of 15 000 light years. *Credit: THINGS survey*

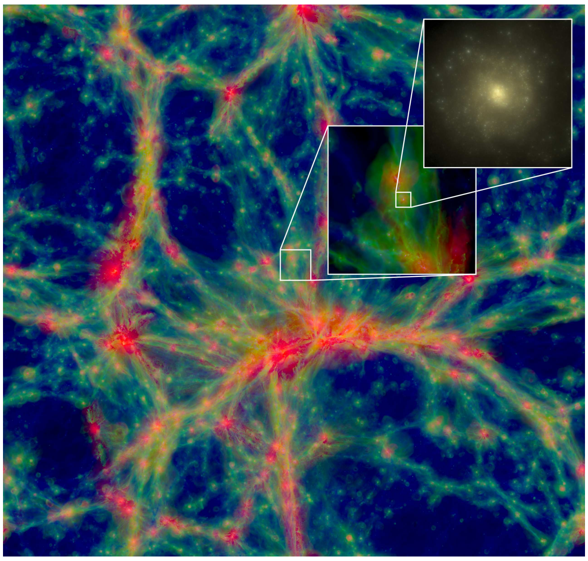

Figure 2.28: Gas in the large EAGLE simulation. Blue represents 'cold' gas ($T \lesssim 30\,000$ K), green warm, and red the hottest gas with $T > 300\,000$ K. The small insets zoom in towards a single galaxy, highlighting the huge dynamic range of the simulation. *Credit: Richard Bower and James Trayford, ICC Durham*

An international collaboration has recently completed the EAGLE project, whose largest simulation contains thousands of galaxies that match their observed counterparts in several aspects such as their stellar mass and size with unprecedented accuracy (see Fig. 2.28). A research team led by MPA scientist Yannick Bahé has now studied how well these simulated galaxies agree with real ones in terms of their atomic hydrogen content: an important test for the simulation model, which also determines whether EAGLE can give trustworthy clues on the evolution of H I in real galaxies.

To make this comparison, the scientists first had to post-process the simulation and calculate how much of the hydrogen in each simulation particle is actually atomic, i.e. not ionised or molecular. Once this was done, the total mass of H I in over 2000 simulated galaxies could be computed and compared to observational data from the GASS survey. The resulting match between simulation and data is extremely good: it represents a significant improvement compared to previous simulations and indicates that the models used in EAGLE provide a reasonable description of the physical processes involved in forming galaxies.

Motivated by this initial success, the scientists tested the EAGLE simulations in more detail by comparing not just the total mass of H I, but also its distribution within galaxies to observations. The above-mentioned Bluedisk project has shown that this distribution is surprisingly independent of the total mass of H I as long as the galaxies' H I discs are scaled to a common size (an effect called self-similarity). For an accurate comparison, the team now 'observed' the EAGLE galaxies in the same way as was done in Bluedisk. As can be seen in Fig. 2.29, both agree surprisingly well: EAGLE reproduces both the self-similarity between normal and H I-rich galaxies (red and green symbols in Fig. 2.29) and the detailed shape of the surface density profile — at least in the outer parts of the simulated galaxies.

In the central regions, however, EAGLE galaxies typically contain too little atomic hydrogen. To test this discrepancy further, the scientists inspected more than 2000 images of the simulated galaxies, which finally gave the crucial clue: many simulated galaxies contain 'holes' in their hydrogen discs that are much larger than what is seen in observations (see Fig. 2.30). Once all simulated galaxies showing these large holes were excluded, the density profiles matched observations almost perfectly even in the centre.

But why do some EAGLE galaxies contain these large holes? The scientists have not yet found a definitive answer, but it is likely that the way

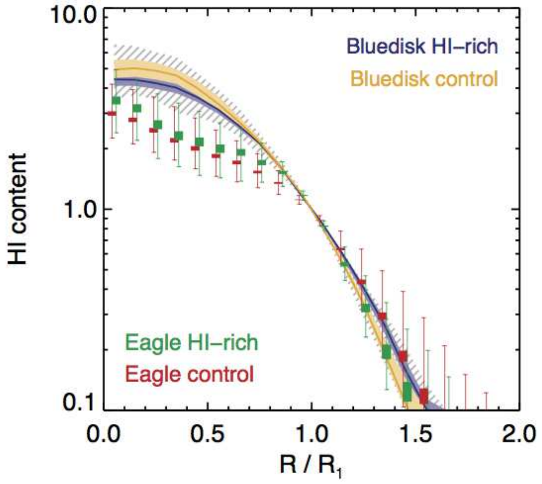

Figure 2.29: The surface density of atomic hydrogen, plotted against distance from the galaxy centre. Yellow and blue bands show data from the Bluedisk survey, comparing galaxies with normal (yellow) and exceptionally high (blue) total atomic hydrogen content. Red and green circles show simulated galaxies from EAGLE in the same categories.

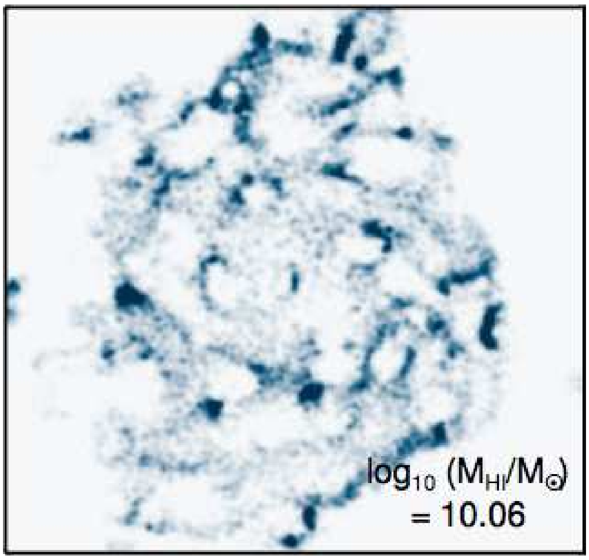

Figure 2.30: Synthetic image showing atomic hydrogen in a simulated galaxy, in analogy to Fig. 2.27. Clearly visible are a number of large holes in the hydrogen disc.

in which supernova explosions are modelled in the simulation plays a major role. This critical part of galaxy formation is still causing headaches for simulators: to include them in galaxy simulations in a fully self-consistent fashion, the resolution of the simulations would need to go up by many orders of magnitude. This will, regrettably, be impossible for a long time to come — even the biggest supercomputers today are just not powerful enough. As a result, EAGLE has to resort to using a highly simplified model for the effects of such supernovae. Another simplified model has to be employed for the dense interstellar matter, because a resolution level that would allow a fully self-consistent treatment can also not yet be achieved in simulations of a representative portion of the Universe. Although these simplified models produce galaxies which are realistic in many ways – such as their size – they do leave a noticeable artefact in some of the simulated hydrogen discs: the large holes discovered by the researchers.

It is therefore an important challenge for astrophysicists to optimise both the simulation codes and the models in such a way that, in conjunction with continually more powerful supercomputers, a self-consistent treatment of the dense interstellar medium can be achieved. Combined with improved supernova models, these future simulations will, hopefully, produce galaxies that match the real Universe even better than EAGLE does. However, the current study also demonstrates that EAGLE can already give valuable insight into the evolution of atomic hydrogen in galaxies. In a follow-up project, the researchers will examine the formation of the simulated galaxies to find out how and why some of them got so much more hydrogen than others. (Yannick Bahé)

Reference:

Bahé Y. M., Crain R. A., Kauffmann G., et al., *The distribution of atomic hydrogen in EAGLE galaxies: morphologies, profiles, and* H I *holes*, MNRAS, **456**, 1115 (2016).

2.12 How supernova explosions shape the interstellar medium and drive galactic outflows

With complex hydrodynamical simulations scientists at MPA investigate the detailed impact of supernova explosions on the chemical composition and the thermodynamic properties of the interstellar medium and galactic outflows.

Only a small fraction of gas in the interstellar medium (ISM) of a star-forming galaxy is converted into stars. And less than one percent of all newborn stars are massive enough to die in a supernova explosion after their relatively short life of about 10 million years. Nevertheless, these explosions can have an enormous impact on the ISM and the cosmic evolution of galaxies. With a European team of astrophysicists (the SILCC collaboration), scientists at the Max Planck Institute for Astrophysics used high-resolution supercomputer simulations to investigate the conditions under which supernova explosions can shape the ISM in a galactic disk: realistically and with dense molecular clouds and diffuse neutral and ionized hydrogen for a wide range of scales. In particular, supernovae exploding outside dense molecular clouds can launch powerful gaseous outflows. These outflows change the galactic gas content and might regulate the cosmic evolution of the whole population of star forming galaxies.

A supernova explosion is a most dramatic event at the end of a massive star's life. Born in dense molecular clouds, massive stars evolve rapidly compared to cosmic timescales. At the end of their life – after several million to a few tens of million years – stars more massive than eight solar masses do not necessarily explode in the dense environment they were born. Some have travelled out of their parental cloud; some explode in low density cavities shaped by their own ionizing radiation and stellar winds or created by previous supernova explosions of nearby stars. The environmental density of a supernova explosion is very important. It determines the explosion impact on the ISM as well as the whole galaxy. An explosion in a dense environment means that the energy of the supernova shock is efficiently converted into radiation and escapes the galaxy. Therefore, the impact on the surrounding ISM is weak. If the explosion occurs in a low-density environment on the other hand, less energy is radiated away and the expanding remnant has more power left for heating and compressing the gas. This can lead to an enhanced production of hot gas but also of dense structures. The hot gas is driven out of the galactic disk and sweeps the colder ISM along.

The thermodynamic evolution of supernova remnants, the structure of their surrounding ISM and the efficiency of outflows are particularly important for the ecosystem of each individual galaxy. These factors play a fundamental role in regulating the gas content in each galaxy and thus the evolution of entire galaxy populations in the Universe. Explaining outflow properties and connecting simulated data to observations is therefore key to understanding the formation history of galaxies.

Together with a European team of experts, scientists at MPA have used high-resolution supercomputer simulations to investigate the impact of supernova explosions on the ISM in a galactic disk. For the first time, the simulations follow not only the kinematics, densities and temperatures of the gas in the ISM but also the chemical transitions from ionized gas, over neutral atomic gas to dense molecular gas. The latter forms mostly on dust grains and can be destroyed by the interstellar radiation field and in strong shocks like those originating from supernova remnants.

Assuming a typical supernova rate (up to a few dozen explosions in one million years) the team has investigated several possible scenarios for the location of supernova explosions. In Fig. 2.31 we show the simulated gas structure of the ISM in a galaxy after 50 million years of evolution, assuming that all supernovae explode in the densest regions of the gas where their progenitor stars were born. Explosions in dense regions inhibit the formation of further cold molecular clouds. The supernova shells loose their energy quickly and cannot efficiently accelerate gas or generate a hot, ionized medium. The result is an interstellar medium mainly made of warm neutral gas with small density contrasts and very few or no molecular clouds. In this configuration – which is not in agreement with observations of the ISM – no outflows are launched.

The situation changes dramatically if supernovae are allowed to explode in low-density environments. In this case the explosions generate a more realistic multi-phase medium, as shown in Fig. 2.32. Low-density regions are filled with hot ionized gas. Compared to observations this model is much more realistic. Fig. 2.33 shows the ISM structure for these models with supernova explosions in low-density regions. The ISM is more structured, filled with hot gas and much more extended out of the plane (in the vertical direction). At the same time the ISM develops dense molecular clouds, while the hot gas in the low density regions is expanding and drags diffuse neutral gas with it, forcing the gas to leave the galactic disk in a clumpy outflow. Fig. 2.34 shows more details on the outflows for such a model. The hot ionized gas is expanding from the disk mid-plane and reaches high velocities of several hundred kilometers per second. It escapes through low-density chimneys from the disk.

To understand how supernova explosions impact the evolution of galaxies, it is crucial to investigate the structural details of the interstellar medium including the chemical composition, the distribution of gas, the positions of supernovae and the efficiency with which gas can escape a galaxy via outflows. The simulations of the SILCC collaboration are therefore an important step forward in understanding the regulation of potential star formation and the gas cycle in star-forming galaxies. (Philipp Girichidis and Thorsten Naab for the SILCC collaboration)

References:

Walch, S., P. Girichidis, Th. Naab, et al. I. Chemical evolution of the supernova-driven ISM. Mon. Not. R. Astron. Soc. **454**, 238 (2015).

Girichidis, P. S. Walch, Th. Naab et al.: SImulating the LifeCycle of molecular Clouds (SILCC): II. Dynamical evolution of the supernova-driven ISM and the launching of outflows. accepted for publication in Mon. Not. R. Astron. Soc. (2015).

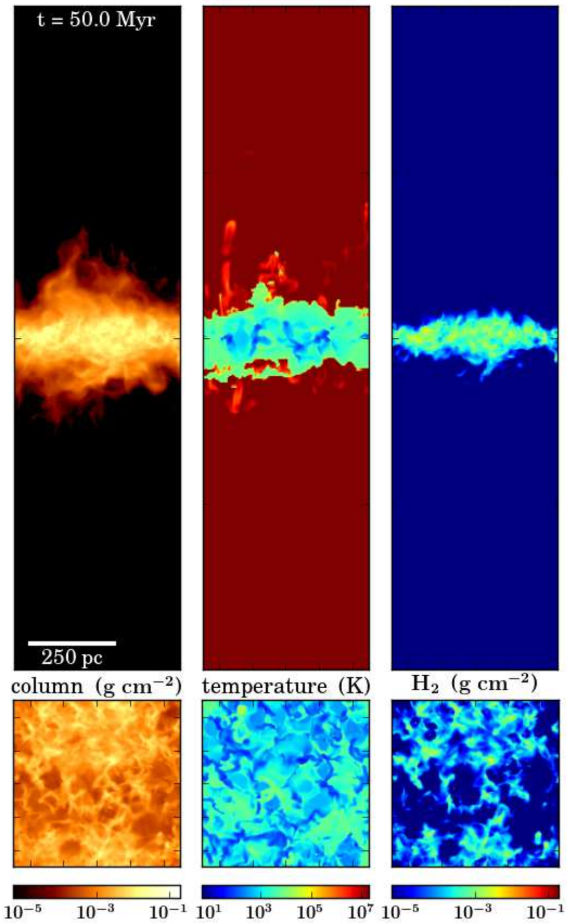

Figure 2.31: Density (left), temperature (middle) and molecular gas distribution (right) in a simulation with supernovae exploding in dense regions. The upper, vertically extended, panels show the edge-on view with the disk in the mid-plane. In the lower panel we show the disk plane seen from above (face-on). The disk is compact, most of the gas is warm and diffuse and no outflows are launched. This is an unrealistic model for the observed multi-phase gas structure in real galaxies.*credit: MPA*

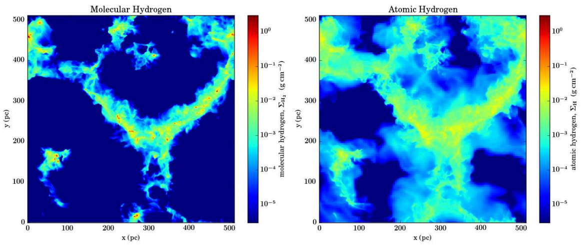

Figure 2.32: Chemical structure of the interstellar medium in a realistic simulation, where supernovae can also explode in low-density regions. The dense molecular gas (left) is assembled in clouds and filaments and embedded in diffuse neutral gas (right). The voids in between contain low-density gas heated to millions of Kelvin by supernova explosions.*credit: MPA*

