MUNICH INSTITUTE FOR ASTRO- AND PARTICLE PHYSICS

2016 - 2017

TUM
LMU
Excellence Cluster
Universe

MIAPP
Munich Institute for
Astro- and Particle Physics

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Directors' Foreword

The Munich Institute for Astro- and Particle Physics (MIAPP) serves as a meeting place for theorists and experimentalists from astrophysics, cosmology, nuclear- and particle physics. Since its foundation in 2012 more than a thousand scientists were able to profit from the atmosphere of creative freedom away from their daily duties.

At MIAPP science is dedicated to the mysteries of the Universe. Its parent institution, the Excellence Cluster “Origin and Structure of the Universe” has become one of the largest and most vivid centres to study physics from the smallest to the largest scales in the Universe. Since its foundation in 2006 the Cluster successfully joins physicists from very diverse fields of expertise coming from the local partner institutions, the Technical University of Munich, the Ludwig-Maximilians-University Munich, the Max Planck Institutes for Physics, Astrophysics, Extraterrestrial Physics and Plasma Physics and the European Southern Observatory. In order to enhance and further increase the interaction among the local scientists but especially to promote exchange with international researchers, MIAPP was founded in 2012.

This centre for scientific exchange, located on the Garching Research Campus, provides scientists from abroad, Germany and the local physics institutes with a place to meet, focus on their research and to foster collaborations and new scientific discoveries. It’s here where young researchers, like PhD students and postdocs, get the chance to tackle open questions in collaboration with world-famous experts and to profit from their knowledge. The cutting edge topics of the six annual four-week programmes are selected by the MIAPP advisory committees. We are especially grateful for the time and effort our advisory board and programme committee members invest in choosing the programmes among the proposals from scientists around the world.

MIAPP is generously funded by the Deutsche Forschungsgemeinschaft through the excellence initiative which allows us to financially support participants from abroad. It’s this support that allows participants to stay for the required period of two to four weeks. Having an amazing time at MIAPP adds to the reputation of Munich and Garching in the scientific world when the participants spread the word among their fellow researchers all over the world.

We are encouraged by the overwhelming response and enthusiasm of everyone involved in MIAPP, making it the success it became. We, therefore, look especially forward to continue MIAPP in the context of the ORIGINS cluster that will allow us to broaden the scope of MIAPP and to involve other disciplines such as biophysics. We hope that the following report can convey the dedication of the participants and the staff to their science and MIAPP.

M. Beneke
Prof. Martin Beneke

R. P. Kudritzki
Prof. Rolf Kudritzki

Andreas
Prof. Andreas Weiler
(MIAPP Directors)

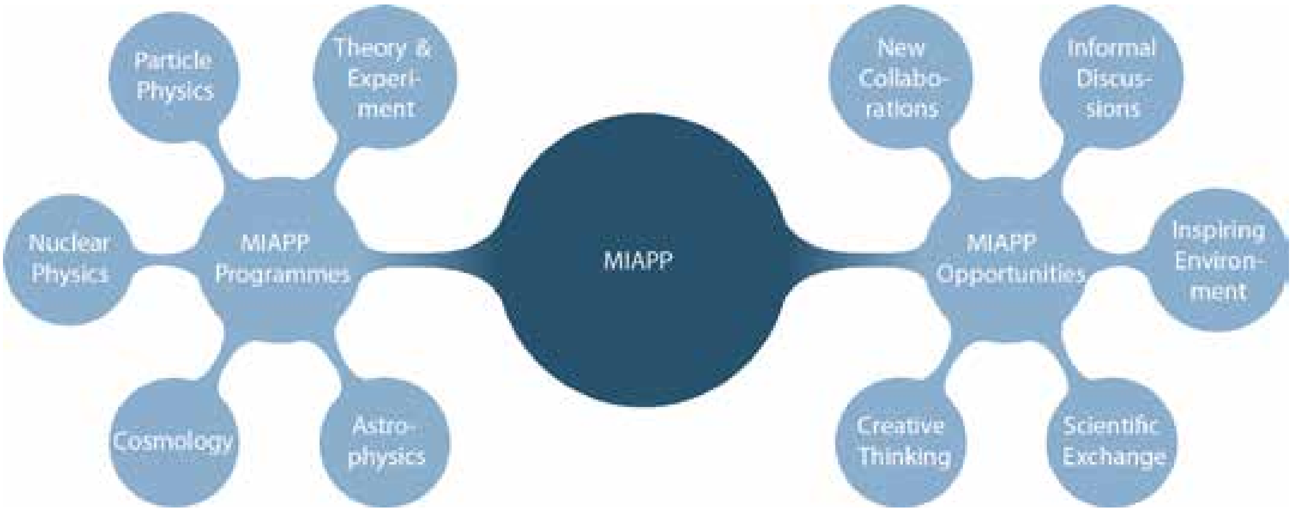
MIAPP:
A creative refuge located in the heart of Bavaria

How did the Universe evolve right after the Big Bang? How does the chemical composition of the galaxy influence the formation of stars and planets? What is the explanation for dark matter and the asymmetry of matter and antimatter? MIAPP is the ideal place to tackle these and other most pressing questions from the smallest to the largest scales within the Universe.

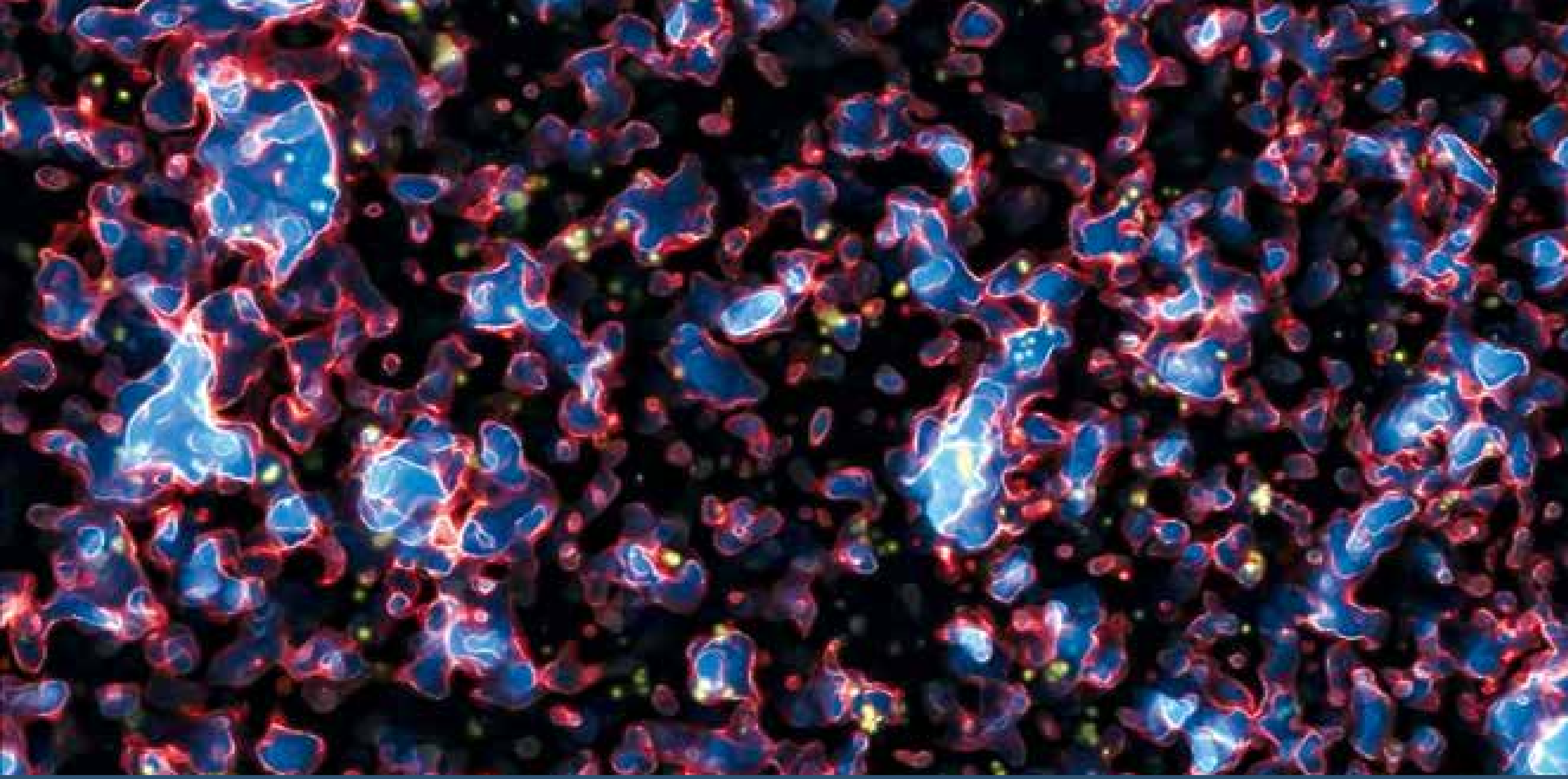
The relaxed and stimulating atmosphere at MIAPP offers an opportunity to take stock and develop ingenious ideas away from daily duties. MIAPP programmes gather international experts from very diverse fields of expertise, stimulating lively debates with different point of views. Thanks to a loose schedule with ideally only one to two talks a day (or even less), the attendees have plenty of time for science. At MIAPP we work hard to provide our visitors with the logistics and environment they need to focus on their research and to profit as much as possible from their stay in Garching. It's our goal to create a stimulating and comfortable place that allows to meet and collaborate as well as to concentrate on individual work. Within the designated MIAPP building common areas are ideal to chat with a colleague over a cup of coffee while the well-equipped offices offer the comfort and space for concentrated, individual work. White and black boards everywhere ensure that ideas and thoughts can be captured right away.

Located in the vicinity of the local physics institutions, the physics departments of the two Munich Universities, the Max Plank Institutes for Astrophysics, Extraterrestrial Physics, Plasma Physics and Physics as well as the European Southern Observatory, MIAPP offers the unique opportunity to collaborate not only with other MIAPP participants but also with local researchers from the surrounding institutes. MIAPP participants are welcomed at this special place that enables them to share their ideas and to broaden their horizons. Due to the longer time spent together the exchange of ideas reaches a deeper level of interaction and collaboration, and hence may lead to an amazingly stimulating interaction with physicists in and outside the own field of expertise.

We, the small team of MIAPP staff, together with the administration at the Excellence Cluster 'Origin and Structure of the Universe' try our best to create an inspiring environment. For us it is the highest reward if participants enjoyed their stay and leave MIAPP full of vim and vigour looking forward to their next stay at MIAPP.
Dr. Ina Haneburger *(MIAPP Programme Manager)*



MIAPP features a broad variety of topics and therefore is the ideal place to tackle up-to-date science. For its visitors MIAPP provides an environment dedicated to creative thinking, informal discussions, interaction and scientific exchange as well as the possibility to reach out for fellow researchers from all over the world which sit in the offices next-door.
Graphics: MIAPP



This still from a scientific simulation depicts the Swiss cheese-like structure of the Universe in the reionisation era. After the dark ages when neutral hydrogen gas was the main constituent of the Universe the first stars started to form. Their ultraviolet radiation ionised the cold dark gas and resulted in the conversion to translucent gas (represented by the blue and transparent areas). *Credit: M. Alvarez (http://www.cita.utoronto.ca/~malvarez), R. Kaehler, and T. Abel/ESO*