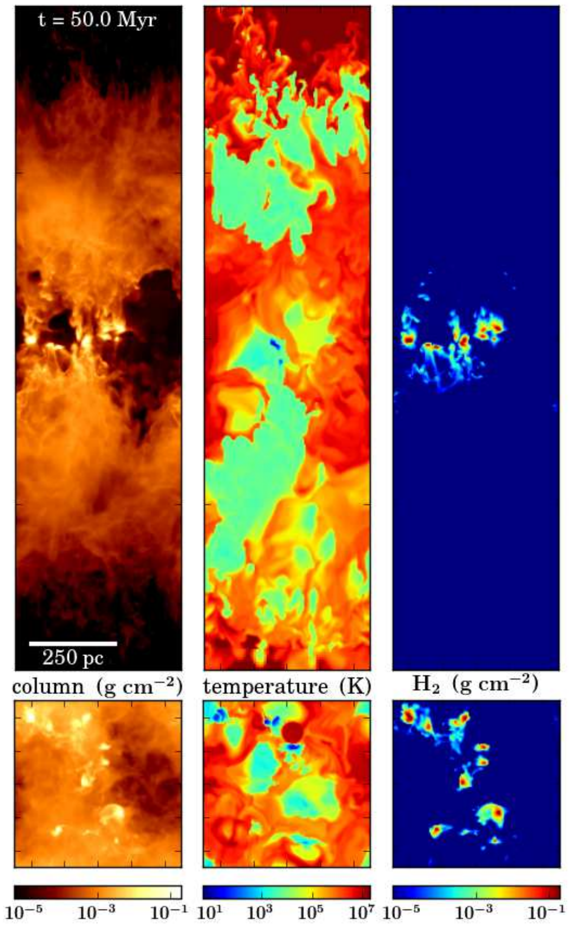

Figure 2.33: Same representation as Fig. 2.31 but for a more realistic setup with supernovae exploding primarily in low-density regions. The explosions couple to the gas efficiently enough to induce large density contrasts, pushing gas out of the disk mid-plane (middle panels) and at the same time compressing gas into dense molecular clouds (right panel).*credit: MPA*

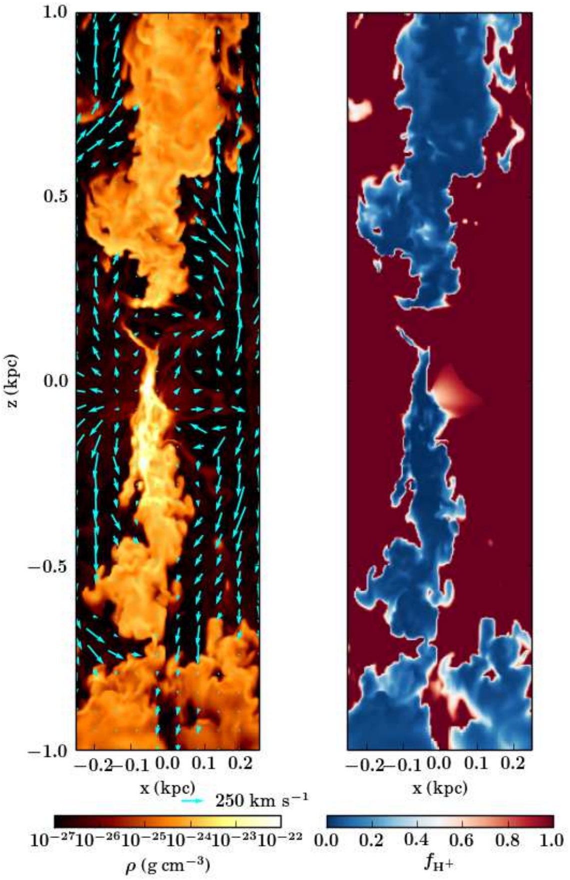

Figure 2.34: Outflow details showing the density (left) the degree of ionization (right) with blue indicating neutral gas and red indicating ionized gas. The density plot (left) also shows gas velocities (arrows). As in Fig. 2.31 and 2.33, the disk mid-plane is at the position z =0. The hot ionized gas expands quickly and escapes through low-density chimneys with velocities of several hundred km/s. The escaping gas drags low-density neutral gas with it.*credit: MPA*

3 Publications and Invited Talks

3.1 Publications in Journals

3.1.1 Publications that appeared in 2015 (272)

Abazajian, K., K. Arnold et al. (incl. E. Komatsu): Neutrino physics from the cosmic microwave background and large scale structure. Astropart. Phys. **63(SI)**, 66-80 (2015).

Abdikamalov, E., Ott, C. D., D. Radice et al.: Neutrino-driven Turbulent Convection and Standing Accretion Shock Instability in Three-Dimensional Core-Collapse Supernovae. The Astrophys. J. **808(1)**, 70 (2015).

Adamo, A., Kruijssen, J. M. D., N. Bastian et al.: Probing the role of the galactic environment in the formation of stellar clusters, using M83 as a test bench. Mon. Not. R. Astron. Soc. **452(1)**, 246-260 (2015).

Ade, P., N. Aghanim et al. (incl. T. A. Enßlin, W. Hovest and J. Knoche): Joint analysis of BICEP2/Keck Array and Planck Data. Phys. Rev. Lett. **114(10)**, 101301 (2015).

Althaus, L. G., Camisassa, M. E., M. M. Miller Bertolami et al.: White dwarf evolutionary sequences for low-metallicity progenitors: The impact of third dredge-up. Astron. Astrophys. **576: A9**, 1-11 (2015).

Amorín, R., E. Pérez-Montero et al. (incl. K. Kovač): Extreme emission-line galaxies out to z $\sim$ 1 in COSMOS – I. Sample and characterization of global properties. Astron. Astrophys. **578**, A105 (2015).

Anderson, M. E., Gaspari, M., S. D. M. White et al.: Unifying X-ray scaling relations from galaxies to clusters. Mon. Not. R. Astron. Soc. **449(4)**, 3806-3826 (2015).

Anderson, M. E., Churazov, E., and J. N. Bregman: Non-detection of X-ray emission from sterile neutrinos in stacked galaxy spectra. Mon. Not. R. Astron. Soc. **452(4)**, 3905-3923 (2015).

Andrássy, R. and H. C. Spruit: Overshooting by differential heating. Astron. Astrophys. **578**, A106, 1-15 (2015).

Andrássy, R. and H. C. Spruit: Convective settling in main sequence stars: Li and Be depletion. Astron. Astrophys. **579**, A122, 1-8 (2015).

Angulo, R. E. and S. J. Hilbert: Cosmological constraints from the CFHTLenS shear measurements using a new, accurate, and flexible way of predicting non-linear mass clustering. Mon. Not. R. Astron. Soc. **448(1)**, 364-375 (2015).

Arnett, W. D., Meakin, C., Viallet, M. and S. W. Campbell: Beyond mixing-length theory: a step toward 321D. The Astrophys. J. **809(1)**, 30, 1-20 (2015).

Asad, K. M. B., L. V. E. Koopmans et al. (incl. B. Ciardi): Polarization leakage in epoch of reionization windows –I. Low Frequency Array observations of the 3C196 field. Mon. Not. R. Astron. Soc. **451(4)**, 3709-3727 (2015).

Assassi, V., Baumann, D. and F. Schmidt: Galaxy bias and primordial non-Gaussianity. J. of Cosmology and Astropart. Phys. **2015(12)**, 043, 1-36 (2015).

Atanasov, D., P. Ascher et al. (incl. H.-T. Janka and O. Just): Precision mass measurements of Cd129-131 and their impact on stellar nucleosynthesis via the rapid neutron capture process. Phys. Rev. Lett. **115(23)**, 232501, 1-6 (2015).

Augustovičová, L., Kraemer, W. P., Špirko, V. and P. Soldán: The role of molecular quadrupole transitions in the depopulation of metastable helium. Mon. Not. R. Astron. Soc. **446(3)**, 2738-2743 (2015).

Augustovičov,́ L., Zámečníková, M., Kraemer, W. P. and P. Soldán: Radiative association of He(23P) with lithium cations. Chemical Physics **462**, 65-70 (2015).

Bahé, Y. M. and I. G. McCarthy: Star formation quenching in simulated group and cluster galaxies: when, how, and why? Mon. Not. R. Astron. Soc. **447(1)**, 969-992 (2015).

Barreira, A., Bose, S., and B. Li: Speeding up N-body simulations of modified gravity: Vainshtein screening models. J. of Cosmology and Astropart. Phys. **2015(12)**, 059, 1-26 (2015).

Baumgarte, T. W., Montero, P. J. and E. Müller: Numerical relativity in spherical polar coordinates: Off-center simulations. Phys. Rev. D **91(6)**, 064035 (2015).

Baumgarte, T. W. and P. J. Montero: Critical phenomena in the aspherical gravitational collapse of radiation fluids. Phys. Rev. D **92(12)**, 124065, 1-12 (2015).

Bauswein, A., Stergioulas, N. and H.-T. Janka: Neutron-star properties from the postmerger gravitational wave signal of binary neutron stars. Phys. of Particles and Nuclei **46(5)**, 835-839 (2015).

Belyaev, A. K., D. S. Rodionov et al. (incl. W. P. Kraemer): Full quantum study of non-radiative inelastic processes in lithium-helium ion-atom collisions. Mon. Not. R. Astron. Soc. **449(3)**, 3323-3332 (2015).

Ben-Ami, S., S. Hachinger et al. (incl. P. A. Mazzali): Ultraviolet spectroscopy of type IIb supernovae: diversity and the impact of circumstellar material. The Astrophys. J. **803(1)**, 40, 1-11 (2015).

Bessell, M. S., R. Collet et al. (incl. Z. Magic): Nucleosynthesis in a primordial supernova: carbon and oxygen abundances in SMSS Jo31300.36-670839.3. The Astrophys. J. Lett. **806(1)**, L16, 1-6 (2015).

Bikmaev, I. F., N. N. Chugai et al. (incl. R. Sunyaev, and E. Churazov): Type Ia supernovae 2014J and 2011fe at the nebular phase. Astron. Lett. – J. Astron. and Space Astrophys. **41(12)**, 785-796 (2015).

Bogdán, Á., M. Vogelsberger et al. (incl. M. Gilfanov and E. Churazov): Hot gaseous coronae around spiral galaxies: probing the illustris simulation. The Astrophys. J. **804(1)**, 72, 1-11 (2015).

Bogdán, Á., M. Vogelsberger et al. (incl. Gilfanov, M. and E. Churazov): Hot gaseous coronae around spiral galaxies: probing the illustris simulation. The Astrophys. J. **804(1)**, 72, 1-11 (2015).

Boneberg, D. M., Dale, J. E., P. Girichidis et al.: Turbulence in giant molecular clouds: the effect of photoionization feedback. Mon. Not. R. Astron. Soc. **447(2)**, 1341-1352 (2015).

Borthakur, S., T. Heckman et al. (incl. G. Kauffmann): Connection between the circumgalactic medium and the interstellar medium of galaxies: results from the COS-GASS survey. The Astrophys. J. **813(1)**, 46, 1-14 (2015).

Bundy, K., M. A. Bershady et al. (incl. G. Kauffmann): Overview of the SDSS-IV MaNGA survey: mapping nearby galaxies at Apache Point Observatory. The Astrophys. J. **798(1)**, 7 (2015).

Bykov, A. M., Churazov, E. M., C. Ferrari et al.: Structures and components in galaxy clusters: observations and models. Space Science Rev. **188(1-4)**, 141-185 (2015).

Cassara, L. P., Piovan, L. and C. Chiosi: Modelling galaxy spectra in presence of interstellar dust – III. From nearby galaxies to the distant Universe. Mon. Not. R. Astron. Soc. **450(3)**, 2231-2250 (2015).

Castorina, E., C. Carbone et al. (incl. K. Dolag): DEMNUni: the clustering of large-scale structures in the presence of massive neutrinos. J. of Cosmology and Astropart. Phys. **2015(7)**, 043, 1-33 (2015).

Cataneo, M., Rapetti, D., F. Schmidt et al.: New constraints on f(R) gravity from clusters of galaxies. Physical Rev. D **92(4)**, 044009, 1-11 (2015).

Chakraborti, S., A. Soderberg et al. (incl. P. Mazzali): A missing-link in the supernova-GRB connection: the case of SN 2012ap. The Astrophys. J. **805(2)**, 187, 1-8 (2015).

Chakraborti, S., A. Soderberg et al. (incl. P. Mazzali): A missing-link in the supernova-GRB connection: the case of SN 2012ap. The Astrophys. J. **805(2)**, 187, 1-8 (2015).

Chakraborty, S., Raffelt, G., Janka, H.-T. and A. B. Müller: Supernova deleptonization asymmetry: Impact on self-induced flavor conversion. Phys. Rev. D **92(10)**, 105002, 1-14 (2015).

Chen, H.-L., T. E. Woods et al. (incl. M. Gilfanov): Population synthesis of accreting white dwarfs – II. X-ray and UV emission. Mon. Not. R. Astron. Soc. **453(3)**, 3024-3034 (2015).

Chiang, C.-T., et al. (incl. F. Schmidt and E. Komatsu): Position-dependent correlation function from the SDSS-III Baryon Oscillation Spectroscopic Survey Data Release 10 CMASS sample. J. of Cosmology and Astropart. Phys. **2015(09)**, 028, 1-30 (2015).

Chiang, Y.-K., R. A. Overzier et al. (incl. C.-T. Chiang): Surveying galaxy proto-clusters in emission: a large-scale structure at $z = 2.44$ and the outlook for HETDEX. The Astrophys. J. **808(1)**, 37, 1-18 (2015).

Childress, M. J., D. J. Hillier et al. (incl. P. Mazzali): Measuring nickel masses in Type Ia supernovae using cobalt emission in nebular phase spectra. Mon. Not. R. Astron. Soc. **454(4)**, 3816-3842 (2015).

Choi, E., J. Ostriker, T. Naab et al.: The impact of mechanical AGN feedback on the formation of massive early-type galaxies. Mon. Not. R. Astron. Soc. **449(4)**, 4105-4116 (2015).

Churazov, E., A. Vikhlinin and R. Sunyaev: (No) dimming of X-ray clusters beyond $z \sim 1$ at fixed mass: crude redshifts and masses from raw X-ray and SZ data. Mon. Not. R. Astron. Soc. **450(2)**, 1984-1989 (2015).

Churazov, E., Sunyaev, R. A., J. Isern et al.: Gamma rays from Type Ia supernova SN 2014J. The Astrophys. J. **812(1)**, 62, 1-17 (2015).

Ciardi, B., S. Inoue et al. (incl. L. Graziani): Simulating the 21 cm forest detectable with LOFAR and SKA in the spectra of high-z GRBs. Mon. Not. R. Astron. Soc. **453(1)**, 101-105 (2015).

Clay, S. J., Thomas, P. A., Wilkins, S. M. and B. M. B. Henriques: Galaxy formation in the Planck cosmology – III. The high-redshift universe. Mon. Not. R. Astron. Soc. **451(3)**, 2692-2702 (2015).

Constantino, T., Campbell, S. W., J. Christensen-Dalsgaard et al.: The treatment of mixing in core helium burning models – I. Implications for asteroseismology. Mon. Not. R. Astron. Soc. **452(1)**, 123-145 (2015).

Cooper, A. P., L. Gao et al. (incl. S. D. M. White): Surface photometry of brightest cluster galaxies and intracluster stars in ΛCDM. Mon. Not. R. Astron. Soc. **451(3)**, 2703-2722 (2015).

Corstanje, A., P. Schellart et al. (incl. B. Ciardi): The shape of the radio wavefront of extensive air showers as measured with LOFAR. Astropart. Phys. **61**, 22-31 (2015).

Crain, R. A., J. Schaye et al. (incl. S. D. M. White): The EAGLE simulations of galaxy formation: calibration of subgrid physics and model variations. Mon. Not. R. Astron. Soc. **450(2)**, 1937-1961 (2015).

Dai, L., E. Pajer and F. Schmidt: Conformal Fermi Coordinates. J. of Cosmology and Astropart. Phys. **2015(11)**, 043, 1-46 (2015).

Dai, L., E. Pajer and F. Schmidt: On separate universes. J. of Cosmology and Astropart. Phys. **2015(10)**, 059, 1-36 (2015).

De Lucia, G., L. Tornatore et al. (incl. S. D. M. White): Erratum: elemental abundances in Milky Way-like galaxies from a hierarchical galaxy formation model. Mon. Not. R. Astron. Soc. **447(4)**, 3420-3421 (2015).

De Pree, C. G., Peters, T., M. M. Mac Low et al.: Evidence of short timescale flux density variations of UC HII regions in Sgr B2 main and north. The Astrophys. J. **815(2)**, 123, 1-9 (2015).

De Souza, R., Vegetti, S. and G. Kauffmann: The massive end of the stellar mass function. Mon. Not. R. Astron. Soc. **454(4)**, 4027-4036 (2015).

De Souza, R. S., J. M. Hilbe et al. (incl. E. E. O. Ishida): The overlooked potential of generalized linear models in astronomy – III. Bayesian negative binomial regression and globular cluster populations. Mon. Not. R. Astron. Soc. **453(2)**, 1928-1940 (2015).

De Souza, R., E. Cameron et al. (incl. B. Ciardi): The overlooked potential of Generalized Linear Models in astronomy – I: Binomial regression. Astron. and Comp. **12**, 21-32 (2015).

De Souza, R. and B. Ciardi: AMADA–Analysis of multidimensional astronomical datasets. Astron. and Comp. **12**, 100-108 (2015).

D'Elia, V., E. Pian and al. (incl. P. A. Mazzali): SN 2013dx associated with GRB 130702A: a detailed photometric and spectroscopic monitoring and a study of the environment. Astron. Astrophys. **577** A116, 1-14 (2015).

Den Heijer, M. et al. (incl. G. Kauffmann, J. Wang and M.-L. Huang): A study of the kinematics of unusually HI-rich galaxies. Astron. Nachr. **339(3)**, 284-311 (2015).

Den Heijer, M., T. A. Oosterloo et al. (incl. T. Naab): The HI Tully-Fisher relation of early-type galaxies. Astron. Astrophys. **581**, A98, 1-11 (2015).

Denissenkov, P. A., D. A. Van den Berg et al. (incl. A. Weiss): The primordial and evolutionary abundance variations in globular-cluster stars: a problem with two unknowns. Mon. Not. R. Astron. Soc. **448(4)**, 3314-3324 (2015).

Diehl, R., Siegert, T., W. Hillebrandt et al.: SN2014J gamma rays from the 56Ni decay chain. Astron. Astrophys. **574**, A72 (2015).

Dolag, K., Gaensler, B. M., A. M. Beck et al.: Constraints on the distribution and energetics of fast radio bursts using cosmological hydrodynamic simulations. Mon. Not. R. Astron. Soc. **451(4)**, 4277-4289 (2015).

Dorn, S., T. Enßlin, M. Greiner, M. Selig, and V. Böhm: Signal inference with unknown response: Calibration-uncertainty renormalized estimator. Phys. Rev. E **91(1)**, 013311 (2015).

Dorn, S. and T. A. Enßlin: Stochastic determination of matrix determinants. Phys. Rev. E **92(1)**, 013302 (2015).

Dorn, S., M. Greiner and T. A. Enßlin: All-sky reconstruction of the primordial scalar potential from WMAP temperature data. J. of Cosmology and Astropart. Phys. **2015(2)** 041 (2015).

Duc, P.-A., J.-C. Cuillandre et al. (incl. T. Naab): The ATLAS3D project – XXIX. The new look of early-type galaxies and surrounding fields disclosed by extremely deep optical images. Mon. Not. R. Astron. Soc. **446(1)**, 120-143 (2015).

Elliott, J., R. S. de Souza et al. (incl. E. Ishida): The overlooked potential of Generalized Linear Models in astronomy – II: Gamma regression and photometric redshifts. Astron. and Comp. **10**, 61-72 (2015).

Ergon, M., A. Jerkstrand et al. (incl. S. Taubenberger): The Type IIb SN 2011dh: Two years of observations and modelling of the lightcurves. Astron. Astrophys. **580**, A142, 1-30 (2015).

Foglizzo, T., R. Kazeroni, J. Guilet et al.: The explosion mechanism of core-collapse supernovae: progress in supernova theory and experiments. Publ. of the Astron. Soc. of Australia **32**, e009 (2015).

Fraser, M., R. Kotak et al. (incl. S. Taubenberger): SN 2009ip at late times – an interacting transient at +2 years. Mon. Not. R. Astron. Soc. **453(4)**, 3886-3905 (2015).

Garsden, H., J. N. Girard et al. (incl. B. Ciardi): LOFAR sparse image reconstruction. Astron. Astrophys. **575**, A90, 1-18 (2015).

Gaspari, M., Brighenti, F. and P. Temi: Chaotic cold accretion on to black holes in rotating atmospheres. Astron. Astrophys. **579**, A62, 1-18 (2015).

Gaspari, M.: Shaping the X-ray spectrum of galaxy clusters with AGN feedback and turbulence. Mon. Not. R. Astron. Soc. Lett. **451(1)**, L60-L64 (2015).

Gatto, A., S. Walch et al. (incl. T. Naab, P. Girichidis and T. Peters): Modelling the supernova-driven ISM in different environments. Mon. Not. R. Astron. Soc. **449(1)**, 1057-1075 (2015).

Genovali, K., B. Lemasle et al. (incl. R.-P. Kudritzki): On the α-element gradients of the Galactic thin disk using Cepheids. Astron. Astrophys. **580**, A17, 1-13 (2015).

Genzel, R., L. J. Tacconi et al. (incl. T. Naab): Combined CO and dust scaling relations of depletion time and molecular gas fractions with cosmic time, specific star-formation rate, and stellar mass. The Astrophys. J. **800(1)**, 20 (2015).

Ghisellini, G., F. Haardt, B. Ciardi et al.: CMB quenching of high-redshift radio-loud AGNs. Mon. Not. R. Astron. Soc. **452(4)**, 3457-3469 (2015).

Giannantonio, T. and E. Komatsu: Bayesian evidence of nonstandard inflation: Isocurvature perturbations and running spectral index. Phys. Rev. D **91(2)**, 023506 (2015).

Gil-Marín, H., L. Verde et al. (incl. C. Wagner): The power spectrum and bispectrum of SDSS DR11 BOSS galaxies – II. Cosmological interpretation. Mon. Not. R. Astron. Soc. **452(2)**, 1914-1921 (2015).

Gil-Marín, H., J. Norena et al. (incl. C. Wagner): The power spectrum and bispectrum of SDSS DR11 BOSS galaxies – I. Bias and gravity. Mon. Not. R. Astron. Soc. **451(1)**, 539-580 (2015).

Gómez, F. A., G. Besla, D. Carpintero et al.: And yet it moves: the dangers of artificially fixing the milky may center of mass in the presence of a massive large magellanic cloud. The Astrophys. J. **802(2)**, 128, 1-16 (2015).

Goriely, S., A. Bauswein et al. (incl. O. Just, E. Pllumbi and H.-T. Janka): Impact of weak interactions of free nucleons on the r-process in dynamical ejecta from neutron star mergers. Mon. Not. R. Astron. Soc. **452(4)**, 3894-3904 (2015).

Gregersen, D., A. C. Seth et al. (incl. A. Monachesi): Panchromatic Hubble Andromeda Treasury – XII. Mapping stellar metallicity distributions in M31. The Astron. J. **150(6)**, 189, 1-12 (2015).

Greiner, J., P. A. Mazzali et al. (incl. S. Taubenberger): A very luminous magnetar-powered supernova associated with an ultra-long γ-ray burst. Nature **480(7559)**, 189-192(2015).

Greiner, M. and T. A. Enßlin: Log-transforming the matter power spectrum. Astron. Astrophys. **574**, A86 (2015).

Grimm-Strele, H., F. Kupka, B. Löw-Baselli et al.: Realistic simulations of stellar surface convection with ANTARES: I. Boundary conditions and model relaxation. New Astronomy **34**, 278-293 (2015).

Guilet, J., Müller, E. and H.-T. Janka: Neutrino viscosity and drag: impact on the magnetorotational instability in protoneutron stars. Mon. Not. R. Astron. Soc. **447(4)**, 3992-4003 (2015).

Guilet, J. and E. Müller: Numerical simulations of the magnetorotational instability in protoneutron stars – I. Influence of buoyancy. Mon. Not. R. Astron. Soc. **450(2)**, 2153-2171 (2015).

Guo, H., Z. Zheng et al. (incl. C. Li): Modelling the redshift-space three-point correlation function in SDSS-III. Mon. Not. R. Astron. Soc. Lett. **449(1)**, L95-L99 (2015).

Heald, G. H., R. F. Pizzo et al. (incl. M. R. Bell and B. Ciardi): The LOFAR Multifrequency Snapshot Sky Survey (MSSS) – I. Survey description and first results. Astron. Astrophys. **582**, A123, 1-22 (2015).

Heinzel, P., Gunár, S. and U. Anzer: Fast approximate radiative transfer method for visualizing the fine structure of prominences in the hydrogen H α line. Astron. Astrophys. **579**, A16, 1-6 (2015).

Henriques, B., S. White et al. (incl. G. Lemson): Galaxy formation in the Planck cosmology – I. Matching the observed evolution of star formation rates, colours and stellar masses. Mon. Not. R. Astron. Soc. **451(3)**, 2663-2680 (2015).

Hirschmann, M., T. Naab et al. (incl. L. Oser): The stellar accretion origin of stellar population gradients in massive galaxies at large radii. Mon. Not. R. Astron. Soc. **449(1)**, 528-550 (2015).

Huang, M.-L. and G. Kauffmann: The variation in molecular gas depletion time among nearby galaxies – II. The impact of galaxy internal structures. Mon. Not. R. Astron. Soc. **450(2)**, 1375-1387 (2015).

Huterer, D., D. Kirkby et al. (incl. F. Schmidt): Growth of cosmic structure: probing dark energy beyond expansion. Astropart. Phys. **63(SI)**, 23-41 (2015).

Huterer, D., D. Shafer, and F. Schmidt: No evidence for bulk velocity from type Ia supernovae. J. of Cosmology and Astropart. Phys. **2015(12)**, 033, 1-20 (2015).

Inayoshi, K. and T. L. Tanaka: The suppression of direct collapse black hole formation by soft X-ray irradiation. Mon. Not. R. Astron. Soc. **450(4)**, 4350-4363 (2015).

Inogamov, N. A. and R. A. Sunyaev: Energy density of standing sound waves at the radiation-dominated phase of the universe expansion (hydrodynamic derivation). Astron. Lett. – a J. of Astron. and Space Astrophys. **41(12)**, 693-703 (2015).

Inserra, C., et al. (S. Taubenberger, and W. Hillebrandt): OGLE-2013-SN-079: A lonely supernova consistent with a helium shell detonation. Astrophys. J. Lett. **799(1)**, L2 (2015).

Ip, H. Y., J. Sakstein and F. Schmidt: Solar system constraints on disformal gravity theories. J. of Cosmology and Astropart. Phys. **2015(10)**, 051, 1-22 (2015).

Ishida, E.E.O, S. Vitenti, M. Penna-Lima, et al.: cosmoabc: Likelihood-free inference via Population Monte Carlo Approximate Bayesian Computation. Astronomy and Computing **13**, 1-11 (2015).

Jee, I., E. Komatsu and S. Suyu: Measuring angular diameter distances of strong gravitational lenses. J. of Cosmology and Astropart. Phys. **2015(11)**, 033, 1-25 (2015).

Jelić, V., A. G. de Bruyn et al. (incl. B. Ciardi): Linear polarization structures in LOFAR observations of the interstellar medium in the 3C 196 field. Astron. Astrophys. **583**, A137, 1-16 (2015).

Jeon, M., V. Bromm, A. Pawlik and M. Milosavljević: The first galaxies: simulating their feedback-regulated assembly. Mon. Not. R. Astron. Soc. **452(2)**, 1152-1170 (2015).

Jeong, D. and F. Schmidt: Large-scale structure observables in general relativity – Focus Issue: Relativistic Effects in Cosmology. Classical and Quantum Gravity **32(4)**, 044001 (2015).

Jerkstrand, A., M. Ergon et al. (incl. S. Taubenberger): Late-time spectral line formation in Type IIb supernovae, with application to SN 1993J, SN 2008ax, and SN 2011dh. Astron. Astrophys. **573**, A12 (2015).

Jerkstrand, A., S. J. Smartt et al. (incl. P. Mazzali): Supersolar Ni/Fe production in the Type IIP SN 2012ec. Mon. Not. R. Astron. Soc. **448(3)**, 2482-2494 (2015).

Junklewitz, H., M. Bell and T. Enßlin: A new approach to multifrequency synthesis in radio interferometry. Astron. Astrophys. **581**, A59, 1-11 (2015).

Just, O., A. Bauswein et al. (incl. A. Ardevol Pulpillo and H.-T. Janka): Comprehensive nucleosynthesis analysis for ejecta of compact binary mergers. Mon. Not. R. Astron. Soc. **448(1)**, 541-567 (2015).

Just, O., M. Obergaulinger and H.-T. Janka: A new multidimensional, energy-dependent two-moment transport code for neutrino-hydrodynamics. Mon. Not. R. Astron. Soc. **453(4)**, 3386-3413 (2015).

Karl, S. J., S. Aarseth, T. Naab et al.: Dynamical evolution of massive black holes in galactic-scale N-body simulations – introducing the regularized tree code 'rvine'. Mon. Not. R. Astron. Soc. **452(3)**, 2337-2352 (2015).

Kashlinsky, A., J.C. Mather, K. Helgason et al.: Reconstructing emission from pre-reionization sources with cosmic infrared background fluctuation measurements by the JWST. The Astrophys. J. **804(2)**, 99, 1-26 (2015).