4th - 29th April 2016

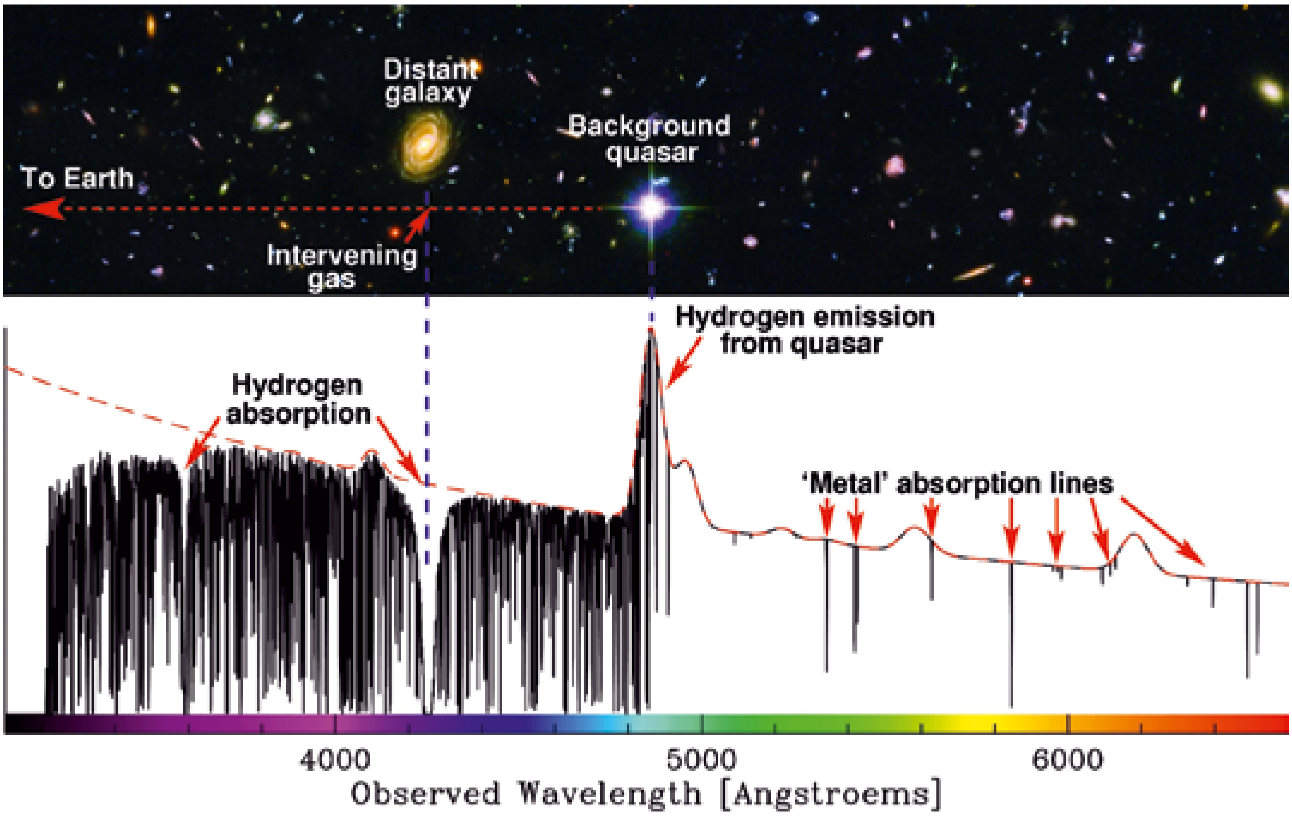
Cosmic Reionisation

Within the Epoch of Reionisation around 4.5 million years after the Big Bang important processes took place which decisively shaped the structure of the Universe observed today. During that period, in which the cosmic gas transformed from neutral to ionised, the first stars appeared, mini-galaxies formed and stellar mass black holes merged to form the seeds of enigmatic super-massive black holes. Hence, the foundation for the Universe as we know it today was lain within the reionisation period. Consequently, it is fundamental to unravel the reionisation history for understanding the early evolution of the Universe.

COORDINATORS: BENEDETTA CIARDI, MARTIN HAEHNELT, DANIEL STARK, SALEEM ZAROUBI

Several processes were important to form the Universe as it is now. About 400,000 years after the Big Bang the density of the Universe had decreased significantly due to the expansion of the Universe. Along with the spread, the Universe had cooled that much that ions and electrons were able to recombine to neutral hydrogen and helium, turning the Universe into a period of darkness. Million years later the first galaxies started to form and to “lighten up” the Universe. Emitted photons, that were only slightly more energetic than the ionisation threshold, reionised the surrounding gas by stripping electrons from the neutral atoms in the Universe. As a consequence, the intergalactic medium (IGM) had a patchy structure of alternating ionised, i.e. transparent, and neutral, i.e. opaque areas during the epoch of reionisation. This Swiss cheese-like topology lasted approximately 1 billion years until after the Big Bang.

The signatures of the cold neutral gas in the IGM can be seen in the spectra of very distant objects in the Universe such as quasars. Quasars are the very luminous centres of galaxies, where matter falls into the central black holes producing an enormous emission of light. This light then shines through the intervening intergalactic clouds of cold neutral gas, which produces spectral lines in absorption superimposed to the light of the distant quasar. Because



The redshifted "Lyman alpha forest" of a distant quasar. Hydrogen along the line of sight absorbs the redshifted emission from more distant quasars. This is visible in the observed spectra as gaps, in which quasar light is absorbed.
Credit: Michael Murphy (Swinburne University of Technology), adapted from original by John Webb (University of New South Wales).

of the expansion of the Universe the wavelengths of the absorption lines are redshifted corresponding to the individual recession velocity of each gas cloud at a different distance. Using the largest telescopes in the world in Hawaii and Chile equipped with powerful and very efficient spectrographs one can observe these spectral lines at optical and near-infrared wavelengths and analyse the degree of ionisation in these gas clouds and the chemical composition (see figure above for a detailed explanation). This provides invaluable information about the physical conditions and the chemical evolution of the Universe.

An alternative method to study the nature of cold IGM clouds is the observation of neutral hydrogen at radio wavelength using the hyperfine structure transition at a wavelength of 21 cm. Since the late 1950s it has been recognised that neutral hydrogen in the IGM may be directly detectable in emission or absorption against the cosmic microwave background (CMB) radiation at the frequency corresponding to the redshifted neutral hydrogen 21 cm line providing a direct probe of the era of cosmological reionisation. It's just now, that the first radio interferometers such as LOFAR, MWA and PAPER are delivering the first data. This will open up a completely new window to investigate the physical structure and evolution of the intergalactic medium through cosmic time.

> **"It was a very rich, stimulating and broad discussion on the topic, featuring the most recent updates on both the theoretical and observational side. Excellent and inspiring."**
>
> *(Dr. Gianni Bernardi, Square Kilometre Array, Cape Town, South Africa)*

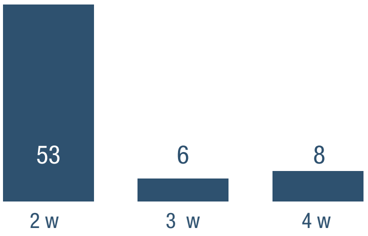
COSMIC REIONISATION

93 registrations

67 participants
from 39 institutions
in 17 different countries

academic seniority:
36 faculty/staff
14 postdocs
17 PhDs

duration of stay:



The LOFAR superterp houses six antenna stations and is part of the gigantic collection of antennas that span half of Europe. Due to its size LOFAR is able to scan frequencies that are not accessible to most other telescopes.
Copyright: SKA; Top-Foto ASSEN

As reionisation occurred many billion years ago, it can't be observed directly. Therefore, all we know and will learn has to be deduced from observations of very distant objects with light that travelled from the very early time, when these objects were formed after the Big Bang. These observations have to be combined with models and simulations of the propagation of light through a vastly inhomogeneous Universe. Questions like what is the nature of the first ionising sources, were the first stars much more massive and therefore much hotter than the stars of today and many others are relevant to understand the evolution of the Universe. The first MIAPP programme 2016 took place just at the right time to discuss many hot topics related to these questions. The new observations of the Cosmic Microwave Background just obtained with the Planck satellite telescope, which among other things had revealed a reduced electron density of the Universe at the time when it became neutral,

"The dialogue between theorists and observers was invaluable to help the two communities being on the same page about recent developments in each branch and current and future limitations and forefronts."
(Dr. Alireza Rahmati, University of Zurich, Switzerland)

Cosmic Reionisation participants discussing in the MIAPP living room. *Credit: Haneburger / MIAPP* stimulated an extensive discussion with a lot of consequences for the existing models. The impact of these new data on the reionisation history was discussed throughout the MIAPP programme. Furthermore, the first result of the neutral hydrogen 21 cm experiments PAPER, LOFAR and MWA were at the centre of the discussion at MIAPP. In addition, the discrepancy of the evolution of bright and faint Lyman-alpha emitters observed at optical wavelengths and how this influences the current understanding of the evolution of the neutral fraction of hydrogen was intensively discussed. The difficulty to cross-correlate results from 21 cm and optical data became apparent and resolving this puzzle was identified as a future priority. On the theory side, the possible escape of ionising radiation from galaxies and cosmological radiative transfer simulations as the key ingredients to analyse the data were critically discussed.

The programme was an excellent opportunity to take stock where the field stands and to define new research directions in preparation for the era of new telescopes like the James Webb Space Telescope (JWST), the Square Kilometre Array in Australia and South Africa (SKA), the Thirty Meter Telescope (TMT) in Hawaii and the European Extremely Large Telescope. Following some recurrent questions, a special session has been set up to discuss the effectiveness of Ly α photons in heating the intergalactic gas. In fact different authors, most of them were attending the programme, had published different results. The session turned out to be extremely useful to answer the question and reach a common agreement, thus, providing a very instructive example how effective the MIAPP format is to settle important scientific questions.

> **“This was one of the most productive meetings I have ever attended. It had all elements to boost collaborative work and avoid rapid saturation with talks which is commonplace in most places. I strongly think that MIAPP should hold such meetings often.”**
> *(Saurabh Singh, Raman Research Institute, Bangalore, India)*

COORDINATORS OF THE PROGRAMME: “COSMIC REIONISATION”


Photo: Schürmann

DR. BENEDETTA CIARDI

Max Planck Institute for
Astrophysics, Garching,
GERMANY

- Early structure formation and feedback effects
- Reionisation of the IGM
- Radiative transfer
- Observational probes
- 21 cm line from neutral hydrogen


Photo: Schürmann

PROF. MARTIN HAEHNELT

University of Cambridge,
UNITED KINGDOM

- Intergalactic medium and QSO absorption lines
- Reionisation
- Formation of galaxies and AGN
- Large scale structure

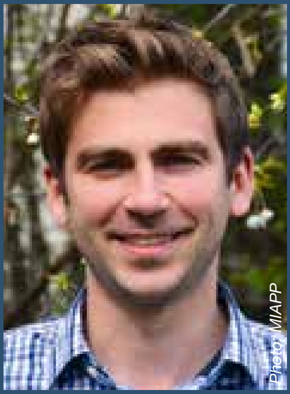


Photo: MIAPP

PROF. DANIEL STARK

University of Arizona, Tucson,
USA

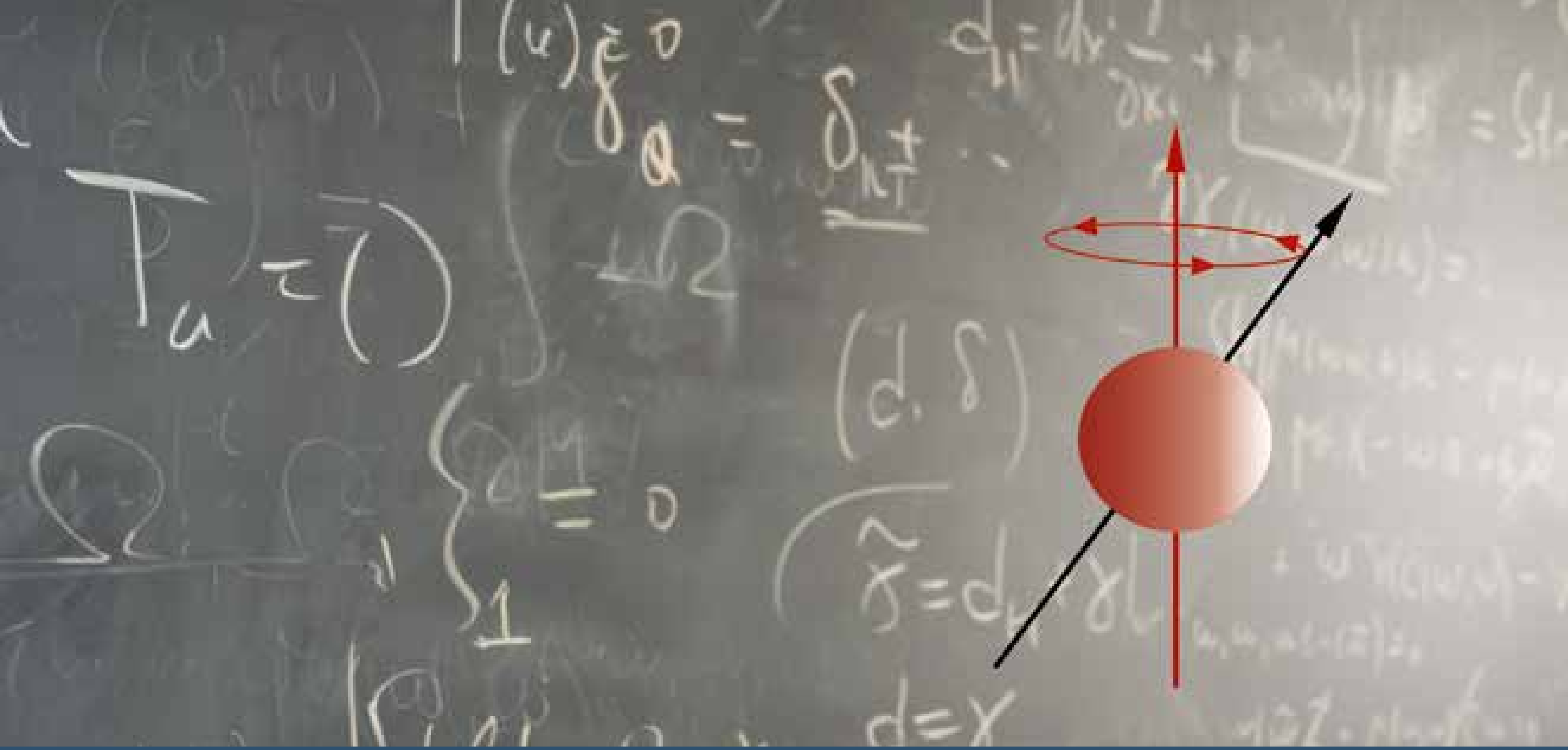
- Galaxy formation and evolution
- Reionisation of the IGM
- Low metallicity stellar populations
- Early structure formation


Photo: Schürmann

PROF. SALEEM ZAROUBI

University of Groningen,
THE NETHERLANDS

- Early structure formation in the Universe
- Probes of the large scale structure
- 21 cm cosmology
- The epoch of reionisation



The rotation of a physical object around its own axis is called spin. Elementary particles are characterised by two quantum numbers: their mass and their spin. The particles observed thus far have a spin of zero (Higgs particle), 1/2 (all fermions) or 1 (gauge bosons). In order to be able to describe gravity in an analogous way, higher-spin theories are discussed, making use of particles with a spin greater or equal to two. *Credit: Haneburger/MIAPP*

2nd - 27th May 2016

Higher Spin Theory and Duality

Elementary particles are characterised by their spin, their charges and their mass. Quantum mechanics tells us that the spin is quantised, i.e. can have discrete values. Particles therefore only have an integer spin of 0, 1/2, 1, 3/2, 2, 5/2 and so on. For example, the force carrier of electro-magnetism, the photon, is a massless spin 1 particle while the graviton, the force carrier of gravity, is a massless spin 2 particle. Surprisingly, these are presumably the only two types of massless particles in nature! Interacting massless particles of even higher spin seem to be over-constrained, and hence do not allow for interesting dynamics to happen. Recently however, a number of breakthroughs effected enormous progress. At the second programme in 2016, experts in higher-spin theories met at MIAPP to discuss the current state of the art and the possible implications for the quantum theory of gravity.

COORDINATORS: JOHANNA ERDMENGER, SIMONE GIOMBI, IGOR KLEBANOV, IVO SACHS, MIKHAIL VASILIEV

Physicists distinguish two types of angular momentum, i.e. the rotations of physical objects. An object can rotate around another object or/and can rotate around itself. This rotation around itself is called spin. Every elementary particle possesses spin. Accordingly, the motion of all elementary particles is characterised by two quantum numbers: their mass and their spin. So far, all observed particles have either spin 0 (the Higgs particle), spin ½ (all matter fields: electrons, neutrinos and quarks) or spin 1 (gauge bosons: photons, gluons, W and Z boson). All experiments on earth can be successfully described and explained with the Standard Model to impressive precision. However, one important missing piece in the Standard Model is gravity. Gravity is described by the theory of General Relativity which Einstein proposed in 1915. It predicts a new, very weakly interacting particle with spin 2: the graviton. Furthermore, since gravity propagates at the speed of light, the graviton has to be massless like the photon.

Can one go further? Is there a reason no massless particles of spin higher than 2 have been observed? In 1965, Steven Weinberg proved some very powerful theorems for ‘soft’ particles, that is particles at almost zero energy. He first showed that the existence of a massless spin 1 particle, like the photon, implies that the electric charge is conserved. If a massless spin 2 particle exists (like the graviton) its interactions have to be very simple: they must be universal! This is Einstein’s equivalence principle. Continuing this argument, one finds that the constraints on massless particles of even higher spin are too constraining: these higher spin particles might exist, but they cannot have interactions which survive the limit of low energy (that is, they cannot be responsible for long-range forces like the photon or the graviton). Weinberg’s theorem is too restrictive.

Furthermore, there is more trouble already at spin 2, which is called the “spin 2 barrier”. Gravitons at very high energies do not behave like photons. Photons interact with similar strength at all energies, gravitational interactions however become stronger at higher energies. This implies that the quantum theory of gravity requires an increasing number of terms in the equations whose coefficients have to be fixed by experiment. Consequently, more and more predictive power is lost. An extension of gravity which does not succomb to the same fate is string theory. String theory contains gravity (in ten dimensions, no less!) and predicts the existence of many new particles of higher and higher spin – corresponding to vibrational modes of the quantum string.

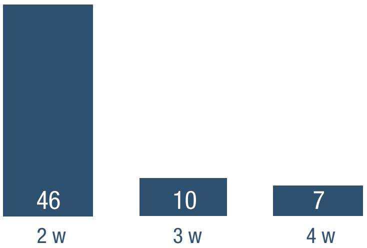
HIGHER SPIN THEORY AND DUALITY

100 registrations

63 participants
from 38 institutions
in 12 different countries

academic seniority:
42 faculty/staff
14 postdocs
7 PhDs

duration of stay:



There is now a common expectation that particles of arbitrarily high spin must be present in any theory containing a consistent quantum theory of gravity. Higher-spin theory and string theory are two candidates for such ultraviolet consistent completions. The structure of higher-spin theories is fixed by an infinite-dimensional gauge symmetry which should be valid at some ultra-high energy scale, even above the Planck mass, which makes them important as funda-

> **“To me one of the best workshops I have participated in – great conditions and excellent atmosphere due to various experts in the field.”**
> *(Slava Didenko, Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia)*

Get together of the “Higher Spin Theory and Duality” programme. Scientific exchange in a relaxed atmosphere allows to make new contacts and to develop new ideas. *Credit: Haneburger/MIAPP* mental theories. The role of higher-spin particles for consistency still remains to be understood properly.

For the development of higher spin theories and their equations many ideas came from the the Russian Academy of Science, more precisely the Lebedev Institute in Moscow. One of the leaders in this field, Mikhail Vasiliev was one of the coordinators of the programme and key to the large Russian participation in the programme. Higher-spin theories not only are a major candidate for a consistent quantum theory of gravity but also arise as dual theories in the context of anti-de Sitter/conformal field theory (AdS/CFT) correspondence. Here, the combination of anti-de Sitter spaces (AdS), applied to quantum gravity, and conformal field theories as quantum field theories play an important role in understanding the microscopic origin of this correspondence without relying on supersymmetry and extra dimensions.

Chris Brust, Igor Klebanov and Kurt Hinterbichler discussing "Aspects of Higher Spin" at the the topcial workshop of the same name, organised in the context of the programme. *Credit: MIAPP*

"It was an excellent workshop, with interesting developments in the duality between higher spin fields on AdS and CFT, in the renewed interest in considering possible interactions in the flat space limit, and in the search of possible extension of Vasiliev's equations."

(Prof. Fiorenzo Bastianelli, University of Bologna, Italy)

To illustrate the concept of a "spin" elementary particles can be imagined as spinning tops. All elementary particles of a given kind have the same magnitude of spin angular momentum, which is indicated by assigning the particle a spin quantum number. *Credit: David Earle (CC BY-SA 4.0)*

Conversely, there is a relation to three (and higher) dimensional critical phenomena. Via the AdS/CFT correspondence higher-spin theories turn out to be dual to many second-order phase transitions in three dimensions, including the famous three-dimensional Ising model, which has remained unsolvable for many decades. Higher-spin theory can lead to a better understanding of the peculiar features of these models. At present a considerable part of the research in higher-spin theories is devoted to understanding their role within the AdS/CFT correspondence, their relation to string theory and to the study of their consistency as a theory of quantum gravity. Among other results the AdS/CFT correspondence revealed that the infinite-dimensional symmetries of higher-spin theories may have a direct application to the study of second-order phase transitions. A clearer picture of the tensionless limit of string theory is starting to emerge, where the exact limit results in a large algebra of symmetries with the higher-spin symmetries playing a fundamental role. It is also evident that higher-spin symmetries may be of use in condensed matter physics, as a new tool to restrict physical observables, e.g. anomalous dimensions, which is important as the models it can be applied to have not yet been solved. There are some evidences, too, that the presence of higher-spin fields may resolve some of the puzzles in the cosmology of the early Universe. The structure of higher-spin interactions and the AdS/CFT matching was certainly one of the hot topics in presentations as well as discussions. There were intense debates about how insights from the AdS/CFT correspondence and conformal field theory may be used for constructing the higher-spin action in anti-de Sitter space.

> **“A question from the audience after my talk prompted me to write up a note on a field dependent central extension that arises in that context. It should appear soon.”**
> *(Dr. Glenn Barnich, Université Libre de Bruxelles, Brussels, Belgium)*

COORDINATORS OF THE PROGRAMME “HIGHER SPIN THEORY AND DUALITY”

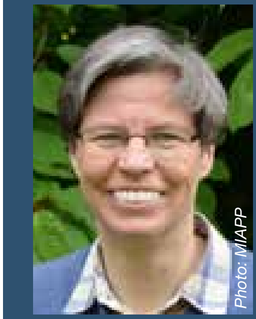


Photo: MIAPP

PROF. JOHANNA ERDMENGER

Max Planck Institute
for Physics, Munich,
GERMANY

- Quantum field theory
- Applications of AdS/CFT
- Conformal field theory
- Higher-spin dualities
- String theory


Photo: MIAPP

PROF. SIMONE GIOMBI

Princeton University,
USA

- Quantum field theory
- String theory and quantum gravity
- Higher-spin theories
- AdS/CFT correspondence


Photo: Schürmann

PROF. IGOR KLEBANOV

Princeton University,
USA

- Quantum field theory
- AdS/CFT correspondence
- Higher-spin theories


Photo: MIAPP

PROF. IVO SACHS

Ludwigs-Maximilians-
University Munich,
GERMANY

- Higher-spin theories
- Quantum field theory
- Gravity
- String theory

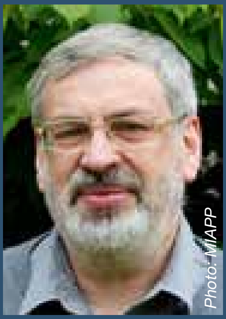
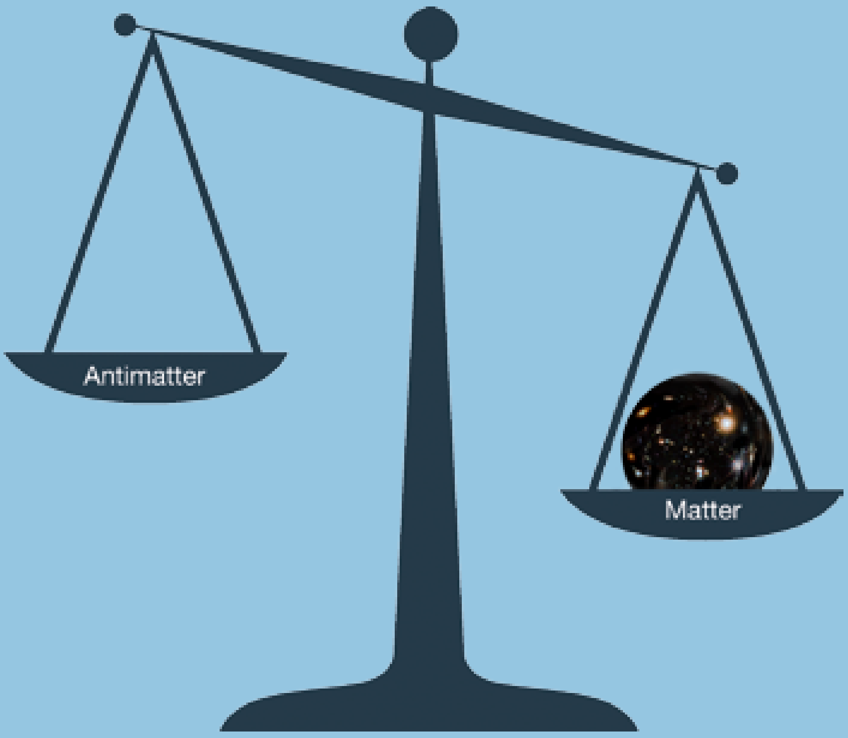


Photo: MIAPP

PROF. MIKHAIL VASILIEV

Lebedev Institute
of Physics, Moscow,
RUSSIA

- Quantum field theory
- Higher-spin theory
- AdS/CFT correspondence
- Integrable systems



If matter and antimatter had been produced to the same extent during the Big Bang, the annihilation of matter and antimatter would have led to the destruction of every form of matter. Yet, we and the matter surrounding us exist, demonstrating impressively the imbalance of matter over anti-matter, as symbolically represented in the above figure. *Credit: collage Haneburger / MIAPP; marble: NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI).*

30th May - 24th June 2016

Why is there more Matter than Antimatter in the Universe?

Why is there something rather than nothing? This question has been raised or commented on by many famous philosophers including Gottfried Wilhelm Leibniz and Ludwig Wittgenstein. The physicists at this MIAPP programme tackled a related question: Why is there more matter than antimatter? It is related to the philosophers' question because if there were equal amounts of matter and anti-matter, they would simply annihilate into radiation. In everyday life it is obvious that there is more matter than anti-matter. What does that mean for the fundamental laws of nature and the conditions in the early Universe?