Kashlinsky, A., R.G. Arendt, F. Atrio-Barandela, F. and K. Helgason: Lyman-tomography of cosmic infrared background fluctuations with Euclid: probing emissions and baryonic acoustic oscillations at z greater than or similar 10. The Astrophys. J. Lett. **813(1)**, L12 (2015).

Kauffmann, G.: The outer stellar populations and environments of unusually HâĂĽI-rich galaxies. Mon. Not. R. Astron. Soc. **450(1)**, 618-629 (2015).

Kauffmann, G., M.-L. Huang, S. Moran and T. M. Heckman: A systematic study of the inner rotation curves of galaxies observed as part of the GASS and COLD GASS surveys. Mon. Not. R. Astron. Soc. **451(1)**, 878-887 (2015).

Kauffmann, G.: Physical origin of the large-scale conformity in the specific star formation rates of galaxies. Mon. Not. R. Astron. Soc. **454(2)**, 1840-1847 (2015).

Khatri, R.: Linearized iterative least-squares (LIL): a parameter-fitting algorithm for component separation in multifrequency cosmic microwave background experiments such as Planck. Mon. Not. R. Astron. Soc. **451(3)**, 3321-3339 (2015).

Khatri, R. and R. A. Sunyaev: Limits on the fluctuating part of y-type distortion monopole from Planck and SPT results. J. of Cosmology and Astropart. Phys. **2015(8)**, 013, 1-16 (2015).

Khatri, R. and R. A. Sunyaev: Constraints on μ-distortion fluctuations and primordial non-Gaussianity from Planck data. J. of Cosmology and Astropart. Phys. **2015(09)**, 026, 1-23 (2015).

Knebe, A., F. R. Pearce et al. (incl. B. Henriques): nIFTy cosmology: comparison of galaxy formation models. Mon. Not. R. Astron. Soc. **451(4)**, 4029-4059 (2015).

Konstandin, L., R. Shetty, P. Girichidis and R. S. Klessen: Hierarchical Bayesian analysis of the velocity power spectrum in supersonic turbulence. Mon. Not. R. Astron. Soc. **446(2)**, 1775-1783 (2015).

Kosenko, D., W. Hillebrandt et al. (incl. M. Kromer and R. Pakmor): Oxygen emission in remnants of thermonuclear supernovae as a probe for their progenitor system. Mon. Not. R. Astron. Soc. **449(2)**, 1441-1448 (2015).

Krivonos, R., S. Tsygankov et al. (incl. E. Churazov and R. A. Sunyaev): INTEGRAL 11-year hard X-ray survey above 100 keV. Mon. Not. R. Astron. Soc. **448(4)**, 3766-3774 (2015).

Kromer, M., S. T. Ohlmann et al. (incl. W. Hillebrandt and S. Taubenberger): Deflagrations in hybrid CONe white dwarfs: a route to explain the faint Type Iax supernova 2008ha. Mon. Not. R. Astron. Soc. **450(3)**, 3045-3053 (2015).

Kruijssen, D., J. E. Dale, and S. N. Longmore: The dynamical evolution of molecular clouds near the Galactic Centre – I. Orbital structure and evolutionary timeline. Mon. Not. R. Astron. Soc. **447(2)**, 1059-1079 (2015).

Kruijssen, D.: Globular clusters as the relics of regular star formation in 'normal' high-redshift galaxies. Mon. Not. R. Astron. Soc. **454(2)**, 1658-1686 (2015).

Krumholz, M. R. and D. Kruijssen: A dynamical model for the formation of gas rings and episodic starbursts near galactic centres. Mon. Not. R. Astron. Soc. **453(1)**, 739-757 (2015).

Kunze, K. and E. Komatsu: Constraints on primordial magnetic fields from the optical depth of the cosmic microwave background. J. of Cosmology and Astropart. Phys. **2015(6)**, 027, 1-14 (2015).

Lagos, C. d. P., R. A. Crain et al. (incl. Y. M. Bahé): Molecular hydrogen abundances of galaxies in the EAGLE simulations. Mon. Not. R. Astron. Soc. **452(4)**, 3815-3837 (2015).

Lam, T. Y., Clampitt, J., Y.-C. Cai et al.: Voids in modified gravity reloaded: Eulerian void assignment. Mon. Not. R. Astron. Soc. **450(3)**, 3319-3330 (2015).

Laporte, C. and J. Penarrubia: Under the sword of Damocles: plausible regeneration of dark matter cusps at the smallest galactic scales. Mon. Not. R. Astron. Soc. Lett. **449(1)**, L90-L94 (2015).

Laporte, C. and S.D.M. White: The redistribution of matter in the cores of galaxy clusters. Mon. Not. R. Astron. Soc. **451(2)**, 1177-1189 (2015).

Lewis, A. R., A. E. Dolphin et al. (incl. A. Monachesi and A. Schruba): The Panchromatic Hubble Andromeda Treasury – XI. The spatially resolved recent star formation history of M31. The Astrophys. J. **805(2)**, 183, 1-21 (2015).

Li, G.-X., F. Wyrowski et al. (incl. X. Shi): G-virial: Gravity-based structure analysis of molecular clouds. Astron. Astrophys. **578**, A97, 1-15 (2015).

Li, M., J. P. Ostriker et al. (incl. T. Naab): Supernova feedback and the hot gas filling fraction of the interstellar medium. The Astrophys. J. **814(1)**, 4, 1-28 (2015).

Lugaro, M., S. Campbell, H. Van Winckel et al.: Post-AGB stars in the Magellanic Clouds and neutron-capture processes in AGB stars. Astron. Astrophys. **583**, A77, 1-6 (2015).

Lyskova, N., J. Thomas, E. Churazov, S. Tremaine and T. Naab: Comparison of simple mass estimators for slowly rotating elliptical galaxies. Mon. Not. R. Astron. Soc. **450(4)**, 3442-3457 (2015).

Ma, Q., Maio, U., Ciardi, B. and R. Salvaterra: PopIII signatures in the spectra of PopII/I GRBs. Mon. Not. R. Astron. Soc. **449(3)**, 3006-3014 (2015).

Maffione, N. P., Gómez, F. A., P. M. Cincotta et al.: On the relevance of chaos for halo stars in the solar neighbourhood. Mon. Not. R. Astron. Soc. **453(3)**, 2830-2847 (2015).

Magic, Z., A. Weiss and M. Asplund: The Stagger-grid: A grid of 3D stellar atmosphere models – III. The relation to mixing length convection theory. Astron. Astrophys. **573**, A89 (2015).

Magic, Z., A. Chiavassa, R. Collet and M. Asplund: The Stagger-grid: A grid of 3D stellar atmosphere models – IV. Limb darkening coefficients. Astron. Astrophys. **573**, A90 (2015).

Mancini, M., R. Schneider et al. (incl. B. Ciardi): The dust mass in $z > 6$ normal star-forming galaxies. Mon. Not. R. Astron. Soc. Lett. **451(1)**, L70-L74 (2015).

Marian, L., R. E. Smith, and R. E. Angulo: An exploration of galaxy-galaxy lensing and galaxy clustering in the Millennium-XXL simulation. Mon. Not. R. Astron. Soc. **451(2)**, 1418-1444 (2015).

Martí, J. M. and E. Müller: Grid-based methods in relativistic hydrodynamics and magnetohydrodynamics. Living Rev. Computational Astrophys. **1(3)**, lrca-2015-3, 1-182 (2015).

Martin, N. F., D. L. Nidever et al. (incl. A. Monachesi): Hydra II: a faint and compact milky way dwarf galaxy found in the survey of the magellanic stellar history. The Astrophys. J. Lett. **804(1)**, L5 (2015).

Mazzali, P. A., Sullivan, M., A. V. Filippenko et al.: Nebular spectra and abundance tomography of the Type Ia supernova SN 2011fe: a normal SN Ia with a stable Fe core. Mon. Not. R. Astron. Soc. **450(3)**, 2631-2643 (2015).

McDermid, R. M., K. Alatalo et al. (incl. T. Naab): The ATLAS3D Project –XXX. Star formation histories and stellar population scaling relations of early-type galaxies. Mon. Not. R. Astron. Soc. **448(4)**, 3484-3513 (2015).

Meinecke, J., P. Tzeferacos et al. (incl. E. Churazov): Developed turbulence and nonlinear amplification of magnetic fields in laboratory and astrophysical plasmas. Proceedings of the Nat. Acad. of Sciences of the U.S.A. **112(27)**, 8211-8215 (2015).

Melson, T., H.-T. Janka and A. Marek: Neutrino-driven supernova of a low-mass iron-core progenitor boosted by three-dimensional turbulent convection. The Astrophys. J. Lett. **801(2)**, L24 (2015).

Melson, T., H.-T. Janka, R. Bollig, F. Hanke et al.: Neutrino-driven explosion of a 20 solar-mass star in three dimensions enabled by strange-quark contributions to neutrino-nucleon scattering. The Astrophys. J. Lett. **808(2)**, L42, 1-8 (2015).

Mendoza-Temis, J., M.-R. Wu et al. (incl. H.-T. Janka): Nuclear robustness of the r process in neutron-star mergers. Phys. Rev. C **92(5)**, 055805, 1-16 (2015).

Messineo, M., J. S. Clark et al. (incl. R.-P. Kudritzki): Massive stars in the W33 giant molecular complex. The Astrophys. J. **805(2)**, 110, 1-20 (2015).

Mewes, V., J.A. Font, and P. J. Montero: Measuring the black hole spin direction in 3D Cartesian numerical relativity simulations. Phys. Rev. D **91(12)**, 124043 (2015).

Meyer, F. and E. Meyer-Hofmeister: SU UMa stars: Rebrightenings after superoutburst. Publications of the Astron. Soc. of Japan **67(3)**, 52 (2015).

Miczek, F., Röpke, F. K. and P. V. F. Edelmann: New numerical solver for flows at various Mach numbers. Astron. Astrophys. **576**, A50, 1-16 (2015).

Milisavljevic, D., R. Margutti et al. (incl. P. Mazzali): The broad-lined type Ic SN 2012ap and the nature of relativistic supernovae lacking a gamma-ray burst detection. The Astrophys. J. **799(1)**, 51 (2015).

Mirbabayi, M., F. Schmidt and M. Zaldarriaga: Biased tracers and time evolution. J. of Cosmology and Astropart. Phys. **2015(7)**, 030, 1-26 (2015).

Mitchell, J. P., J. Braithwaite et al. (incl. H. Spruit): Instability of magnetic equilibria in barotropic stars. Mon. Not. R. Astron. Soc. **447(2)**, 1213-1223 (2015).

Moldón, J., A. T. Deller et al. (incl. B. Ciardi and S. D. M. White): The LOFAR long baseline snapshot calibrator survey. Astron. Astrophys. **574**, A73 (2015).

Morales-Garoffolo, A., N. Elias-Rosa et al. (incl. S. Taubenberger): SN 2011fu: a type IIb supernova with a luminous double-peaked light curve. Mon. Not. R. Astron. Soc. **454(1)**, 95-114 (2015).

Morosan, D. E., P. T. Gallagher et al. (incl. B. Ciardi): LOFAR tied-array imaging and spectroscopy of solar S bursts. Astron. Astrophys. **580**, A65, 1-6 (2015).

Müller, B. and H.-T. Janka: Non-radial instabilities and progenitor asphericities in core-collapse supernovae. Mon. Not. R. Astron. Soc. **448(3)**, 2141-2174 (2015).

Nakauchi, D., K. Kashiyama et al. (incl. Y. Suwa): Optical synchrotron precursors of radio hypernovae. The Astrophys. J. **805(2)**, 164, 1-7 (2015).

Naruko, A., E. Komatsu and M. Yamaguchi: Anisotropic inflation reexamined: upper bound on broken rotational invariance during inflation. J. of Cosmology and Astropart. Phys. **2015(4)**, 045, 1-23 (2015).

Nelles, A., P. Schellart et al. (incl. B. Ciardi): Measuring a Cherenkov ring in the radio emission from air showers at 110–190 MHz with LOFAR. Astropart. Phys. **65**, 11-21 (2015).

Nelles, A., J. R. Hörandel et al. (incl. B. Ciardi): Calibrating the absolute amplitude scale for air showers measured at LOFAR. J. of Instrumentation **10(1)**, P11005, 1-33 (2015).

Nielsen, M. T. B. and M. Gilfanov: Attenuation of supersoft X-ray sources by circumstellar material. Mon. Not. R. Astron. Soc. **453(3)**, 2927-2936 (2015).

Noebauer, U. M. and S. A. Sim: Self-consistent modelling of line-driven hot-star winds with Monte Carlo radiation hydrodynamics. Mon. Not. R. Astron. Soc. **453(3)**, 3120-3134 (2015).

Noll, S., W. Kausch et al. (incl. A. M. Jones): OH populations and temperatures from simultaneous spectroscopic observations of 25 bands. Atmospheric Chemistry and Physics **15(7)**, 3647-3669 (2015).

Ogrean, G. A., R. J. van Weeren et al. (incl. E. Churazov): Frontier fields clusters: Chandra and JVLA view of the pre-merging cluster MACS J416.1-2403. The Astrophys. J. **812(2)**, 153, 1-19 (2015).

Oman, K. A., J. F. Navarro et al. (incl. S. D. M. White): The unexpected diversity of dwarf galaxy rotation curves. Mon. Not. R. Astron. Soc. **452(4)**, 3650-3665 (2015).

Oppermann, N., H. Junklewitz et al. (incl. M. Greiner, T. A. Enßlin and V. Vacca): Estimating extragalactic Faraday rotation. Astron. Astrophys. **575**, A118, 1-25 (2015).

Orrù, E., S. van Velzen et al. (incl. B. Ciardi): Wide-field LOFAR imaging of the field around the double-double radio galaxy B1834+620: a fresh view on a restarted AGN and doubeltjes. Astron. Astrophys. **584**, A112, 1-12 (2015).

Paldus, J., T. Sako and G.H.F. Diercksen: On the cluster structure of linear-chain fermionic wave functions. Journal of Mathematical Chemistry **53(2)**, 629-650 (2015).

Pan, Y.-C., M. Sullivan et al. (incl. P. A. Mazzali): Type Ia supernova spectral features in the context of their host galaxy properties. Mon. Not. R. Astron. Soc. **446(1)**, 354-368 (2015).

Pan, Y.-C., R. J. Foley (incl. W. Hillebrandt and S. Taubenberger): 500 days of SN 2013dy: spectra and photometry from the ultraviolet to the infrared. Mon. Not. R. Astron. Soc. **452(4)**, 4307-4325 (2015).

Pastorello, A., S. Benetti et al. (incl. S. Taubenberger): Massive stars exploding in a He-rich circumstellar medium – IV. Transitional Type Ibn supernovae. Mon. Not. R. Astron. Soc. **449(2)**, 1921-1940 (2015).

Pastorello, A., et al. (incl. S. Benitez-Herrera and S. Taubenberger): Massive stars exploding in a He-rich circumstellar medium – VI. Observations of two distant Type Ibn supernova candidates discovered by La Silla-QUEST. Mon. Not. R. Astron. Soc. **449(2)**, 1954-1966 (2015).