COORDINATORS: MICHAEL RAMSEY-MUSOLF, BJÖRN GARBRECHT, STEPHAN HUBER, JING SHU

For each type of particle, there is an antiparticle of exactly the same mass and lifetime but opposite charge. When particles and antiparticles meet, they annihilate into radiation. Nonetheless, the visible Universe consists almost exclusively of matter, whereas anti-matter is only produced by small amounts in secondary processes and can be found in cosmic rays or in collider experiments. When considering only the present Universe, it may still be plausible that it contains regions that are dominated by anti-matter rather than matter. However, going back in time toward the Big Bang, such regions would meet the matter dominated ones leaving behind traces of violent annihilation events that we do not observe.

Moreover, the so-called inflation paradigm of cosmology predicts that the initial conditions to the Big Bang scenario are matter-antimatter symmetric. The asymmetry must therefore come about dynamically in a process called baryogenesis. Baryons contain the dominant building blocks of visible matter: the protons and neutrons which make up the core of nuclei. Amazingly, the asymmetry is precisely quantifiable by considerations of nuclear reactions and recently by the oscillations of baryons in gravitational potentials

BBQ in the MIAPP “beergarden”. These get togethers facilitate networking and allow to talk about science in a casual and relaxed atmosphere. *Credit: Jacobs / MIAPP*

shortly after the Big Bang. The corresponding observations of the chemical elements composing the primordial gas clouds and of the Cosmic Microwave Background tell us that shortly after the Big Bang, there was one excess particle per ten billion particle-antiparticle pairs that have annihilated eventually. In that sense, the asymmetry was originally very small!

> **“It is really nice for people who work on related subjects to work together. It creates a stimulating atmosphere. Thanks a lot for the organisation!”**
>
> *(Anonymus participant)*

In 1964, it was observed in decays of particles called kaons that there are phenomena that violate the matter-anti-matter asymmetry by a small amount in a subtle and inherently quantum-mechanical way. The underlying effect is referred to as CP-violation (see box on page 28). It was Sakharov who in 1966 – exactly fifty years prior to the third MIAPP programme in 2016 – realised that particle physics apparently holds the key to solving the puzzle of the cosmic asymmetry. Since then, particle physics has been striding forward, most spectacularly leading to the theoretical framework of the Standard Model of particle physics and its experimental confirmation completed by the discovery of the Higgs boson in 2012.

Sakharov’s necessary conditions for creating an asymmetry through particle physics processes are: first, violation of baryon number, second, CP violation (along with the more easily realised so-called C violation) and third, a deviation from thermal equilibrium. While the Standard Model satisfies all these criteria in principle, it became clear when the fundamental physical constants (such as couplings between particles and the mass of the Higgs boson) had been determined, that it cannot address the cosmic asymmetry quantitatively: The amount of CP violation and the deviation from

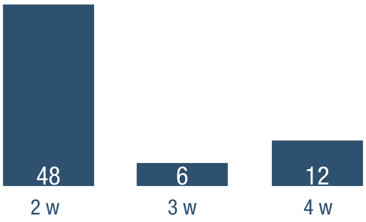
WHY IS THERE MORE MATTER THAN ANTIMATTER IN THE UNIVERSE?

106 registrations

66 participants
from 38 institutions
in 21 different countries

academic seniority:
35 faculty/staff
21 postdocs
10 PhDs

duration of stay:

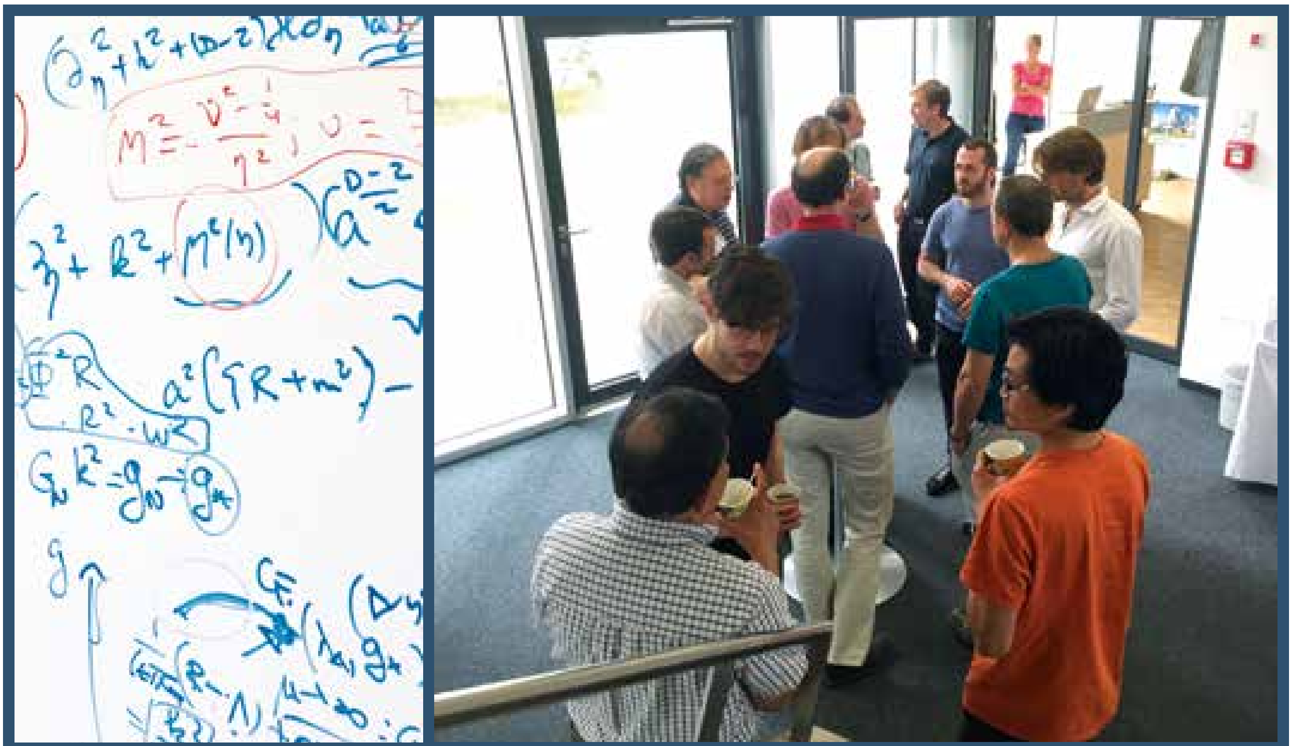


> **“I find it difficult to single out particular events. Certainly the topical workshop was a particularly intensive time (especially some of the high profile experimental speakers I have never met in person before). ”**
>
> *(Dr. Stephan Huber, University of Sussex, United Kingdom)*

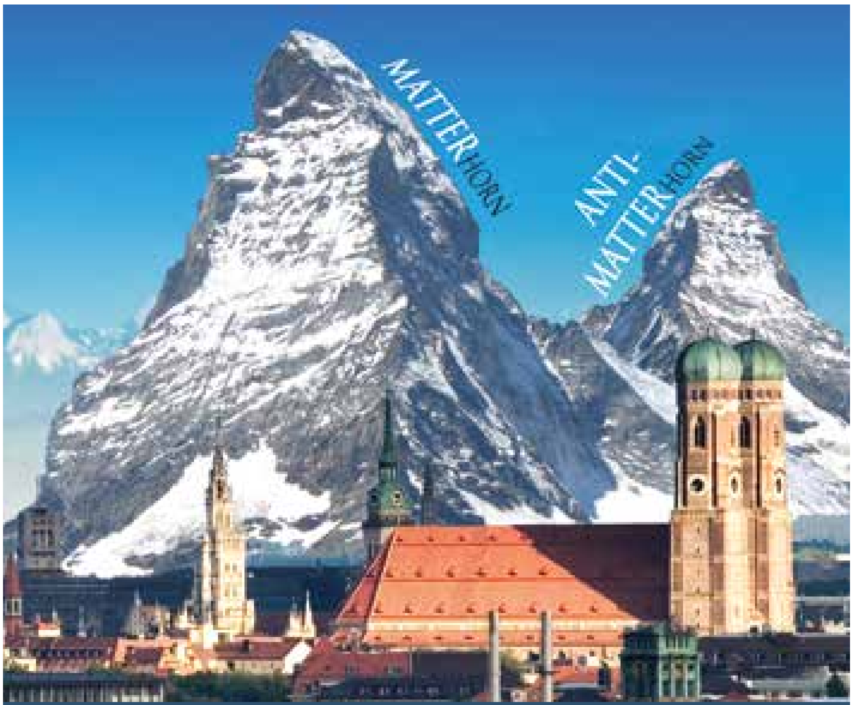
equilibrium are too tiny in order to explain the small observed asymmetry. Therefore, the cosmic asymmetry stands as one of the main motivations for looking for an extension of the Standard Model (along with the question of origin and nature of dark matter, dark energy and the unification of forces).

Out of the manifold solutions for the problem of the baryon asymmetry, the focus of the MIAPP programme 2016 fell on two of the most prominent paradigms: leptogenesis and electroweak baryogenesis. Leptogenesis provides an explanation for the imbalance of matter over anti-matter by introducing heavy right-handed neutrinos. Yukawa couplings of these right-handed neutrinos with left-handed lepton doublets result in masses for the neutrinos. The scenario therefore not only explains the cosmic asymmetry but also the existence of small neutrino masses. The lightest right-handed neutrino in the early Universe could possibly decay (at temperatures below its own mass) into a lepton and a Higgs boson (or their corresponding anti-particles) Complex CP-violating phases in the Yukawa couplings of neutrinos can then result in an uneven distribution of the production of leptons over anti-leptons. An excess of leptons can thus be generated in case that the expansion rate of the Universe exceeds the decay rate of the right-handed neutrinos, providing the necessary deviation from equilibrium. This imbalance would then be translated to the baryon sector via electroweak sphalerons.

Besides leptogenesis, electroweak baryogenesis is a very attractive explanation for the observed baryon asymmetry. Electroweak baryogenesis addresses all of Sakharov’s requirements possibly leading to an asymmetry in the number density of baryons during electroweak phase transitions. Albeit electroweak scenarios can have different characteristics, they all have features in common. Typically, the initial condition of the early Universe



Left: Theoretical considerations captured on one of the MIAPP white boards. Right: Coffee break at the focussed topical workshop “Baryogenesis – Status of Theory and Experiment” at MPA. The theory-oriented four-week programme was sparked by reports on current experimental efforts and discussions in the second week. *Credit: Haneburger / MIAPP* is to be hot and radiation-dominated with no baryon net charge, and the emergence of the observed asymmetry requires new sources of CP violation that are looked for in particle colliders but also in smaller precision experiments, such as searches for permanent electric dipole moments of atoms, nuclei and nucleons. Furthermore, electroweak baryogenesis requires a “strong” first order electroweak phase transition, implying that similar to boiling water, there emerge bubbles of the different phases of the electroweak sector. When these bubbles collide, they produce gravitational waves that are potentially observable in future interferometers such as the proposed space-based eLISA experiment. As strong phase transitions do not exist within the Standard Model, new particles and interactions tantalisingly close to current experimental reach need to be added to the theory. The appeal of electroweak baryogenesis is that it is thought to be testable in upcoming collider and precision experiments.



In order to illustrate the imbalance and asymmetry of matter and antimatter the allusion of the Matterhorn and a mirrored, smaller “Anti-Matterhorn” was used for the poster announcing the topical workshop. *Credit: Munich (istock.com/bkindler); Matterhorn viewed from the Gornergratbahn, Riffelberg / Zermatt, Switzerland by Andrew Bossi (Wikimedia Commons collection) Collage: MIAPP*

With all these different explanations conceivable and none of them proven so far, good and solid predictions and models are needed. These models can then be used by phenomenologists to bridge between the theoretical mathematical models and experimental particle physics. Conversely, new experimental results from the LHC, neutrinoless double beta decay and electric dipole moment searches – together with the prospects for next generation gravitational wave probes and high energy colliders – motivate much of the theoretical activity for both model-building and phenomenology. The confrontation of theory with experiment also underlines the importance of obtaining more robust computations of the baryon asymmetry, requiring continued progress on outstanding challenges for finite-temperature out-of-equilibrium dynamics. In this respect, it was particularly valuable for members of the phenomenology and model-building communities to become more aware of the open field theoretical problems; for those working on the field theory of leptogenesis and weak scale baryogenesis to exchange ideas; and for the field theorists to become aware of new model developments and their possible phenomenological consequences.

> **“Fantastic facilities, interesting discussions, good quality of speakers, and a relaxing and pleasant campus to stimulate new ideas.”**
> *(Anonymous participant)*

Among the aspects discussed in particular depth during the programme are the following: Leptogenesis from right-handed neutrinos at the GeV scale is of particular interest because particles with these masses do not require the most energetic colliders for their production. Nonetheless, due to their feeble interactions, large numbers of collisions are required in order to produce sizable signals. Various groups have presented and discussed their strategies for not only discovering right-handed neutrinos in this mass range but also how to test whether their interactions are consistent with leptogenesis. As for electroweak baryogenesis, first order phase-transitions were in the main focus. The participants worked together on the consequences of the recent finding that sound waves in the plasma dominate the production of gravitational waves and how to make fast and reliable predictions for the nature of the phase transition for a wide class of models. The programme had an outcome on the research activities as clearly evidenced by a number of subsequent publications. In the case of leptogenesis, a large fraction of the participants has teamed up to publish a review volume on the current state of the art in the International Journal of Modern Physics. Baryogenesis remains an arena where a fundamental question of physics brings up intriguing field-theoretical challenges and fascinating possibilities of experimental discovery. This programme has been of great benefit to the theory community to push for an eventual breakthrough on the puzzle of the cosmic asymmetry.

The four-week programme was complemented by a focused workshop entitled “Baryogenesis – Status of Theory and Experiment”. The goal was to complement the theory-oriented four-week programme with reports and discussions on experiments, in particular on precision measurements and searches for charge-parity violation (in permanent electric dipole moments as well as in decays of heavy mesons), baryon- and lepton-number violation (neutrinoless double beta decay and neutron-antineutron oscillations) as well as lepton flavour violation (for charged leptons as well as in neutrino oscillations). The workshop attracted leading speakers from the forefront experimental groups that were supplemented with theory talks pertinent to the interpretation of the data as well as talks clarifying the relevance of these observational efforts in the wider context of baryogenesis.

COORDINATORS OF THE PROGRAMME “WHY IS THERE MORE MATTER THAN ANTIMATTER IN THE UNIVERSE?”

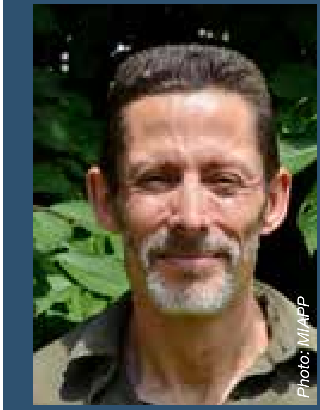


Photo: MIAPP

PROF. MICHAEL RAMSEY-MUSOLF

University of Massachusetts Amherst, USA

- Baryogenesis
- Physics beyond the Standard Model
- Fundamental symmetries
- Dark matter
- Electroweak symmetry breaking
- Effective field theories


Photo: MIAPP

PROF. BJÖRN GARBRECHT

Technical University of Munich, GERMANY

- Baryo-/leptogenesis
- Quantum field theory in curved space-times
- Quantum field theory in and out-of equilibrium
- Cosmic inflation
- Phase transitions


Photo: MIAPP

DR. STEPHAN HUBER

University of Sussex, Brighton, UNITED KINGDOM

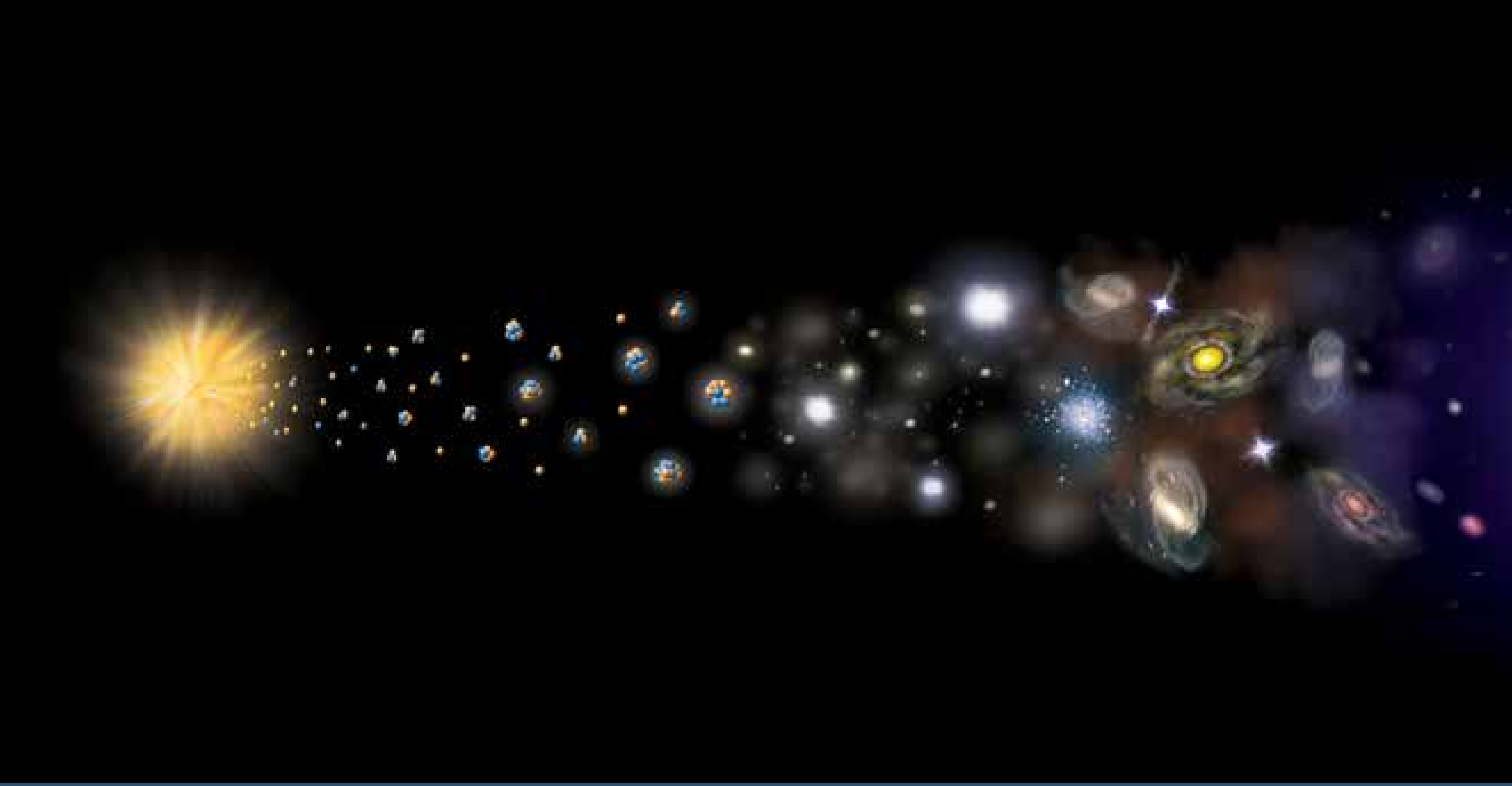
- Baryogenesis
- Cosmic phase transitions
- Physics beyond the standard model
- Electroweak symmetry breaking
- Gravitational waves


Photo: MIAPP

PROF. JING SHU

Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, CHINA

- Quantum field theory
- Beyond the Standard Model Physics
- Baryogengesis
- The origin of electroweak symmetry breaking
- Collider physics
- Cosmology
- Effective field theory



During the Big Bang only light elements were formed. The complexity of elements in the Universe further increased within the cycle of birth and death of stars. Still, the overall amount of heavy elements (metals) to the baryonic matter only accounts to 2%. While this seems to be an astonishing small number, these heavy elements were the crucial

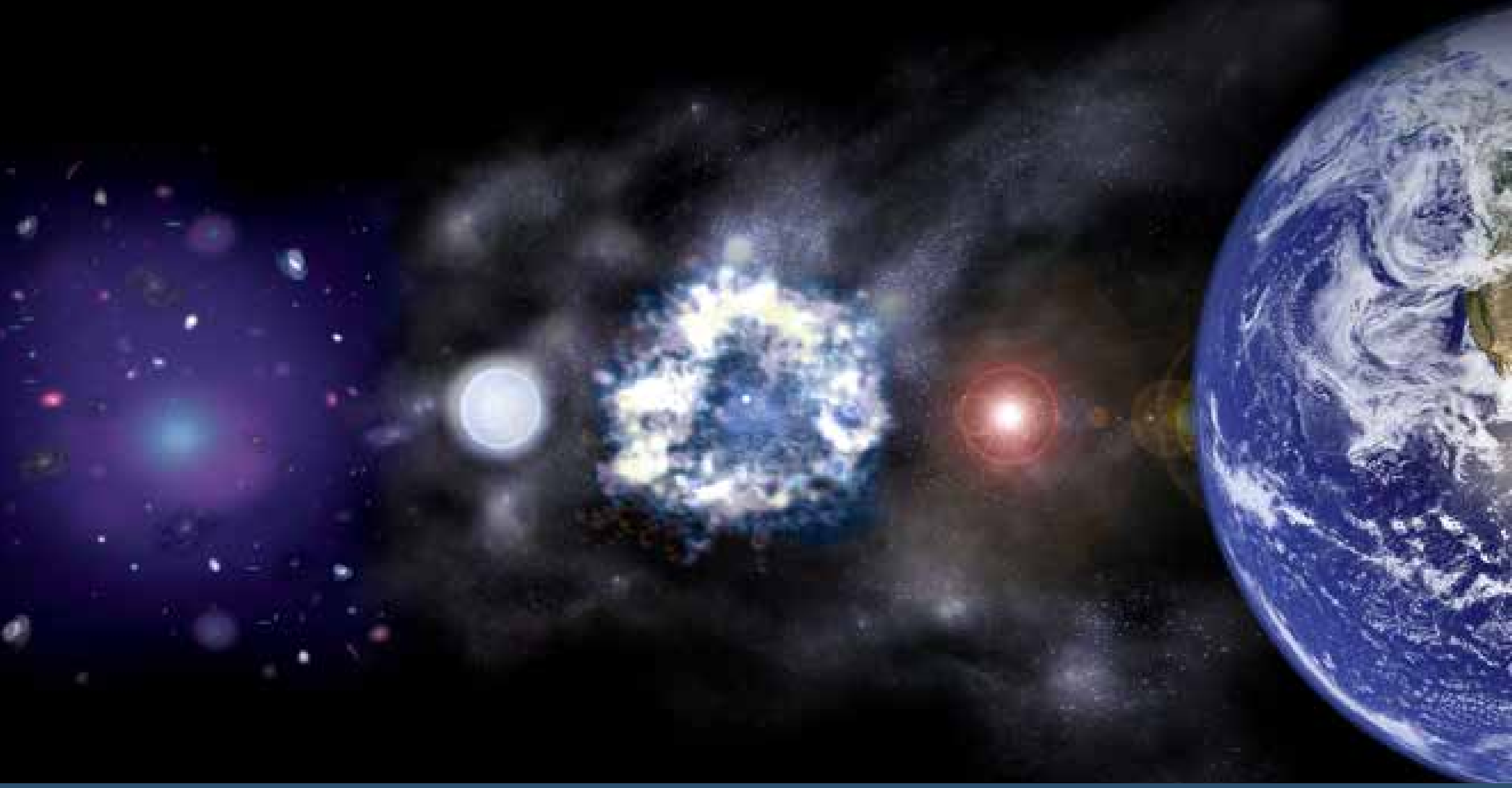
25th July - 19th August 2016

The Chemical Evolution of Galaxies

The building blocks of galaxies are formed out of tiny quantum fluctuations of matter shortly after the birth of the Universe in the Big Bang. These building blocks merge and accumulate matter from their surroundings in more than billions of years. Thus, they developed to the mature giant galaxies with hundreds of billions of stars, which we see in the local Universe today. This process of galaxy formation and evolution is intimately connected with the chemical evolution of galaxies. During the Big Bang only light elements like hydrogen (H), deuterium (D), helium (He) and lithium (Li) were created. All the heavier elements, for an astrophysicist "metals", were later produced, after stars formed in galaxies as the result of nuclear fusion reactions in the stellar interior. Stellar winds and supernovae explosions spread the metals into the interstellar medium of galaxies and the next generation of stars formed was enriched with metals. Thus, the measurement of chemical composition of stars and of interstellar gas in galaxies provides crucial information about the very complex process of galaxy formation and evolution.

COORDINATORS: BEN DAVIES, MARIA BERGEMANN, FABIO BRESOLIN, ANDREEA FONT, ROLF-PETER KUDRITZKI

It is common knowledge that the Universe evolved from a very hot and dense state to what it is now. The explosion and rapid expansion of the Universe, called the Big Bang, led to the production of light elements such as hydrogen (H), deuterium (D), helium (He) and a tiny fraction of lithium (^{7}Li). All elements with a mass number equal 12 or higher, "metals" as astrophysicists call them, were then later produced in the cycle of birth and death of stars. 73% of today's baryonic matter in our Universe is hydrogen, while 25% are helium. The remaining 2% comprise all heavier elements, the metals. Albeit composing only a minor fraction of the total baryonic matter, metals are crucial for many impor-



ingredients to create life on Earth. Hence, understanding the chemical evolution of Galaxies is key to learn more about the evolution of the Universe and to fully be able to understand the evolution of life. *Credit: NASA / CXC / M.Weiss*

tant processes in astrophysics, most importantly, the formation of life in the Universe. We as humans and every living organism on Earth are built out of them.