Pastorello, A., et al. (incl. U. M. Noebauer, S. Taubenberger and E. E. O. Ishida): Massive stars exploding in a He-rich circumstellar medium – VII. The metamorphosis of ASASSN-15ed from a narrow line Type Ibn to a normal Type Ib Supernova. Mon. Not. R. Astron. Soc. **453(4)**, 3649-3661 (2015).

Pastorello, A., et al. (incl. U. M. Noebauer, S. Taubenberger and E. E. O. Ishida): Massive stars exploding in a He-rich circumstellar medium – VIII. PSN J07285387+3349106, a highly reddened supernova Ibn. Mon. Not. R. Astron. Soc. **454(4)**, 4293-4303 (2015).

Patat, F., Taubenberger, S., N. L. J. Cox et al.: Properties of extragalactic dust inferred from linear polarimetry of Type Ia Supernovae. Astron. Astrophys. **577**, A53, 1-10 (2015).

Pattarakijwanich, P. and F. Schmidt: Dust content, galaxy orientations, and shape noise in imaging surveys. The Astrophys. J. **805(2)**, 108, 1-13 (2015).

Pawlik, A. H., J. Schaye and C. D. Vecchia: Spatially adaptive radiation-hydrodynamical simulations of galaxy formation during cosmological reionization. Mon. Not. R. Astron. Soc. **451(2)**, 1586-1605 (2015).

Peters, T., P. Girichidis, A. Gatto, T. Naab et al.: Impact of supernova and cosmic-ray driving on the surface brightness of the galactic halo in soft X-rays. The Astrophys. J. Lett. **813(2)**, L27, 1-7 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XVIII. The millimetre and sub-millimetre emission from planetary nebulae. Astron. Astrophys. **573**, A6 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XIX. An overview of the polarized thermal emission from Galactic dust. Astron. Astrophys. **576**, A104, 1-33 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXI. Comparison of polarized thermal emission from Galactic dust at 353 GHz with interstellar polarization in the visible. Astron. Astrophys. **576**, A106, 1-17 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XX. Comparison of polarized thermal emission from Galactic dust with simulations of MHD turbulence. Astron. Astrophys. **576**, A105, 1-27 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXII. Frequency dependence of thermal emission from Galactic dust inensity and polarization. Astron. Astrophys. **576**, A107, 1-25 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXIII. Galactic plane emission components derived from Planck with ancillary data. Astron. Astrophys. **580**, A13, 1-27 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXIII. Galactic plane emission components derived from Planck with ancillary data. Astron. Astrophys. **580**, A13, 1-27 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXIV. Constraints on variations in fundamental constants. Astron. Astrophys. **580**, A22, 1-25 (2015).

Planck Collaboration (incl. MPA Planck group): Planck 2013 results – XXXII. The updated Planck catalogue of Sunyaev-Zeldovich sources. Astron. Astrophys. **581**, A14, 1-8 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXVI. Optical identification and redshifts of Planck clusters with the RTT150 telescope. Astron. Astrophys. **582**, A29, 1-13 (2015).

Planck and Fermi Collaborations (incl. MPA Planck group): Planck intermediate results – XXVIII. Interstellar gas and dust in the Chamaeleon clouds as seen by Fermi LAT and Planck. Astron. Astrophys. **582**, A31, 1-32 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXV. The Andromeda galaxy as seen by Planck. Astron. Astrophys. **582**, A28, 1-23 (2015).

Planck Collaboration (incl. MPA Planck group): Planck intermediate results – XXVII. High-redshift infrared galaxy overdensity candidates and lensed sources discovered by Planck and confirmed by Herschel-SPIRE. Astron. Astrophys. **582**, A30, 1-29 (2015).

Pllumbi, E., et al. (incl. H.-Th. Janka and L. Hüdepohl): Impact of neutrino flavor oscillations on the neutrino-driven wind nucleosynthesis of an electron-capture supernova. Astrophys. J. **808**, 188 (2015).

Polshaw, J., R. Kotak et al. (incl. S. Taubenberger and W. Hillebrandt): A supernova distance to the anchor galaxy NGC 4258. Astron. Astrophys. **580**, L15, 1-6 (2015).

Rahmati, A., Schaye, J., R. G. Bower et al.: The distribution of neutral hydrogen around high-redshift galaxies and quasars in the EAGLE simulation. Mon. Not. R. Astron. Soc. **452(2)**, 2034-2056 (2015).

Rasia, E., S. Borgani et al. (incl. K. Dolag): Cool core clusters from cosmological simulations. The Astrophys. J. Lett. **813(1)**, L17, 1-6 (2015).

Rathborne, J. M., S. N. Longmore et al. (incl. J. M. D. Kruijssen): A cluster in the making: Alma reveals the initial conditions for high-mass cluster formation. The Astrophys. J. **802(2)**, 125, 1-20 (2015).

Reinecke, M. and E. Hivon: Efficient data structures for masks on 2D grids. Astron. Astrophys. **580**, A132, 1-9 (2015).

Roediger, E., R. P. Kraft et al. (incl. E. Churazov): Stripped elliptical galaxies as probes of ICM physics – I. Tails, wakes, and flow patterns in and around stripped ellipticals. The Astrophys. J. **806(1)**, 103, 1-18 (2015).

Roediger, E., R. P. Kraft et al. (incl. E. Churazov): Stripped elliptical galaxies as probes of ICM physics – II. Stirred, but mixed? Viscous and inviscid gas stripping of the virgo elliptical M89. The Astrophys. J. **806(1)**, 104, 1-15 (2015).

Roychowdhury, S., M.-L. Huang, G. Kauffmann et al.: The spatially resolved Kennicutt-Schmidt relation in the HâĂĽi-dominated regions of spiral and dwarf irregular galaxies. Mon. Not. R. Astron. Soc. **449(4)**, 3700-3709 (2015).

Rybak, M., J. P. McKean et al. (incl. S. Vegetti and S. D. M. White): ALMA imaging of SDP.81 – I. A pixelated reconstruction of the far-infrared continuum emission. Mon. Not. R. Astron. Soc. Lett. **451(1)**, L40-L44 (2015).

Rybak, M., S. Vegetti et al. (incl. S. D. M. White): ALMA imaging of SDP.81 – II. A pixelated reconstruction of the CO emission lines. Mon. Not. R. Astron. Soc. Lett. **453(1)**, L26-L30 (2015).

Sanchis-Gual, N., J. Degollado, P. Montero, and J. Font: Quasistationary solutions of self-gravitating scalar fields around black holes. Phys. Rev. D **91(4)**, 043005 (2015).

Sanchis-Gual, N., J. Degollado, P. Montero, and J. Font: Quasistationary solutions of self-gravitating scalar fields around collapsing stars. Phys. Rev. D **92(8)**, 083001, 1-16 (2015).

Sasdelli, M., W. Hillebrandt et al. (incl. S. Benitez-Herrera, M. Fink, E. E. O. Ishida, M. Kromer, P. A. Mazzali and S. Taubenberger): A metric space for Type Ia supernova spectra. Mon. Not. R. Astron. Soc. **447(2)**, 1247-1266 (2015).

Sazonov, S. and R. A. Sunyaev: Preheating of the Universe by cosmic rays from primordial supernovae at the beginning of cosmic reionization. Mon. Not. R. Astron. Soc. **454(4)**, 3464-3471 (2015).

Sazonov, S., E. Churazov and R. Krivonos: Does the obscured AGN fraction really depend on luminosity? Mon. Not. R. Astron. Soc. **454(2)**, 1202-1220 (2015).

Schaye, J., R. A. Crain et al. (incl. S.D.M. White and A. Rahmati): The EAGLE project: simulating the evolution and assembly of galaxies and their environments. Mon. Not. R. Astron. Soc. **446(1)**, 521-554 (2015).

Schellart, P., T. Trinh et al. (incl. B. Ciardi): Probing atmospheric electric fields in thunderstorms through radio emission from cosmic-ray-induced air showers. Phys. Rev. Lett. **114(16)**, 165001 (2015).

Schmidt, F., N.E. Chisari and C. Dvorkin: Imprint of inflation on galaxy shape correlations. J. of Cosmology and Astropart. Phys. **2015(10)**, 032, 1-35 (2015).

Schneider, N., S. Bontemps et al. (incl. P. Girichidis): Detection of two power-law tails in the probability distribution functions of massive GMCs. Mon. Not. R. Astron. Soc. Lett. **453(1)**, L41-L45 (2015).

Schneider, N., V. Ossenkopf et al. (incl. P. Girichidis): Understanding star formation in molecular clouds – I. Effects of line-of-sight contamination on the column density structure. Astron. Astrophys. **575**, A79, 1-17 (2015).

Schwartz, P., S. Jejčič et al. (incl. U. Anzer): Prominence visibility in Hinode/XRT images. The Astrophys. J. **807(1)**, 97, 1-9 (2015).

Seitenzahl, I. R., A. Summa et al. (incl. W. Hillebrandt, M. Kromer and A. J. Ruiter): 5.9-keV Mn K-shell X-ray luminosity from the decay of 55Fe in Type Ia supernova models. Mon. Not. R. Astron. Soc. **447(2)**, 1484-1490 (2015).

Seitenzahl, I. R., M. Herzog, A. J. Ruiter et al.: Neutrino and gravitational wave signal of a delayed-detonation model of type Ia supernovae. Phys. Rev. D **92(12)**, 124013, 1-9 (2015).

Selig, M. and T. A. Enßlin: Denoising, deconvolving, and decomposing photon observations Derivation of the D3PO algorithm. Astron. Astrophys. **574**, A74 (2015).

Selig, M., Vacca, V., Oppermann, N. and T. A. Enßlin: The denoised, deconvolved, and decomposed Fermi γ-Ray sky: an application of the D3PO algorithm. Astron. Astrophys. **581**, A126, 1-16 (2015).

Shamshiri, S., P. A. Thomas et al. (incl. B. M. Henriques and G. Lemson): Galaxy formation in the Planck cosmology – II. Star-formation histories and post-processing magnitude reconstruction. Mon. Not. R. Astron. Soc. **451(3)**, 2681-2691 (2015).

Shao, L., C. Li, G. Kauffmann and J. Wang: The nature of obscuration in AGNs – II. Insights from clustering properties. Mon. Not. R. Astron. Soc. Lett. **448(1)**, L72-L76 (2015).

Shi, X., E. Komatsu, K. Nelson and D. Nagai: Analytical model for non-thermal pressure in galaxy clusters – II. Comparison with cosmological hydrodynamics simulation. Mon. Not. R. Astron. Soc. **448(1)**, 1020-1029 (2015).

Shulevski, A., R. Morganti et al. (incl. B. Ciardi): The peculiar radio galaxy 4C 35.06: a case for recurrent AGN activity? Astron. Astrophys. **579**, A27, 1-10 (2015).

Smartt, S. J., S. Valenti et al. (incl. S. Taubenberger and W. Hillebrandt): PESSTO: survey description and products from the first data release by the Public ESO Spectroscopic Survey of Transient Objects. Astron. Astrophys. **579**, A40, 1-25 (2015).

Smith, R. E. and L. Marian: Towards optimal estimation of the galaxy power spectrum. Mon. Not. R. Astron. Soc. **454(2)**, 1266-1289 (2015).

Soraisam, M. D. and M. Gilfanov: Constraining the role of novae as progenitors of type Ia supernovae. Astron. Astrophys. **583**, A140, 1-13 (2015).

Sotomayor-Beltran, C., C. Sobey et al. (incl. M. R. Bell, B. Ciardi and F. de Gasperin): Calibrating high-precision Faraday rotation measurements for LOFAR and the next generation of low-frequency radio telescopes (Corrigendum). Astron. Astrophys. **581**, C4, 1-2 (2015).

Spiniello, C., L. V. E. Koopmans et al. (incl. S. Vegetti): The X-Shooter Lens Survey – II. Sample presentation and spatially-resolved kinematics. Mon. Not. R. Astron. Soc. **452(3)**, 2434-2444 (2015).

Spiniello, C., Napolitano, N. R., L. Coccato et al.: VIMOS mosaic integral-field spectroscopy of the bulge and disc of the early-type galaxy NGC 4697. Mon. Not. R. Astron. Soc. **452(1)**, 99-114 (2015).

Spiniello, C., M. Barnabè, L. Koopmans et al.: Are the total mass density and the low-mass end slope of the IMF anticorrelated? Mon. Not. R. Astron. Soc. Lett. **452(1)**, L21-L25 (2015).

Spiniello, C., C. Trager, and L. Koopmans: The non-universality of the low-mass end of the IMF is robust against the choice of SSP model. The Astrophys. J. **803(2)**, 87, 1-15 (2015).

Spruit, H. C.: The growth of helium-burning cores. Astron. Astrophys. **582**, L2, 1-3 (2015).

Steinborn, L. K., Dolag, K., M. Hirschmann et al.: A refined sub-grid model for black hole accretion and AGN feedback in large cosmological simulations. Mon. Not. R. Astron. Soc. **448(2)**, 1504-1525 (2015).

Sun, X. H., L. Rudnick et al. (incl. M. R. Bell): Comparison of algorithms for determination of rotation measure and faraday structure. – I. 1100 – 1400 MHZ. The Astron. J. **149(2)**, 60 (2015).

Suwa, Y. and N. Tominaga: How much can 56Ni be synthesized by the magnetar model for long gamma-ray bursts and hypernovae? Mon. Not. R. Astron. Soc. **451(1)**, 282-287 (2015).

Suwa, Y., T. Yoshida, M. Shibata et al.: Neutrino-driven explosions of ultra-stripped Type Ic supernovae generating binary neutron stars. Mon. Not. R. Astron. Soc. **454(3)**, 3073-3081 (2015).

Tartaglia, L., A. Pastorello, S. Taubenberger et al.: Interacting supernovae and supernova impostors. SN 2007sv: the major eruption of a massive star in UGC 5979. Mon. Not. R. Astron. Soc. **447(1)**, 117-131 (2015).

Taubenberger, S., N. Elias-Rosa, W. Kerzendorf et al.: Spectroscopy of the Type Ia supernova 2011fe past 1000d. Mon. Not. R. Astron. Soc. Lett. **448(1)**, L48-L52 (2015).

Teklu, A. F., R.-S. Remus et al. (incl. K. Dolag, A. Burkert and A. S. Schmidt): Connecting angular momentum and galactic dynamics: the complex interplay between spin, mass, and morphology. The Astrophys. J. **812(1)**, 29, 1-24 (2015).

Thaler, I. and H. C. Spruit: Small-scale dynamos on the solar surface: dependence on magnetic Prandtl number. Astron. Astrophys. **578**, A54, 1-5 (2015).

Travaglio, C., R. Gallino et al. (incl. W. Hillebrandt): Testing the role of SNe Ia for galactic chemical evolution of p-nuclei with two-dimensional models and with s-process seeds at different metallicities. The Astrophys. J. **799(1)**, 54 (2015).

Utrobin, V. P. and N. N. Chugai: Parameters of type IIP SN 2012A and clumpiness effects. Astron. Astrophys. **575**, A100, 1-7 (2015).