Metals are produced during the life cycle of stars. Stars form out of dense gas clouds in the interstellar medium. They shine bright and visible over large distances because of the nuclear reactions in their interior, which release an enormous amount of energy but also leave heavy elements as the ashes of the nuclear fire in the interior. Once the nuclear fuel in the interior of stars is exhausted, stars die in spectacular ways through the ejection of so-called planetary nebulae or through supernova explosions. Supernova explosions or even more spectacular events like gravitational-wave-emitting kilonovae also produce additional elements much heavier than iron through neutron capture processes. During the death of stars metals are dispersed into the galaxies' interstellar medium, the gas that serves as the seeding component of new stars. In the next cycle of star formation a new generation of stars is formed with a chemical composition representing the metal enrichment in the "element soup" of the interstellar medium.

Because of the metal producing life cycle of stars, analysing the metal content can serve as a fossil record of a galaxy's star forming history. However, the situation is more complicated. Galaxies are not closed systems. They lose matter through powerful galactic winds created through the energy of supernovae explosions and strong winds of massive stars. The winds carry metals away. At the same time galaxies also accrete matter from the so-called cosmic web, which is the intergalactic distribution of matter remnant from the Big Bang. The accretion of such matter dilutes the concentration of metals in a galaxy. On the other hand, some of the metals previously ejected through galactic winds may fall back into the

> **"MIAPP is just an amazing experience, specially for young researchers. For me it is always a great opportunity to become immersed in science and to network with so many talented people from different parts of the world."**
> *(Dr. Alan Alves-Brito, Federal University of Rio Grande do Sul, Porto Alegre, Brazil)*

galaxy, themselves enriching the interstellar medium with metals. The goal of the fourth MIAPP programme 2016 was to disentangle the role of all these processes.

The chemical evolution of galaxies can be analysed by detailed and accurate spectroscopic observations combined with quantitative spectral analyses to determine chemical compositions or numerical simulations of the formation of large scale structures and galaxies in the Universe. In both areas there has been tremendous progress in recent years. The hydrodynamic simulations of galaxy formation and evolution combine calculations of gas dynamics, gravitational collapse, star formation and evolution with the formation of elements and their ejections through stellar winds and supernovae. They make bold predictions about the properties of galaxies including their chemical composition, for instance the relationship between the total stellar mass of a galaxy and its metal content and the distribution of metal abundance across a galaxy as function of the radial distance from the centre (the so-called abundance gradients). Since these calculations are extremely challenging, it is not surprising that the results obtained by different groups show significant variations.

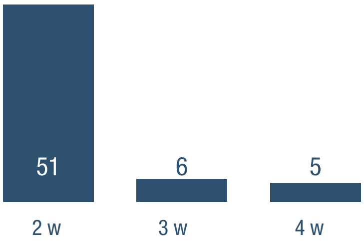
THE CHEMICAL EVOLUTION OF GALAXIES

98 registrations

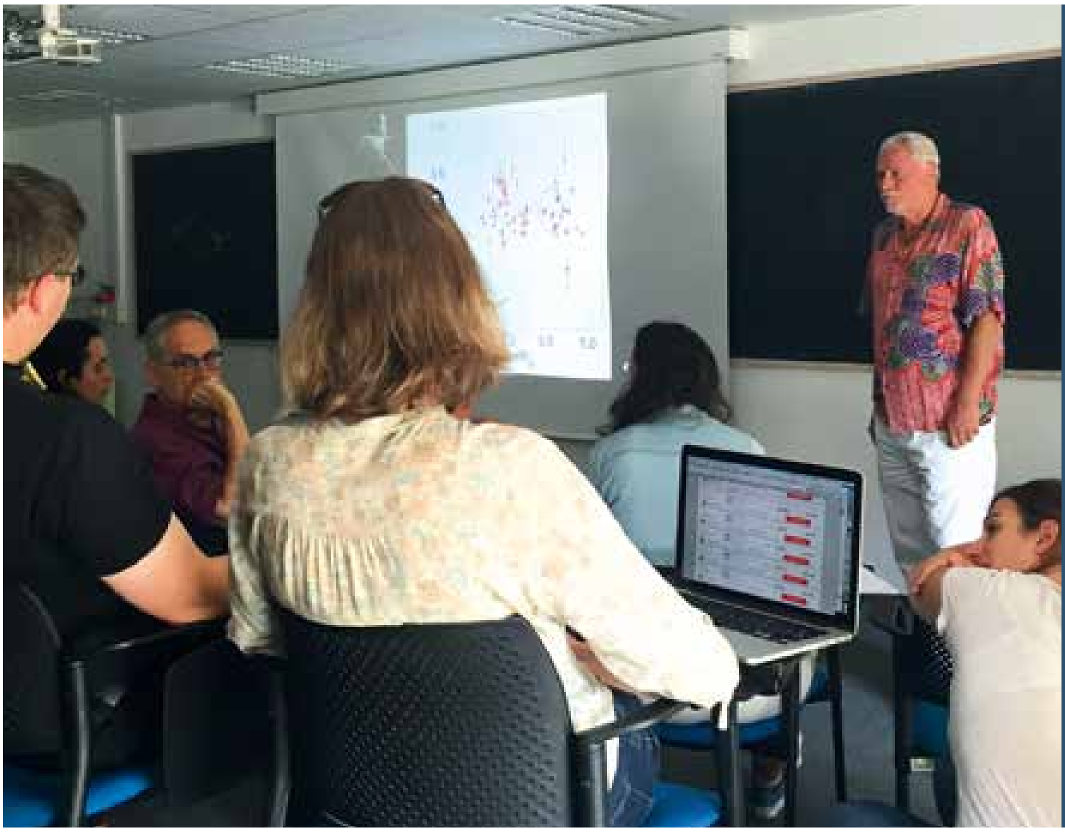
62 participants
from 33 institutions in
15 different countries

academic seniority:
30 faculty/staff
20 postdocs
12 PhDs

duration of stay:



> **“Scientific highlights: The great effort from the observational and theoretical side to understand chemical evolution, metallicity gradients and scaling relations, especially with other probes of metallicity such as cepheids, red and blue supergiants, super star clusters, etc. And the need to converge to a “metallicity reference” from both the stellar and the ionised-gas communities.”**
> *(Prof. Dr. Fabián Rosales-Ortega, Instituto Nacional de Astrofísica, Óptica y Electrónica, Puebla, Mexico)*



Discussion session after the talk by Rolf Kudritzki. One of “his” skeletons in the closet being projected in the background.
Credit: Haneburger / MIAPP

Image of the giant spiral galaxy M81. Spiral galaxies have different chemical compositions in their inner and outer parts. They have a much higher content of heavy elements in the inner regions than in the outskirts. Measuring these metallicity gradients provides crucial information about the formation and evolution of galaxies.
Credit: Jean-Charles Cuillandre/ Canada-France-Hawaii Telescope (CFHT)

With the help of extremely accurate spectroscopic measurements theoretical simulations can be tested and compared against each other. Still, providing measurements at the level of accuracy necessary for this critical comparison processes proves to be challenging. The fourth MIAPP programme 2016 therefore aimed at bringing a broad range of observers, studying a wide variety of chemical composition tracers such as different types of stars and the interstellar medium, together with theorists from competing groups.

With all these inputs the participants aimed at identifying differences between models, producing testable predictions and at designing experiments to discriminate between available models.

In very lively and refreshingly controversial discussions theorists and observers discussed competing numerical and analytical models of chemical evolution and their predictions for the origins of the mass-metallicity relationship and of the observed metallicity gradients. Thanks to these discussions a considerable progress was made in understanding the differences and unique features of these models.

At the same time enormous progress was accomplished regarding the cross-calibration of the spectroscopic chemical abundance diagnostics using different abundance tracers. In a common effort the strengths and weaknesses of multiple tracers, such as hot stars, cool stars, massive stars, low-mass stars, old stars, young stars, planetary nebulae, neutral and ionised gas in the interstellar medium were

“The format of the MIAPP workshop is really excellent! Lots of opportunities for extensive interactions with colleagues, plus only a few talks per day to broaden ones horizon, and for stimulating further discussions.“
(Prof. Dr. Norbert Christlieb, Universität Heidelberg, Germany)

dissected. Even more profound, several participants got together to design a possible 'metallicity ladder' project to put all diagnostics onto the same scale. Such a unified scale would in turn enable the community to compare and verify results with the help of a common measure.

During the MIAPP programme new techniques, for instance, the low resolution spectroscopy of individual very bright supergiant stars at optical and infrared light were introduced. Improved standard methods, such as the use of optical spectroscopy of cool-stars to map chemical abundances in the bulge of the Milky Way Galaxy were expertly presented, as was the pioneering work to switch such analyses to the infrared. As an unexpected consequence of the presentations and discussions a number of participants discussed ideas to expand this work, with the focus of ultimately breaking the community's dependence on optical data. Stellar abundances of star-forming galaxies can, in principle, be determined with the use of integrated light of the stellar population. The MIAPP programme with the intense interaction and discussion between the participants led to the development of a completely new method to determine the metal content of star forming galaxies, which has now been carefully tested and which is published.

Reading the feedback by the participants it became apparent that key to the success of the programme had been the nice and relaxed atmosphere that allowed for vivid and open discussions. The scientific coordinators asked everyone to show "the hidden skeleton(s) in the closet", i.e. to point towards the weaknesses of their analyses or methods. Obviously, this frankness payed off as participants could fully profit from the concentrated expertise present at the programme to improve methods and to develop new pioneering ideas.

"I especially liked the perfect balance between scientific talks (including topics which I would not normally meet in the conferences I usually attend), interaction with other scientific collagues and having time for my own projects in a perfect working environment."

(Dr. Sergio Simon-Diaz, Instituto de Astrofísica de Canarias, La Laguna, Spain)

COORDINATORS OF THE PROGRAMME "THE CHEMICAL EVOLUTION OF GALAXIES"

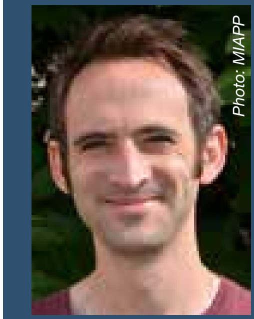


Photo: MIAPP

DR. BENJAMIN DAVIES

Liverpool John Moores University,
UNITED KINGDOM

- Galactic chemical evolution
- Massive stars and supernovae
- Star formation
- Young stellar clusters


Photo: Thomas Hartmann, Quelle: Max-Planck-Gesellschaft

DR. MARIA BERGEMANN

MPI for Astronomy,
Heidelberg, GERMANY

- Abundances of chemical elements
- Stellar spectroscopy and radiative transfer
- Physics of stars
- Nucleosynthesis of elements in nature
- Exoplanet-host stars


Photo: Bresolin

DR. FABIO BRESOLIN

University of Hawaii,
Honolulu, USA

- Galaxy evolution, chemical abundances
- Extragalalctic distances
- HII regions
- Nebular and stellar spectroscopy


Photo: MIAPP

DR. ANDREEA FONT

Liverpool John Moores University,
UNITED KINGDOM

- Formation and evolution of galaxies
- Origin of galactic stellar haloes
- Assembly of the Milky Way

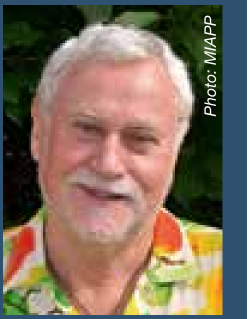


Photo: MIAPP

PROF. ROLF-PETER KUDRITZKI

LMU Munich and
University of Hawaii,
Honolulu, USA

- Extragalactic stellar astronomy
- Supergiant stars as tracers of chemical evolution and distances of galaxies
- Extragalactic distances

Snapshot from a simulation of an exploding supermassive star. Depicted is the inner helium core where helium is converted to oxygen in the process of nuclear burning. Shown is a slice through the interior one day after the onset of the explosion.
Credit: Ken Chen, UC Santa Cruz

22nd August – 16th September 2016

The Physics of Supernovae

The explosion of a star at the end of its live is called a supernova. This deadly event unleashes enormous energies so that the dying star becomes as bright as a whole galaxy consisting of billions of stars. Supernovae are unique beacons allowing us to investigate the distances to galaxies and the accelerated expansion of the Universe. In addition, because of the fast nuclear reaction processes during the explosion supernovae contribute to the production and spread of heavy elements in the Universe. Therefore, understanding supernovae and the underlying mechanisms leading to their explosion contributes substantially to our comprehension of the evolution of the Universe.