Utrobin, V. P., A. Wongwathanarat, H.-T. Janka and E. Müller: Supernova 1987A: neutrino-driven explosions in three dimensions and light curves. Astron. Astrophys. **581**, A40, 1-18 (2015).

van Daalen, M. P. and J. Schaye: The contributions of matter inside and outside of haloes to the matter power spectrum. Mon. Not. R. Astron. Soc. **452(3)**, 2247-2257 (2015).

Vedantham, H. K., L. V. E. Koopmans et al. (incl. B. Ciardi): Lunar occultation of the diffuse radio sky: LOFAR measurements between 35 and 80 MHz. Mon. Not. R. Astron. Soc. **450(3)**, 2291-2305 (2015).

Velliscig, M., M. Cacciato et al. (incl. M. P. van Daalen): The alignment and shape of dark matter, stellar, and hot gas distributions in the EAGLE and cosmo-OWLS simulations. Mon. Not. R. Astron. Soc. **453(1)**, 721-738 (2015).

Velliscig, M. and M. Cacciato et al. (incl. P. M. van Daalen): Intrinsic alignments of galaxies in the EAGLE and cosmo-OWLS simulations. Mon. Not. R. Astron. Soc. **454(3)**, 3328-3340 (2015).

Viallet, M., C. Meakin, V. Prat, and D. Arnett: Toward a consistent use of overshooting parametrizations in 1D stellar evolution codes. Astron. Astrophys. **580**, A61, 1-5 (2015).

Wagner, C., F. Schmidt, C.-T. Chiang and E. Komatsu: Separate universe simulations. Mon. Not. R. Astron. Soc. Lett. **448(1)**, L11-L15 (2015).

Wagner, C., F. Schmidt, C.-T. Chiang and E. Komatsu: The angle-averaged squeezed limit of nonlinear matter N-point functions. J. of Cosmology and Astropart. Phys. **08**, 042, 1-33 (2015).

Walch, S., P. Girichidis et al. (incl. T. Naab, A. Gatto and T. Peters): The SILCC (Simulating the LifeCycle of molecular Clouds) project – I. Chemical evolution of the supernova-driven ISM. Mon. Not. R. Astron. Soc. **454(1)**, 238-268 (2015).

Walch, S. and T. Naab: The energy and momentum input of supernova explosions in structured and ionized molecular clouds. Mon. Not. R. Astron. Soc. **451(3)**, 2757-2771 (2015).

Walker, D. L., S. N. Longmore et al. (incl. J. M. D. Kruijssen): Tracing the conversion of gas into stars in Young Massive Cluster Progenitors. Mon. Not. R. Astron. Soc. **449(1)**, 715-725 (2015).

Wang, E., J. Wang, G. Kauffmann et al.: H i scaling relations of galaxies in the environment of H i-rich and control galaxies observed by the Bluedisk project. Mon. Not. R. Astron. Soc. **449(2)**, 2010-2023 (2015).

Wang, L., R. Spurzem et al. (incl. T. Naab): nbody6++gpu: ready for the gravitational million-body problem. Mon. Not. R. Astron. Soc. **450(4)**, 4070-4080 (2015).

White, C. J., M. M. Kasliwal et al. (incl. A. Sternberg): Slow-speed Supernovae from the Palomar transient factory: two channels. The Astrophys. J. **799(1)**, 52 (2015).

Williams, B. F., J. J. Dalcanton et al. (incl. A. Monachesi): A global star-forming episode in M31 2-4. The Astrophys. J. **806(1)**, 48, 1-9 (2015).

Winther, H. A., F. Schmidt et al. (incl. A. Barreira and R. E. Smith): Modified gravity N-body code comparison project. Mon. Not. R. Astron. Soc. **454(4)**, 4208-4234 (2015).

Wongwathanarat, A., E. Müller and H.-T. Janka: Three-dimensional simulations of core-collapse supernovae: from shock revival to shock breakout. Astron. Astrophys. **577**, A48 (2015).

Yan, L., R. Quimby et al. (incl. P. Mazzali): Detection of broad Hα emission lines in the late-time spectra of a hydrogen-poor superluminous supernova. The Astrophys. J. **814(2)**, 108, 1-14 (2015).

Yokozawa, T., M. Asano et al. (incl. Y. Suwa): Probing the rotation of core-collapse supernova with a concurrent analysis of gravitational waves and neutrinos. The Astrophys. J. **811(2)**, 86, 1-12 (2015).

Yoon, M. and D. Huterer: Kinematic dipole detection with galaxy surveys: forecasts and requirements. The Astrophys. J. Lett. **813(1)**, L18, 1-4 (2015).

Zhukovska, S., M. Petrov, and T. Henning: Can star cluster environment affect dust input from massive AGB stars? The Astrophys. J. **810(2)**, 128, 1-14 (2015).

Zhuravleva, I., E. Churazov et al. (incl. R. A. Sunyaev): Gas density fluctuations in the Perseus Cluster: clumping factor and velocity power spectrum. Mon. Not. R. Astron. Soc. **450(4)**, 4184-4197 (2015).

Zivick, P., P. M. Sutter et al. (incl. T. Y. Lam): Using cosmic voids to distinguish f(R) gravity in future galaxy surveys. Mon. Not. R. Astron. Soc. **451(4)**, 4215-4222 (2015).

3.1.2 Publications accepted in 2015 (19)

Buntemeyer, L., R. Banerjee, T. Peters, et al:: Radiation hydrodynamics using characteristics on adaptive decomposed domains for massively parallel star formation simulations. New Astronomy.

Bulla, M. et al. (incl. S. Taubenberger, W. Hillebrandt): Type Ia supernovae from violent mergers of carbon–oxygen white dwarfs: polarization signatures. Mon. Not. R. Astron. Soc.

Constantino, T. N., S. W. Campbell, J.C. Lattanzio, and A. van Duijneveldt, A.: The treatment of mixing in core helium burning models – II. Constraints from cluster star counts. Mon. Not. R. Astron. Soc.

D'Souza R., S. Vegetti, and G. Kauffmann: The Massive End of the Stellar Mass Function. Mon. Not. R. Astron. Soc.

Dariush, A., S. Dib, et al. (incl. S. Zhukovska): H-ATLAS/GAMA: the nature and characteristics of optically red galaxies detected at submillimetre wavelengths. Mon. Not. R. Astron. Soc.

Girichidis, P., T. Naab, et al. (incl. T. Peters): Launching cosmic-ray-driven outflows from the magnetized interstellar medium. Astrophys. J. Lett.

Girichidis, P., T. Naab, et al. (incl. T. Peters): The SILCC (SImulating the LifeCycle of molecular Clouds) project - II. Dynamical evolution of the supernova-driven ISM and the launching of outflows. Mon. Not. R. Astron. Soc.

Gómez, A. Facundo, S.D.M. White, F. Marinacci et al.: A fully cosmological model of a Monoceros-like ring. Mon. Not. R. Astron. Soc.

Griffen, B., A.P. Ji, et al. (incl. F. Gómez): The Caterpillar Project: A Large Suite of Milky Way Sized Halos. Astrophys. J..

Miller Bertolami, M., M. Viallet, et al. (incl. A. Weiss): On the relevance of bubbles and potential flows for stellar convection. Mon. Not. R. Astron. Soc.

Latour, M. et al. (incl. W. Hillebrandt, S. Taubenberger): Quantitative spectral analysis of the sdB star HD–188112: A helium-core white dwarf progenitor. Astron. Astrophys.

Maguire, K., S. Taubenberger et al.: Searching for swept-up hydrogen and helium in the late-time spectra of 11 nearby Type Ia supernovae. Mon. Not. R. Astron. Soc.

Monachesi, A., E.F. Bell, D.J. Radburn-Smith et al.: The GHOSTS survey -II. The diversity of halo colour and metallicity profiles of massive disc galaxies. Mon. Not. R. Astron. Soc.

Peñarrubia, J., F. A. Gómez, G. Besla et al.: A timing constraint on the (total) mass of the Large Magellanic Cloud. Mon. Not. R. Astron. Soc.

Prat, V., Lignieres, and J. Ballot: Asymptotic theory of gravity modes in rapidly rotating stars. I. Ray dynamics. Astron. Astrophys.

Rembiasz, T., M. Obergaulinger et al. (incl. E. Müller): Termination of the magnetorotational instability via parasitic instabilities in core-collapse supernovae. Mon. Not. R. Astron. Soc.

Streich, D., R.S. de Jong, et al. (incl. A. Monachesi): Extragalactic archeology with the GHOSTS Survey. I. The age-resolved disk structure of nearby low-mass galaxies. Astron. Astrophys.

Suwa, Y., S. Yamada, T. Takiwaki, and K. Kotake: The Criterion of Supernova Explosion Revisited: The Mass Accretion History. Astrophys. J.

Vrbanec, D., B. Ciardi, V. Jelić et al.: Predictions for the 21 cm-galaxy cross-power spectrum observable with LOFAR and Subaru: 03/2016, Mon. Not. R. Astron. Soc.

3.2 Publications in proceedings

3.2.1 Publications in proceedings appeared in 2015 (38)

Bonafede, A., Vazza, F., et al. (incl. V. Vacca): Unravelling the origin of large-scale magnetic fields in galaxy clusters and beyond through Faraday Rotation Measures with the SKA. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-9 (2015).

Ciardi, B., Inoue, S., Mack, K., et al.: 21-cm forest with the SKA. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-10, (2015).

Corsico, A. H., Althaus, L. G., et al. (incl. Miller Bertolami): Asteroseismic constraints on the neutrino magnetic dipole moment. In: P. Dufour, P. Bergeron, and G. Fontaine (Eds.), 19th European Workshop on White Dwarfs, pp. 229-232, (2015).

Di Bernardo, G., D. Grasso, C. Evoli and D. Gaggero: Diffuse synchrotron emission from galactic cosmic ray electrons, ASTRA Proceedings, 2, 21-26, (2015).

Dorn, S., Ramirez, E., et al. (incl. T. Enßlin): Generic inference of inflation models by local non-Gaussianity. In: A. Heavens, J.-L. Starck, and A. Krone-Martins (Eds.), Statistical Challenges in 21st Century Cosmology (IAU Symposium 306) Cambridge, UK: Cambridge University Press. pp. 51-53, (2015).

Ferrari, C., A. Dabbech, et al. (incl. V. Vacca): Non-thermal emission from galaxy clusters: feasibility study with SKA. In Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-10 (2015).

Forman, W., E. Churazov, C. Jones, and A. Vikhlinin: Supermassive black holes (SMBH) at work: M87, a case study of the effects of SMBH outbursts. In: F. Massaro, C. C. Cheung, E. Lopez, and A. Siemiginowska (Eds.), Extragalactic Jets from every Angle (IAU Symposium 313) Cambridge, UK: Cambridge University Press, pp. 309-314 (2015).

Giovannini, G., Bonafede, A., et al. (incl. V. Vacca): Mega-parsec scale magnetic fields in low density regions in the SKA era: filaments connecting galaxy clusters and groups. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-9 (2015).

Govoni, F., Murgia, M., et al. (incl. V. Vacca): (2015). Cluster magnetic fields through the study of polarized radio halos in the SKA era. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-9 (2015).

Ishida, E., R. de Souza, and F.B. Abdalla: Improved KPCA for supernova photometric classification. In: A. Heavens, J.-L. Starck, and A. Krone-Martins (Eds.), Statistical Challenges in 21st Century Cosmology (IAU Symposium 306). Cambridge, UK: Cambridge University Press. pp. 326-329 (2015).

Jelic, V., Ciardi, B., E. Fernandez, H. Tashiro, and D. Vrbanec: SKA - EoR correlations and cross-correlations: kSZ, radio galaxies, and NIR background. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-10 (2015).

Johnston-Hollitt, M. et al. (incl. T. Enßlin and V. Vacca): Using SKA rotation measures to reveal the mysteries of the magnetised universe. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-18 (2015).

Jones, C., W. Forman, E. Churazov, and P. Nulsen: X-ray jets and nuclear emission in low redshift early-type galaxies. In F. Massaro, C. C. Cheung, E. Lopez, and A. Siemiginowska (Eds.), Extragalactic Jets from every Angle (IAU Symposium 313) Cambridge, UK: Cambridge University Press. pp. 266-270 (2015).

Just, O., Bauswein, A., et al. (incl. H.-Th. Janka): Nucleosynthesis in dynamical and torus ejecta of compact binary mergers. In: XIII Nuclei in the Cosmos - NIC XIII, pp. 1-7 (2015).

Khatri, R.: Mixing of blackbodies: increasing our view of inflation to 17 e-folds with spectral distortions from silk damping. In: Proceedings of the MG13 Meeting on General Relativity. R. T. Jantzen, and K. Rosquist (Eds.) Singapore [u.a.]: World Scientific. pp. 1482-1484 (2015).

Kholtygin, A. F., Castro, N., et al. (incl. H. Spruit): The B Fields in OB Stars (BOB) Survey. In: Y. Y. Balega, I. I. Romanyuk, and D. O. Kudryavtsev (Eds.), Physics and Evolution of Magnetic and Related Stars, pp. 79-85 (2015).

Killedar, M., S. Borgani, D. Fabjan, et al. (incl. K. Dolag): Cluster strong lensing: a new strategy for testing cosmology with simulations. In: A. Heavens, J.-L. Starck, and A. Krone-Martins (Eds.), Statistical Challenges in 21st Century Cosmology (IAU Symposium 306) Cambridge, UK: Cambridge University Press, pp. 113-115 (2015).

Kim, J. W., G. Lemson, N. Bulatovic, et al.: AWOB: a collaborative workbench for astronomers. In: A. R. Taylor, and E. Rosolowsky (Eds.), Astronomical Data Analysis Software and Systems XXIV (ADASS XXIV) pp. 491-494 (2015).

Koopmans, L., Pritchard, J., et al. (incl. B. Ciardi): The cosmic dawn and epoch of reionisation with SKA. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-28 (2015).

Lemson, G., and O. Laurino: Astronomical data integration beyond the virtual observatory. In: A. R. Taylor, and E. Rosolowsky (Eds.), Astronomical Data Analysis Software and Systems XXIV (ADASS XXIV) pp. 513-522 (2015).

Maio, U., Ciardi, B., and L. Koopmans et al.: Bulk flows and end of the dark ages with the SKA. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-9 (2015).

McKean, J., N. Jackson, S. Vegetti, M. Rybak, et al.: Strong gravitational lensing with the SKA. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-18 (2015).

Miller Bertolami, M. M.: Post-asymptotic giant branch evolution of low- and intermediate-mass stars: preliminary results. In: P. Dufour, P. Bergeron, and G. Fontaine (Eds.), 19th European Workshop on White Dwarfs, pp. 83-88 (2015).

Miller Bertolami, M., B. Melendez, L. Althaus, and J. Isern: Testing fundamental particle physics with the galactic white dwarf luminosity function. In: P. Dufour, P. Bergeron, and G. Fontaine (Eds.), 19th European Workshop on White Dwarfs, pp. 133-136 (2015).

Monachesi, A., E. Bell, D. Radburn-Smith et al.: Testing galaxy formation models with the GHOSTS survey: The stellar halo of M81. Highlights of Astronomy, Volume 16, pp. 379-379 (2015).

Obergaulinger, M., H.-T. Janka and M. Aloy: Magnetic field amplification in non-rotating stellar core collapse. In: N. V. Pogorelov, E. Audit, and G. P. Zank (Eds.), 9th International Conference of Numerical Modeling of Space Plasma Flows Astronum 2014, pp. 115-120 (2015).

Oppermann, N., and T. Enßlin: Bayesian CMB foreground separation with a correlated log-normal model. In: A. Heavens, J.-L. Starck, and A. Krone-Martins (Eds.), Statistical Challenges in 21st Century Cosmology (IAU Symposium 306) Cambridge, UK: Cambridge University Press. pp. 16-18 (2015).

Pavlinsky, M., et al. (incl. R. Sunyaev, E. Churazov and M. Gilfanov): Status of ART-XC / SRG instrument. In: S. L. O'Dell, and G. Pareschi (Eds.), Optics for EUV, X-Ray, and Gamma-Ray Astronomy VII. p. 1-12, (2015).

Pawlik, A. H., V. Bromm, V., and M. Milosavljevič: Assembly of the first disk galaxies under radiative feedback from the first stars. Memorie della Societa Astronomica Italiana, 85(3), p. 565-569 (2015).

Prandoni, I., Melis, A., et al. (incl. V. Vacca): The SRT in the context of european networks: astronomical validation and future perspectives. In: 12th European VLBI Network Symposium and Users Meeting - EVN 2014 pp. 1-8 (2015).

Remus, R.-S., Dolag, K., and A. Burkert: The dark halo – spheroid conspiracy reloaded: evolution with redshift. In: M. Cappellari, and S. Courteau (Eds.), Galaxies Masses as Constraints of Formation Models (IAU Symposium 311) Cambridge, UK: Cambridge University Press. pp. 116-119, (2015).

Sanchis-Gual, N., Montero, P. et al. (incl. E. Müller): Comparison between the fCCZ4 and BSSN formulations of Einstein equations in spherical polar coordinates. Journal of Physics: Conference Series, 600: 012058, 1-6 (2015).

Sunyaev, R. A., and R. and Khatri: Unavoidable CMB spectral features and blackbody photosphere of our universe. In: Proceedings of the MG13 Meeting on General Relativity. R. T. Jantzen, and K. Rosquist (Eds.) Singapore [u.a.]: World Scientific. pp. 373-397 (2015).

Suwa, Y., Yokozawa, T., et al. (incl. E. Müller): What can we learn from gravitational waves from nearby core-collapse supernovae? Journal of Physics: Conference Series, 600: 012009, 1-6 (2015).

Torres, S., García-Berro, E., Althaus, L. G., and M. Miller Bertolami: A population synthesis study of the white dwarf cooling sequence of 47 Tucanae. In: P. Dufour, P. Bergeron, and G. Fontaine (Eds.), 19th European Workshop on White Dwarfs, pp. 379-384 (2015).

Travaglio, C., Gallino, R., et al. (incl. W. Hillebrandt): The key role of SNIa at different metallicities for galactic chemical evolution of p-nuclei. In: XIII Nuclei in the Cosmos - NIC XIII pp. 1-6 (2015).

Vacca, V., Oppermann, N., T. Enßlin, et al.: Statistical methods for the analysis of rotation measure grids in large scale structures in the SKA era. In: Advancing Astrophysics with the Square Kilometre Array - AASKA14, pp. 1-9 (2015).

Zámečníková, M., Augustovičová, L., Kraemer, W. P., and P. Soldán: Formation of molecular ion LiHe+ by radiative association of metastable helium He(23P) with lithium ions. Journal of Physics: Conference Series, 635: 022038, 1-1, (2015).

3.2.2 Publications available as electronic file only

Marti, J.M., Müller, E.:Grid-based methods in relativistic hydrodynamics and magnetohydrodynamics. <http://computas trophys.livingreviews.org/Articles/lrca-2015-3/>
`http://computastrophys.livingreviews.org/Articles/lrca-2015-3/`

Ritter, H. and U. Kolb: Catalogue of cataclysmic binaries, low-mass X-ray binaries and related objects (Edition 7.23). `http://www.mpa-garching.mpg.de/RKcat/`
`http://physics.open.ac.uk/RKcat/`
`http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=B/cb`
`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=B/cb`

3.3 Talks

3.3.1 Invited review talks at international meetings

E. Churazov: – Probing the Universe in Depth and Detail with the X-Ray Surveyor (Washington, 06.10-08.10)
– The Physics of Supermassive Black Hole Formation and Feedback (Annapolis, 12.10-14.10).

B. Ciardi: – Accurate astrophysics. Correct cosmology (London, UK, 13.7.-16.7)
– Reionization: A Multi-wavelength Approach (Kruger Park, South Africa, 1.6.-5.6.)

G. Di Bernardo: – Transport of electron cosmic rays in the turbulent galactic magnetic fields.
– Cosmic Ray Anisotropies, Physik Zentrum (Bad Honnef, 26.1.-30.1.)

T.A. Enßlin: – Deutschen Physikalischen Gesellschaft (Wuppertal, 12.3.)
– Matter and Universe (Jülich, 13.9.) – Rencontre de Blois (Blois, 31.5.)
– High-energy Astroparticle Physics Dark Matter Conference (Karlsruhe, 21.9.)

M. Gilfanov: – Workshop on Relativistic Astrophysics (Turku, 17.8.–21.8.)
– Radiation mechanisms of astrophysical objects (St.-Petersburg, 21.09.-25.9.)
– Space Science: Yesterday, Today and Tomorrow (Moscow, 30.9.–2.10.)

J. Guilet: – Ringberg workshop “The Magneto–Rotational Instability Confronts Observations” (Tegernsee, 134.–17.4.) – SF2A conference (Toulouse 26.–5.6.)

H.-Th. Janka: – Workshop on Binary Neutron Star Mergers (27.5.–29.5.)
– F.O.E. Fifty-One Erg (Raleigh, 1.6.–5.6.)
– Neutrino Astrophysics and Fundamental Properties (Seattle, 21.6.–26.6.)
– The many Faces of Neutron Stars (7.9.–18.9.)

G. Kauffmann: – Baryons at low densities: the stellar halos around galaxies, (ESO Garching, 23.2.–27.2.) – Rainbows on the Southern Sky: science and legacy value of the ESO Public Surveys and Large Programmes, (ESO Garching, 5.10.–9.10.)

E. Komatsu: – Annual Meeting of German Physical Society (Berlin, 15.3.-20.3)
– Annual Meeting of Astronomical Society of Japan (Osaka, Japan, 18.3.-21.3.)
– General Relativity and Gravitation: A Centennial Perspective (Pennsylvania, USA, 7.6.-12.6.)
– B-mode from Space (Tokyo, Japan, 10.12.-16.12.)

E. Müller: – Assymetries and instabilities in core collapse supernovae,
12th School on Nuclear Astrophysics, (Russbach, Austria, 9.3.-11.3.)

Th. Naab: – A 3D View on Galaxy Evolution: from Statistics to Physics (Heidelberg, 5.7.-9.7.)
– Zwicky workshop 2015 (Braunwald, Switzerland, 31.8.-4.9.)

H. Spruit: – Transitional Pulsars (International Space Science Institut, Bern, 2.3-5.3.)
– The Zoo of Accreting Compact Objects (Lorentz Center Leiden, 2.8.-5.8.)
– Solar convection, (Tata Institute for Fundamental Research, Mumbai, 7.12-12.12.)

Y. Suwa: – Fifth International Conference on Nuclear Fragmentation (Kemer, 4.10-11.10)

S. Vegetti: – MPA-MPE science day (Garching, 16.7.)
– Assembley and Fall Meeting of the Astronomische Gesellschaft 2015 (Keil, 14.9.–18.9.)
– Workshop on Astrophysics of dark matter (Tokyo, 13.10.–16.10.)

S. White: – The Olympian Symposium 2015 Cosmology and the Epoch of Reionization (Mount Olympus, Greece, 17.5.-22.5.)
– Cosmic Microwave Background Conference, (Princeton University, 10.6.-12.6.)
– Scales in the Cosmic Clustering of Dark and Baryonic Matter (IAU, Hawaii, 12.8.)
– The gas content of dark halos as revealed by Planck (IAU, Hawaii, 13.8)
– The gas content of dark halos (GPE, Cambridge, U.K. 3.9.)
– RAS London, Cluster Cosmology Meeting (London, U.K., 1.12.)

S. Zhukovska: – Nice AGB workshop 2015 (Nice, 7.5)

3.3.2 Invited Colloquia talks

E. Churazov: – CfA, 15.04. – Univ. of Wisconsin, 22.04. – Univ. of Chicago, 24.04.
– GSFC, Greenbelt, 9.10. – ESOC, Darmstadt, 4.11. – USM, Munich, 18.11.

B. Ciardi: – Trieste Observatory, Trieste; 21.1.

T.A. Enßlin: – University Heidelberg; 13.1.) – Physics Department, University Bonn; 23.1.
– Argelander Institute for Astronomy, University Bonn; 13.3.
– Canadian Institute for Astrophysics, Toronto; 23.3.
– Wuppertal University; 13.7. – Dortmund University; 14.7.
– University of British Colombia, Vancouver; 26.8.
– DESY Hamburg; 13.10. – DESY Zeuthen; 14.10. – DESY Zeuthen; 15.10.
– Gesellschaft für Schwerionenforschung, Darmstad; 20.10.
– Freiburg University; 2.11. – Tübingen University; 4.11.
– Oskar Klein Centre, Stockholm; 24.11.
– Brain Electrical Source Analysis Company, Gräfelfing; 10.12.
– Physics department, Technical University Munich; 7.12.

J. Guilet: – Seminar in Princeton University, 20.02.
– Seminar in Paris-Meudon Observatory, 26.11.

H.-Th. Janka: – Univ. Bremen; 3.3.

O. Just: - Binary Neutron Star Workshop, Thessaloniki (Greece, 28.5.)
- MICRA Workshop, Stockholm (Sweden, 17.8.)
- CoCoNuT Workshop, Malaga (Spain); 19.11.

G. Kauffmann: – Geneva Observatory; 12.5. – Laboratoire d'Astrophysique de Marseille; 1.6.
– Paco Yndurain Colloquium (Universidad Autonoma de Madrid; 20.10.

E. Komatsu: – Columbia Univ. 9.2. – Univ. of Edinburgh; 27.2. – Univ. of Leipzig; 14.4.
– Univ. of Groningen; 20.4. – MPI für Radioastronomie; 16.10. – Univ. of Utrecht; 4.11.
– Instituto de Astrofisica de Canarias; 12.11.

V. Prat: Annual meeting of the French Society of Astron. and Astrophys. (Toulouse, 4.6.)

C. Spiniello: – The XLENS Project: Constrain the Initial Mass Function and the Luminous and Dark Matter distribution in massive ETGs (Tenerife, Spain, 22.6.-24.6.)
– The XLENS Survey - Workshop at Space Telescope Science Institute, Baltimore, USA, 26.6.-1.7.

H. Spruit: MPI für Sonnensystemforschung, (Göttingen, 20.5.) – Indian Institute for Astrophysics (Bangalore, 1.12.) – Interuniversity Center for Astrophysics (Pune, 3.12.)

S. Vegetti: – IfA, University of Edinburgh, 16.6. – ICG, University of Portsmouth, 26.6.

S. White: – Colloquia Göttingen (10.4.) – Colloquia Heidelberg (21.4.)
– Colloquia MPQ, Garching (28.4.)

S. Zhukovska: – Invited Institutsseminar IFK (Friedrich Schiller Univ. Jena)

3.3.3 Public talks

Y. Bahe: Lange Nacht der Wissenschaften (MPA, Garching 27.6.)

G. Börner: Schultheater der Länder (Dresden 23.9.)
– Urania Graz (Graz 10.11.) – Naturkunde Museum Ulm (Ulm 25.11.)

T.A. Enßlin: Lange Nacht der Wissenschaften (MPA, Garching 27.6.)
– Astronomietage (Münster; 16.10.) – Experimenta (Heilbronn; 3.11.)
– 100 Jahre Allgemeine Relativitätstheorie: Einstein Symposium (Zürich, 13.11.)

M. Gilfanov: Max-Planck-Institute for Astrophysics (27.05.) – Kazan Federal University (8.10.)

H.-Th. Janka: Planetarium Nürnberg (Nürnberg, 24.2.)
– Bremer Haus der Wissenschaften (Bremen, 3.3.)
– Lehrerfortbildung "Sternentwicklung", Bildungsausschuss der AG (Garching, 6.3.)
– International Supercomputing Conference (Frankfurt, 14.7.)
– Lehrerfortbildung DFG-Transregio CRC 110 (Garching, 6.11.)
– 100 Jahre Allgemeine Relativitätstheorie, Einstein Symposium (Zürch, 14.11.)
– 1915 - 2015 Einsteins Gravitation, 100 Jahre Allgemeine Relativitätstheorie (München, 23.11.)

E. Komatsu: Elitenetzwerk FORUM (LMU; 26.1.)
– Simons Lecture, Simons Foundation (New York, USA; 11.2.)
– Japan Society of Promotion of Science Abend (Bonn; 2.9.)
– Taisha Junior High School (Hyogo, Japan; 30.11.)
– Yamaguchi Junior High School (Hyogo, Japan; 1.12.)
– Hitachi Civic Center (Ibaraki, Japan; 9.12.)

E. Müller: ESO further training for high-school teacher (Garching 6.3.)
– Volkshochschule (Garching 24.3.) – Science Night (Garching 27.6.)
– Gymnasium Beilgries (Garching 30.9.) – TUM (Garching 25.11.)
– Deutsches Museum (München 25.11.)

T. Naab: Lange Nacht der Wissenschaften (MPA, Garching 27.6.)

F. Schmidt: Lange Nacht der Wissenschaften (MPA, Garching 27.6.)
– "Cafe und Kosmos", (München, 15.9.)

3.4 Lectures and lecture courses

3.4.1 Lectures at LMU and TUM

T. A. Enßlin, SS 2015, LMU München

W. Hillebrandt, WS 2014/2015, TU München

H.-Thomas Janka, WS 2014/2015 and SS 2015, TU München

E. Müller, WS 2014/2015 and SS 2015, TU München

H. Ritter, SS 2015, LMU München, WS 15/16, LMU München

A. Weiss, SS 2015 and WS 2015/15, LMU München

3.4.2 Short lecture courses

G. Kauffmann: “Structure and galaxy formation” (IMPRS on Astrophysics, Garching, 30.11.–7.12.)

E. Komatsu: “Cosmic Microwave Background” (IMPRS on Astrophysics, Garching, 19.1.–23.1.)

4 Personnel

4.1 Scientific staff members

Directors

E. Komatsu (Managing Director), G. Kauffmann, R. Sunyaev, S.D.M. White.

Research Group Leaders

E. Churazov, B. Ciardi, T. Enßlin, M. Gilfanov, H.-Th. Janka, T. Naab, E. Müller. S. Vegetti.

External Scientific Members

M. Asplund, R. Giacconi, R.-P. Kudritzki, W. Tscharnuter.

Emeriti

H. Billing, W. Hillebrandt, R. Kippenhahn, F. Meyer, E. Trefftz.

Staff/Postdoc

N. Amorisco (since 1.10.), M. Anderson, Y. Bahe, A. Barreira (since 1.10.), S. Campbell (since 1.9.), G. Di Bernardo, A. Ford (until 30.4.), M. Gabler, M. Gaspari (unitl 30.9.), E. Gatuzz (since 22.9.), P. Girichidis, F.A. Gomez, F. Guglielmetti (since 1.12.), J. Guilet, H. Hämmerle, K. Helgason, B. Henriques (unitl 31.8.), S. Hilbert, A. Jones, O. Just, R. Khatri (until 31.7.), Jaiseung Kim (until 31.5.), A. Kolodzig (1.5.-30.9.) D. Kruijssen (until 31.8.), N. Lyskova, M. Miller-Bertolami (unitl 30.6.), S. Mineo (until 17.7.), A. Monachesi, P. Montero (until 31.12.), D. Nelson (since 1.11.), M. Nielsen, U. Nöbauer, L. Oser (until 31.12.), A. Pawlik (until 11.1.), Th. Peters, V. Prat (until 31.10.), M. Reinecke, S. Roychowdhury (until 31.12.), F. Schmidt, X. Shi, C. Spiniello, A. Summa, X.P. Tang (since 28.9.), S. Taubenberger, V. Vacca (until 30.9.) S. Vegetti, M. Viallet, J. von Groote (until 31.8.), C. Wagner (until 31.12.), A. Weiss, W. Zhang (since 5.10.).