COORDINATORS: CLAES FRANSSON, SAURABH JHA, KATE MAGUIRE, STAN WOOSLEY

The bright explosion of a star is called a supernova. These destructive events not only unleash enormous energies but also are the major sources for heavy elements within the Universe. When a star collapses at the end of its life to form a neutron star or a black hole a large fraction of its mass is at the same time ejected in a violent explosion. The extremely high temperatures and densities encountered in this situation trigger nuclear reactions, which produce heavy elements such as oxygen, silicone and iron and all the elements heavier than iron. As a consequence of the explosion these elements are spread into the Universe and lead to the chemical evolution of galaxies.

The extremely bright events of some supernovae have already been observed in the early modern ages as they sometimes can be seen by naked eye. In 1572 Tycho Brahe observed a new bright star in the Cassiopeia constellation which started to fade within a year and called it stellae novae. In 1933 Fritz Zwicky and Walter Baade introduced the term supernovae for the first time and established supernovae as a distinct class of astronomical objects. Thanks to their brightness, supernovae are observable at extremely large distances, allowing to determine the distances to galaxies and to study the accelerated expansion of the Universe.

Theorists categorise supernovae according to the mechanism leading to the explosion. One category is related to massive stars. Stars more massive than at least eight solar masses at the end of their life develop to very cool red supergiant stars with a compact stellar core and a giant envelope with a diameter of about thousand solar radii. The stellar core becomes unstable and collapses to a neutron star or black hole, core-collapse supernovae, while part of the core reverses its motion and gets ejected together with the envelope in a giant explosion. The second category is related to compact white dwarf stars of slightly less than 1.4 solar masses in binary systems. Because of the gravitational interaction between the two stars, matter is transferred to the white dwarf and its mass increases. As soon as the mass becomes larger than the critical threshold of 1.4 solar masses, the so-called Chandrasekhar limit, the white dwarf becomes unstable and collapses creating a thermonuclear explosion.

In contrast to theorists observers distinguish different classes and subclasses of supernovae depending on the observable characteristics of the supernovae. Based on the absence or presence of certain features in the optical spectra supernovae are classified into four main categories. Supernovae spectra containing hydrogen are classified as Supernovae type II; those without hydrogen as type I. Type I supernovae are further subdivided into type Ia supernovae (containing silicon), Ib (no silicon but helium in the spectrum) and Ic that possesses neither silicon nor helium. One now knows that supernovae types II, Ib and Ic result from core-collapses of massive stars whereas supernovae Ia result from thermonuclear explosions of white dwarfs. Theoretical explosion models are used to explore different explosion mechanisms. Mapping the models onto the observations has worked fairly well overall with the type Ia supernovae associated to thermonuclear explosions and the type II supernovae connected to stellar core collapses. In recent years the classification system has evolved to include other effects, like the mass of the envelope of the progenitor star at explosion or the circumstellar environment, which shape the observed characteristics. Especially valuable have been the observational data derived from nearby supernovae. The past years have seen the

> **“A lot of interesting discussions especially about future instrumentation and where we could push SN science in the future. Another great point was the workshop, especially the focused day on superluminous supernovae”**
> *(Dr. Cosimo Inserra, Queen’s University Belfast, United Kingdom)*

Discussion session at the topical workshop “Supernovae: the Outliers” on first-generation supernovae and supernova-GRB connections. *Credit: Schürmann/TUM* brightest type Ia supernovae in decades (SNe 2014J and 2011fe) leading to unique observations, like the direct detection of gamma-rays from the radioactive decay of nickel produced in the explosion or mid-infrared light curves. Long-term observations like the observation of SN 1987A in the nearby Large Magellanic Cloud allow new insights and surprises, like the additional heating of the inner ejecta through the shocks in the circumstellar ring and the first direct imaging of the asymmetries of the explosion. Taking a step back and looking at pre-explosion images of several core-collapse supernovae revealed information about their progenitor stars and the evolutionary state of the star before explosion. In addition to that also progenitor systems of peculiar Type Ia supernovae have been observed recently. However, massive progenitor stars (M > 25 solar masses) as well as the elusive progenitors of normal Type Ia supernovae have not been observed. This continues to be an enigma.

THE PHYSICS OF SUPERNOVAE

121 registrations

75 participants

from 41 institutions

in 15 different countries

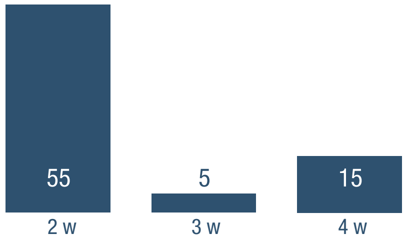
academic seniority:

46 faculty/staff

23 postdocs

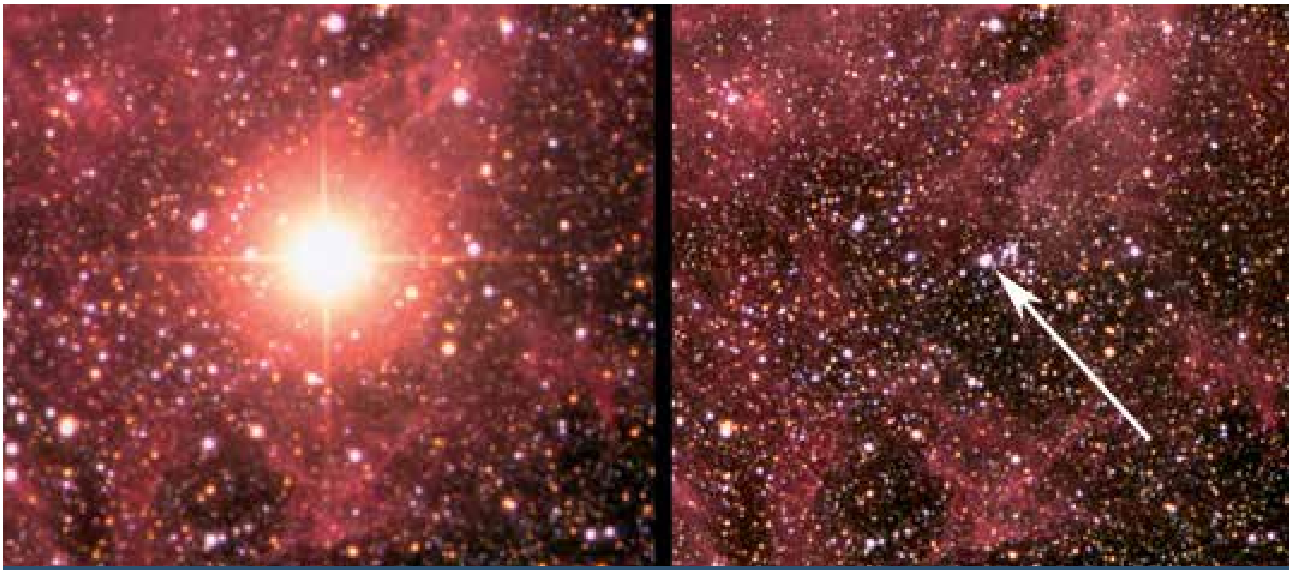
6 PhDs

duration of stay:



> **“The open format made this one of the best SN workshop in a long time. The many possibilities for discussions were extremely useful.”**
>
> *(Dr. Bruno Leibundgut, European Southern Observatory, Garching, Germany)*

Therefore, at MIAPP the pros and cons of different supernova progenitor models were discussed. Alternative strategies for comprehensive future supernovae sky surveys were developed, more transients vs. better studied events,



Supernovae SN 1987A before (right) and during explosion (left). The explosion of the massive star Sanduleak -69° 202 in the Large Magellanic Cloud was the first supernova being observable with the unaided eye since 400 years.
Credit: David Malin / Australian Astronomical Observatory

and heavily debated. Furthermore, lively discussion sessions covered debates on the electromagnetic counterparts of gravitational wave detections, i.e. gamma-ray emission from supernovae. For instance, the detection of gravitational wave signals from a core-collapse supernova would provide new and independent insights in the explosion mechanism and dynamics. So far none of the designated experiments was able to detect such a signal. Nevertheless, the detection of gravitational waves from the merger of two black holes in 2015 by LIGO raised hope that one will be able to detect a similar signal from the collapse of a supernova. In order to be able to address one of the major questions remaining about what stellar systems explode to produce type Ia supernovae, the importance of very detailed and improved numerical radiation-hydrodynamic simulations was stressed.

During the last week of the programme the topical workshop “Supernovae: the Outliers” took place at the Max-Planck Institute for Astrophysics in Garching. The workshop allowed to broadcast the results of the first three weeks to a broader audience. It focused on strange transient events and was very complementary to the MIAPP programme as the first three workshop weeks had focused on ‘normal’ supernovae but the final week of the topical workshop covered all the weird supernovae that have been predicted and/or observed in transient surveys. Some of these observations are relatively new and not yet understood. Yet, they produce most exciting results as enormous energies and many superlatives are involved. Therefore, in 2017 a MIAPP programme dedicated to one of these “weird” types, i.e. superluminous supernovae, was arranged.

> **“The highlight, for me, was getting useful feedback on a paper I was writing. I also received new ideas to further a project I had been working on for the past couple of years. Face-to-face discussion is always better than a skype meeting.”**
> *(Christopher Frohmaier, University of Southampton, United Kingdom)*

COORDINATORS OF THE PROGRAMME “THE PHYSICS OF SUPERNOVAE”

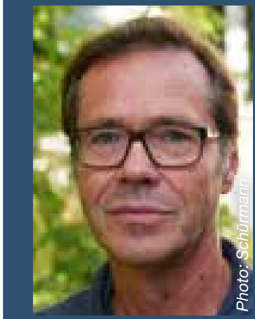


Photo: Schürmann

PROF. CLAES FRANSSON
Stockholm University,
SWEDEN

- Models and observations of core collapse and thermonuclear supernovae
- Nucleosynthesis
- Interaction with the circumstellar medium


Photo: Schürmann

PROF. SAURABH JHA
Rutgers, the State University of New Jersey,
USA

- Type Ia supernovae
- Supernova distances and cosmology
- Unusual white dwarf supernovae
- Observational time-domain astrophysics


Photo: Schürmann

DR. KATE MAGUIRE
Queen’s University Belfast,
UNITED KINGDOM

- Explosive transients
- Cosmology
- Supernova progenitors
- Physics and explosion mechanism of supernovae


Photo: Schürmann

PROF. MARYAM MODJAZ
New York University,
USA

- Stellar death astrophysics
- Progenitors of supernovae and gamma-ray bursts
- Host galaxies and environments of supernovae and gamma-ray bursts

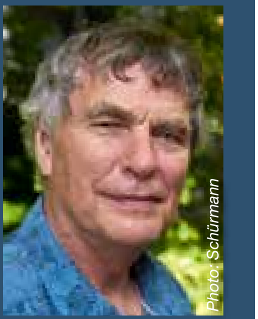


Photo: Schürmann

PROF. STAN WOOSLEY
University of California,
Santa Cruz, USA

- Models for supernovae of all types
- Nuclear astrophysics and the origin of the elements
- Evolution of massive stars

The Belle II detector at KEK (Japan). First tests and background measurements are expected for 2017/2018. The first measurements with the completely assembled detector are envisioned for 2019. *Credit: Shota Takahashi/KEK*

24th October - 18th November 2016

Flavour Physics with High-Luminosity Experiments

The interactions of elementary particles are best described by the so-called Standard Model. It contains the constituents of matter, the quarks and electrons, which in turn come in three copies with very different masses. The transitions between the different species of quarks, dubbed "flavours", are believed to provide a sensitive probe for physics beyond the Standard Model, complementary to the search for new particles at high-energy colliders such as the LHC at CERN. A new generation of experiments is under construction to measure flavour transitions, especially those of the heavier particles, with superb statistics. In anticipation of these opportunities, experimentalists and theorists worked together at this MIAPP programme to identify the most relevant measurements and experimental strategies.

COORDINATORS: STEPHAN PAUL, MARCO CIUCHINI, BOŠTJAN GOLOB, PETER KRIŽAN, THOMAS MANNEL

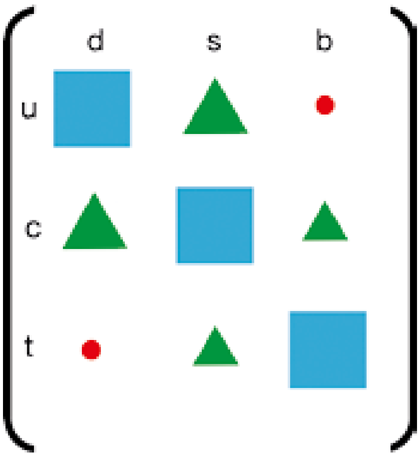
When the muon, an elementary particle identical to the electron in all respects except for its much larger mass, was discovered in 1936, theorist Isidor I. Rabi exclaimed: "Who ordered that?" The muon now finds its place in a beautiful but probably incomplete model called the Standard Model together with a third, even heavier copy, the tau lepton. The structure repeats itself with the quarks, which exist not only as the up- and down-quark, which make up protons and neutrons, but also in the form of heavier quarks, named "strange", "charm", "bottom" and "top". Most of the fundamental constants of nature are related to the fact that the leptons and quarks come in three generations. One now knows that the different physical properties of these particles are exclusively due to their different interactions with the recently discovered Higgs boson. But the question inherent to Rabi's exclamation, why there are three generations and what causes these different interactions still remains unanswered. Intriguingly, the quark flavour sector is also the only place in the Standard Model where the phenomenon of CP violation appears (see box on the next page), which is also at the root of the imbalance of matter and antimatter in the Universe.