Ph.D. Students

[1] A. Agrawal*, R. Andrassy* (until 31.8.), H. Andresen*, V. Böhm*, R. Bollig, A. Boyle* (since 1.9.), M. Bugli*, Ph. Busch* (since 1.9.), H.L. Chen, C.T. Chiang (until 31.8.), A. Chung*, D. D'Souza*, R. D'Souza*, S. Dorn (until 31.12.), M. Eide* (since 1.9.), T. Ertl, M. Frigo* (since 1.8.), A. Gatto*, M. Greiner, W. Hao*, N. Hariharan* (until 30.9.), S. Heigl* (until 31.5./terminated), C.H. Hu*, M.L. Huang (until 31.10.), H.Y. Ip*, I. Jee, A. Jendreieck (30.6.), S. Jia, K. Kakiichi*, A. Klitsch* (since 1.11.), F. Koliopanos* (until 30.6.), A. Kolodzig* (until 30.4.), S. Komarov*, T. Lazeyras, Q. Ma, T. Melson, M. Molaro*, A. Pardi*, E. Pllumbi* (until 31.12.), B. Röttgers, M. Rybak*, M. Sasdelli* (until 30.6.), A. Schmidt (since 1.11.), M. Selig (until 28.2.), M. Soraism*, T. Steininger (since 1.4.), J. Stücker* (since 19.10.), T. Vasallo (1.8.-13.11./terminated) (D. Vrbanec*, G. Wagstaff*, T. Woods* (until 30.6.), Luo Yu.

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[1] *IMPRS Ph.D. Students

Master students

R. Glas (since 1.4.), M. Glatzle (since 12.10.), J. Knollmüller (since 12.10.) R. Leike (since 5.10.), A. Peterson (1.1.-31.8.), N. Schwarz (until 30.4.), M. Straccia (since 1.12.), C. Vogl (since 1.5.).

Technical staff

Computational Support: H.-A. Arnolds (head of the computational support), B. Christandl, H.-W. Paulsen , A. Weiss.

Secretaries: M. Depner, J. Dreher (until 31.3.), S. Gründl, G. Kratschmann, C. Rickl (secretary of the management), S. Veith (since 1.5.).
Library: C. Bartels (head of the library), E. Blank.

Associated Scientists:

U. Anzer, G. Börner, G. Diercksen, W. Kraemer, E. Meyer–Hofmeister, H. Ritter, J. Schäfer, H. Spruit, R. Wegmann.

4.1.1 Staff news

Eiichiro Komatsu received the “Chushiro Hayashi Prize” of Astronomical Society of Japan during its annual meeting in March.

Eiichiro Komatsu elected Fellow of American Physical Society.

Fabian Schmidt received an ERC Starting Grant.

Rashid Sunyaev received the Zel’dovich Gold Medal of the Russian Academy of Sciences.

Rashid Sunyaev receivede the Eddington Medal from the Royal Astronomical Society.

Simona Vegetti started her own junior research group at MPA.

Simon White has been elected as a Foreign Member to the Chinese Academy of Sciences.

4.2 PhD Thesis 2015 and Diploma thesis 2015

4.2.1 Ph.D. theses 2015

Robert Andrassy: Convective overshooting in stars. University of Amsterdam.

Chi-Ting, Chiang: Position-dependent power spectrum: a new observable in the large-scale structure. Ludwig-Maximilians-Universität München.

Sebastian Dorn: Non-Gaussianity and inflationary models. Ludwig-Maximilians-Universität München (submitted).

Nitya Hariharan: Numerical Developments of the Radiative Transfer code CRASH. Ludwig-Maximilians-Universität München.

Mei-Ling Huang: Spatially-resolved star formation histories and molecular gas depletion time of nearby galaxies. Ludwig-Maximilians-Universität München.

Filippos Koliopanos: X-ray diagnostics of ultra compact X-ray binaries. Ludwig-Maximilians-Universität München.

Alexander Kolodzig: Large-scale structure studies using AGN in X-ray surveys – Challenges from XBOOTES and prospects for eROSITA. Ludwig-Maximilians-Universität München.

Else Pllumbi: Aspects of nucleosynthesis in core-collapse supernovae. Technische Universität München.

Michele Sasdelli: Principal Components Analysis of type Ia supernova spectra. Ludwig-Maximilians-Universität München.

Marco Selig: Information theory based high energy photon imaging Ludwig-Maximilians-Universität München.

Tyrone Woods: Emission line diagnostics of the progenitors of type Ia supernovae. Ludwig-Maximilians-Universität München.

4.2.2 Master theses 2015

Daniel Pumpe: Information field theory for gravitational wave analysis. Technische Universität München.

Nicole Schwarz: Long-Time Evolution of Neutron Star Merger. Technische Universität München.

Santiago Varona: Formation of naked singularities in Tolman-Bondi spacetimes. Technische Universität München.

4.2.3 PhD Thesis (work being undertaken)

Aniket Agrawal: An Analytical Model for Redshift Space Distortions. Ludwig-Maximilians-Universität München.

Haakon Andresen: Gravitational waves from core collapse supernova. Ludwig-Maximilians-Universität München.

Ricard Ardevol: Nucleosynthesis in Neutron Star-Neutron Star and Black Hole-Neutron Star mergers. Technische Universität München.

Vanessa Böhm: Gravitational Lensing of the Cosmic Microwave Background: Reconstruction of Deflection Potential and unlensed Temperature Map using Information Field Theory. Ludwig-Maximilians-Universität München.

Robert Bollig: Long term cooling studies of proto-neutronstars with full neutrino flavour treatment and muonisation. Technische Universität München.

Aoife Boyle: Constraining neutrino masses from large scale structure. Ludwig-Maximilians-Universität München.

Matteo Bugli: Study of viscous accretion disks around Kerr black holes. Technische Universität München.

Philipp Busch: Topology of large scale structures. Ludwig-Maximilians-Universität München.

Andrew Chung: High-redshift Lyman-α945; Emitters. Ludwig-Maximilians-Universität München.

Durand D'Souza: Radiative levitation and other processes in massive stars. Ludwig-Maximilians-Universität München.

Richard D'Souza: Stellar Halos of Galaxies. Ludwig-Maximilians-Universität München.

Marius Berge Eide: IGM Reionization. Ludwig-Maximilians-Universität München.

Maximilian Eisenreich: The wondrous multi-phase ISM of elliptical galaxies. Ludwig-Maximilians-Universität München.

Thomas Ertl: Progenitor-remnant connection of core-collapse supernovae. Technische Universität München.

Matteo Frigo: Confronting theory with observations: Which physical processes determine the stellar and gas-dynamical evolution of galaxies. Ludwig-Maximilians-Universität München.

Sebastian Dorn: Non-Gaussianity and inflationary models. Technische Universität München.

Andrea Gatto: The impact of stellar feedback on the formation and evolution of molecular clouds. Ludwig-Maximilians-Universität München.

Mahsa Ghaempanah: Information field theory for INTEGRAL gamma ray data. Ludwig-Maximilians-Universität München.

Maksim Greiner: Galactic tomography. Ludwig-Maximilians-Universität München.

Wei Hao: Supermassive black hole binaries in Galaxy centres. Ludwig-Maximilians-Universität München.

Chia-Yu, Hu: A new star formation recipe for large-scale SPH simulations. Ludwig-Maximilians-Universität München.

Hiu Yan Sam Ip: Testing Gravity with Large-Scale Structure. Ludwig-Maximilians-Universität München.

Inh Jee: Measuring angular diameter distances of strong gravitational lenses. Ludwig-Maximilians-Universität München.

Andressa Jendreieck: Stellar Parameter Estimation for Kepler Stars. Ludwig-Maximilians-Universität München.

Anne Klitsch: Chemical evolution of galaxies in hydrodynamical simulations. Ludwig-Maximilians-Universität München.

Kakiichi Koki: The high redshift universe: galaxy formation and the IGM. Ludwig-Maximilians-Universität München.

Sergey Komarov: Physics of Intracluster Medium. Ludwig-Maximilians-Universität München.

Titouan Lazeyras: Investigations into galaxy and halo bias. Ludwig-Maximilians-Universität München.

Tobias Melson: Implementation of a two-moment closure scheme for neutrino transport into the Yin-Yang grid environment for three-dimensional simulations of core-collapse supernovae with the Prometheus-Vertex code. Technische Universität München.

Margherita Molaro: X-ray binaries' contribution to the Galactic ridge X-ray emission. Ludwig-Maximilians-Universität München.

Anabele Pardi: The Dynamics and Evolution of the Interstellar Medium Ludwig-Maximilians-Universität München.

Bernhard Röttgers: AGN feedback in cosmological simulations and the comparison to observations. Ludwig-Maximilians-Universität München.

Andreas Schmidt: Simulation of the large-scale Lyman-alpha forest. Ludwig-Maximilians-Universität München.

Li Shao: Understanding the connection between AGNs and their host galaxies. Ludwig-Maximilians-Universität München.

Shi Shao: Disk dynamics in live halos. NAOC, China

Monika Soraism: Progenitors of Type Ia Supernovae. Ludwig-Maximilians-Universität München.

Theo Steininger: Reconstruction of the Galactic magnetic field. Ludwig-Maximilians-Universität München.

Jens Stücker: The Phase Space Structure of Dark Matter Haloes. Ludwig-Maximilians-Universität München.

Dijana Vrbanec: Cross-correlation of Lyman Alpha Emitters & 21-cm signal from the Epoch of Reionization. Ludwig-Maximilians-Universität München.

Graham Wagstaff: Structure of coolster envelopes and atmospheres. Ludwig-Maximilians-Universität München.

4.3 Visiting scientists

Name	home institution	Duration of stay at MPA
Isabelle Baraffe	(Exeter Univ.)	6.7.–4.8.
Andrey K. Belyaev	(Herzen Univ., St.Petersburg, Russia)	15.11.–14.12.
Ilfan Bikmaev	(Kazan Univ.)	1.11.–15.11.
Sergei Blinnikov	(ITEP, Moscow)	7.6.–21.6.
Gilles Chabrier	(Exeter Univ.)	6.7.–31.7.
Yanmei Chen	(Nanjing Univ.)	8.7.–30.8.
Scott Clay	(Univ. of Sussex)	12.1.–13.4.
Adrian Bittner	(bachelor student)	13.4.–15.7.
Jon Braithwaite	(Uni Bonn)	23.8.–20.9.
Tiziana di Matteo	(Carnegie Mellon Univ.)	12.07.–25.07.
Ryan Endsley	(DAAD student)	since 1.10.
Bill Forman	(Harvard Univ.)	11.6.–22.6.
Michael Fruehauf	(bachelor student)	15.4.–15.7.
Ilkham Galiullin	(Kazan Univ.)	1.11.–15.11.
Benjamin Harmsen	(Michigan Univ.)	14.6.–28.6.
Petr Heinzel	(Ondrejov Univ.)	5.11.–8.12.
Michaela Hirschmann	(IAP, France)	22.11.–5.12.
Dragan Huterer	(Univ. of Michigan)	02.01.–31.08.
Nail Inogamov	(IKI, Moscow)	13.7.–16.8.
Emille Ishida	(Sao Paulo, Brazil)	until 31.12.
Anatoli Iyudin	(Moscow State Univ. Russia)	19.10.–30.10.
Donghui Jeong	(Penn State Univ.)	12.06.–12.08.
Ildar Khabibullin	(IKI Moscow)	4.2.–15.3. and 29.6.–19.8. and 1.11.–6.12.
Matthias Kober	(Werkstudent)	1.8.-15.9.
Christina Kreisch	(Washington Univ. in St. Lois) since 1.10.	
Chervine Laporte	(Columbia Univ.)	28.2–4.4.
Yu Luo	(PMO, Nanjing, China)	until 15.4.
Paolo Mazzali	(Liverpool Univ.)	15.9.30.10.
Vassilios Mewes	(Univ. Valencia)	5.1–27.2.
Ilya Mereminskiy	(IKI Moscow)	1.11.–6.12.
Marcelo Miller Bertolami	(La Plata Univ., Argentina)	12.10.–15.12.
Bernhard Müller	(Monash Univ.)	15.6.–26.6.
Nicolas Maffione	(FCAGLP, de La Plata, Argentina)	1.10.–22.12.
Jessica Muir	(Univ. of Michigan)	7.7.–7.8.
Marcello Musso	niv. of Pennsylvania)	nce 29.6.

Name	home institution	Duration of stay at MPA
Daisuke Nagai	(Yale Univ.)	24.05.–25.07.
Igor V. Ovchinnikov	(Univ. of California/Los Angeles)	15.7.–5.8.
Natalia Porqueres	(DAAD student)	1.7.–30.8.
Mika Rafieferantsoa	(South Africa Astron. Observ.)	since 1.12.
Tokuei Sako	(Nihon Univ.)	5.8.–9.9.
Sergey Sazonov	(IKI Moscow)	29.6.–29.7.
Daniel Shafer	(Univ. of Michigan)	17.7.–18.8.
Nikolai Shakura	(IKI Moscow)	31.10.–1.12.
Alexey Tolstov	(IPMU Tokyo Japan)	25.7.–12.8.
Regner Trampedach	(Colorado Univ.)	2.2.–12.2.
Grigorii Uskov	(Kazan Univ.)	1.11.-15.11.
Victor Utrobin	(ITEP Moscow Russia)	15.10.–15.12. and 15.10.–15.12.
Stan Woosley	(Ucolick Obs.)	21.6.–8.7.
Svetlana Yakovleva	(St. Petersburg, Russia)	23.11.–6.12.
Mijin Yoon	(University of Michigan)	03.03.–30.06.
Lev Yungelson	(IKI Moscow)	2.11.–30.11.
Zhongli Zhang	(Univ. of Tokyo)	7.6.–4.12.
Irina Zhuravleva	(Stanford Univ.)	13.6.–27.6.