The transformation of quarks of one flavour into another is described by a three-by-three matrix, the CKM matrix, whose entries become smaller further away from the diagonal (see pictorial representation on this page). When the strength of the transition is very weak, such as between a bottom- and an up-quark, or a top- and a down-quark, chances are that it could be modified substantially by a new interaction. This is best investigated by first producing pairs of bottom and anti-bottom quarks in large numbers and then analysing their decays.

“The majority of discussions and seminars were instructive and full of information. In particular, I benefited a lot from presentations and discussions on new and exotic hadrons.”
(Prof. Simon Eidelman, Budker Institute of Nuclear Physics, Novosibirsk, Russia)

From 1999 to 2008 the first precision experiments at so-called flavour factories have made decisive progress in the current understanding of CP violation and the CKM matrix. None of the first generation experiments and the later LHCb experiment provided significant evidence for new physics, although a few hints of discrepancies with the Standard Model predictions exist. To further improve precision, the Belle II experiment was designed. Belle II succeeds the first generation flavour factory Belle at the KEK accelerator centre in Japan. It consists of the upgraded SuperKEKB accelerator that produces a more intense beam than its predecessor and the upgraded Belle II detector that is able to cope with the increased luminosity. A shrinkage of the beam size at the interaction point further contributes to the increase in precision. With the new set-up Belle II is expected to collect 50 times more data than the Belle experiment starting from 2018/2019. Around the same time, the LHCb experiment will undergo a major upgrade. With the expected vast amount of new data, rare processes will be measured for the first time, and the probability to identify new physics modifications and to prove them at high statistical significance will be very much enhanced.

The MIAPP programme “Flavour Physics with High-Luminosity Experiments” was hosted only a little over a year after the previous flavour physics programme. However, whereas the 2015 programme was dominantly attended by theoretical physicists who discussed their ideas on how the Standard Model might be modified and what would be the implications on flavour physics, the present programme was a truly joint experimental and theoretical enterprise. Experimentalists especially made



CP SYMMETRY/ -VIOLATION

In particle physics CP symmetry describes the fact that in case all particles are replaced by their antiparticles and all space coordinates are mirrored the laws of physics remain intact. Yet, several decay processes are known where this CP symmetry is violated. This implies that particles and antiparticles can behave intrinsically differently.

Left: Pictorial representation of the CKM matrix which describes the transitions of one quark flavour into another (quark flavours up, charm, top and down, strange, bottom). The size of the symbols represents the strength of the transition. For small entries chances are that the interaction is modified by a new, so-far unknown, interaction. Right: A scary “physics” pumpkin creates halloween atmosphere at MIAPP. *Credit: Haneburger/MIAPP*

During the fourth week the B2TiP topical workshop took place at the Institute of Advanced Studies of TUM in Garching. Scientists involved in the different working groups of the Belle II theory platform (B2TiP) met here in order to finalise the Belle 2 Theory White Paper. *Credit: Blauwitz / MIAPP*

> **“My highlight: The mixture of having hadron physicists and particle physicists in one room with time to discuss issues, which usually are mutually avoided. The connection of tau decays to the problems in hadron physics was another highlight for me.”**
>
> *(Dr. Sebastian Neubert, Universität Heidelberg, Germany)*

FLAVOUR PHYSICS WITH HIGH-LUMINOSITY EXPERIMENTS

90 registrations

62 participants
from 41 institutions
in 18 different countries

academic seniority:
43 faculty/staff
12 postdocs
7 PhDs

duration of stay:

the unusual effort to free themselves from their daily duties to meet the MIAPP two-week minimum attendance requirement. According to feedback this paid off by the ability to focus on the important questions. Several challenges arise from the anticipated much larger data set. The experimental methods need to be reviewed in order not to blindly employ assumptions and approximations that were adequate in the past but need to be refined when data and theory advances allow the much more precise determination of various observables. Among such subtle issues are detector-induced asymmetries in the charm CP-asymmetry measurements as well as the effect of neutral kaons in the final states that are caused by differences in the particle – antiparticle interaction with the detector material. The need for common tools and methods among experiments was also emphasised in order to assess the compatibility of the results. But not always is experiment the limiting factor. Although the flavour-changing interactions are very weak, quarks are confined in bound states of quarks and antiquarks by the strong interaction. The effect of this strong binding on the decay is very difficult and sometimes impossible to calculate, preventing the detection of small effects of new physics no matter how precise is the measurement. This MIAPP programme contained a special focus on such hadronic effects, which require a particularly close collaboration between experimentalists and theorists in identifying the useful measurements. The spirit of cross-disciplinarity became visible in a spontaneously organised two-day satellite workshop pursuing the complementarity of measurements in the light-quark sector to those from the more traditional heavy-quark sector.

The time at MIAPP was also used to tackle more general questions such as the expected sensitivity that can be reached for rare and forbidden decays according to the Standard Model and how theoretical uncertainties can be reduced to match the experimental precision. Whether it is possible to further optimise observables in order to guarantee maximal sensitivity. How the complementarity among different experiments can be exploited most efficiently. And how does the impact of favour physics on the search for new physics compare with the prospects of discovering the new particles of an extension of the Standard Model directly.

Many of these questions are also pursued in a global effort coordinated in the framework of the Belle II theory interface platform (B2TiP). The MIAPP programme was coordinated in cooperation with B2TiP and many of the conveners of the B2TiP working groups attended the programme for an extended period of time. In the last week of the programme three days were dedicated to the concluding workshop in a series of global B2TiP workshops, which started in 2014. The conveners came to the Institute of Advanced Studies of TUM to summarise the results of their working groups and to finalise the Belle II physics book, which formulates a roadmap for discoveries at Belle II.

> **“I could discuss with experts on the controversial problems in a private manner. That is very unusual and it was very useful.”**
> *(Anonymous participant)*

COORDINATORS OF THE PROGRAMME “FLAVOUR PHYSICS WITH HIGH-LUMINOSITY EXPERIMENTS”

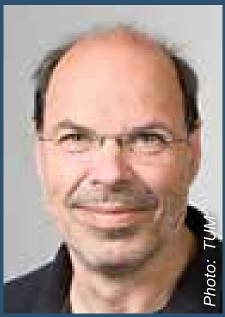


Photo: TUM

PROF. STEPHAN PAUL

Technical University of Munich, GERMANY

- Hadron physics
- Particle physics with neutrons
- Instrument development
- Symmetry violation
- Spectroscopy


Photo: MIAPP

DR. MARCO CIUCHINI

INFN Roma Tre, ITALY

- Particle physics theory and phenomenology
- Flavour physics and CP violation
- Electroweak physics

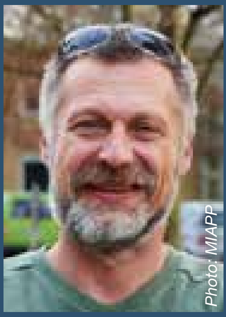


Photo: MIAPP

PROF. BOŠTJAN GOLOB

Jožef Stefan Institute, University of Ljubljana, SLOVENIA

- High precision experimental particle physics
- Physics of heavy quarks and leptons
- Symmetries violations


Photo: MIAPP

PROF. PETER KRIŽAN

Jožef Stefan Institute, University of Ljubljana, SLOVENIA

- Experimental particle physics
- Physics of B and D mesons
- Detectors of particle physics experiments
- Cherenkov detectors


Photo: MIAPP

PROF. THOMAS MANNEL

University of Siegen, GERMANY

- Theoretical particle physics (phenomenology)
- Quark flavour physics
- Effective field theories

How could the interaction of a hypothetical dark matter candidate with ordinary matter occur? Weakly interacting massive particles (WIMPs) hardly interact with ordinary matter. In case of a rare collision event WIMPs would scatter from the atomic nucleus while photons and electrons scatter from atomic electrons. The Large Underground Xenon dark matter experiment LUX *(right)* aims at directly detecting galactic dark matter. The central part of the detector is filled with 368 kg of ultra-pure liquefied xenon. Interactions with putative dark matter particles would result in light production equal to the energy deposited.

Credits: Michael Attisha/ Brown University reproduction with kind permission by Bernard Sadoulet/University of California, Berkeley (left image); Sanford Underground Research Facility (right image)

6th - 31st March 2017

Astro-, Particle and Nuclear Physics of Dark Matter Direct Detection

It has been known for many decades that there has to be something in addition to the normal matter in the Universe, which is invisible to the naked eye and to telescopes. Despite intensive searches, the nature of this new (dark) matter is still unknown. The first MIAPP programme in 2017 gathered experts from astro-, particle and nuclear physics to find new ways of detecting dark matter particles through very rare collisions with nuclei in underground detectors.

COORDINATORS: RICCARDO CATENA, JAN CONRAD, CHRISTIAN FORSSÉN, ALEJANDRO IBARRA, FEDERICA PETRICCA

Observations of spiral galaxies led to the discovery that there must be something in addition to visible matter. Contrary to expectations the velocity of stars within a galaxy remains constant to distances far away from the centre of the galaxy. That is, all stars, no matter where they are located within a galaxy, circle its centre at nearly the same speed. Envisioning a rotating system under the influence of gravitation, one would expect the more distant stars to be slower than the stars closer to the centre, similar to the planets in the solar system. Otherwise these stars would detach from the centre and fly away. As the existing visible matter cannot account for this effect, an invisible new form of matter, "dark matter", was conjectured. Analyses of the cosmic microwave background with the Planck satellite and other observations confirmed that there is in fact much less known matter than unknown matter in the Universe.

Despite all the evidences for dark matter its nature is still unknown. If it is indeed a new form of matter it most likely consists of yet unidentified particles. Being invisible entails that it hardly interacts with normal baryonic matter. Which is one of the reasons why its nature is still a mystery. Scientists search for dark matter with different approaches. In the highest-energy particle colliders unknown particles might be produced, which may turn out to be candidates for the dark matter particle. Alternatively, once in a while two dark matter particles annihilate somewhere in the Universe and the annihilation products may manifest themselves on Earth as cosmic rays. The third and most direct approach consists of detecting the scattering of dark matter particles in the halo into which the Milky Way is embedded on target nuclei

Participants of the third week of the "Astro-, Particle and Nuclear Physics of Dark Matter Direct Detection" programme taking place in spring 2017. *Credit: Haneburger/MIAPP*

of terrestrial detectors. The scattering is extremely feeble. To shield the instrument from the cosmic ray background it is placed deep underground.

The first MIAPP programme in 2017 focused on this third approach. The topic is indeed timely as in a few years of now the traditional direct detection methods approach a limiting barrier that requires the invention of new theoretical ideas and experimental techniques to be overcome. The programme therefore collected scientists from the often disjoint fields of astro-, particle- and nuclear physics to join their expertise and to discuss the future of dark matter direct detection. Consequently, during each week, the programme hosted at least one talk on astrophysical aspects of dark matter direct detection, one on particle physics methods applied to dark matter-quark and -nucleon interactions, one on nuclear physics aspects of the non-relativistic scattering of dark matter particles by target nuclei, and, finally, an experimental talk on current and future efforts in dark matter direct detection. The mixture of disciplines allowed to gain new insights from different points of views and to discuss their influence on direct dark matter detection.

> **"The interdisciplinary nature of this particular programme was just about perfect. Often in 'interdisciplinary' discussions people talk past each other, but here the interaction between particle, nuclear, and astro-physics was just right."**
>
> *(Prof. Calvin Johnson, San Diego State University, USA)*

Different candidates for dark matter particles are conceivable and different models suggest different natures. The most prominent ones being a new weakly interacting massive particle (WIMP) or a hypothetical sterile neutrino. However, a much larger variety is theoretically possible and the mass of the dark matter particle is almost unconstrained. This provides a challenge for direct detection experiments, which look for the nuclear recoil produced in the collision of dark matter particles with a target nucleus and are therefore kinematically limited for dark matter masses smaller than the proton mass. Another limitation arises in the sensitivity to the scattering strength of the dark matter particles. In the near future, the detectors will become so sophisticated and precise that even going deep underground will not shield them

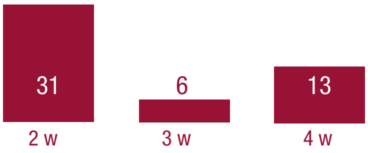
ASTRO-, PARTICLE AND NUCLEAR PHYSICS OF DARK MATTER DIRECT DETECTION

74 registrations

50 participants
from 30 institutions
in 15 different countries

academic seniority:
18 faculty/staff
23 postdocs
9 PhDs

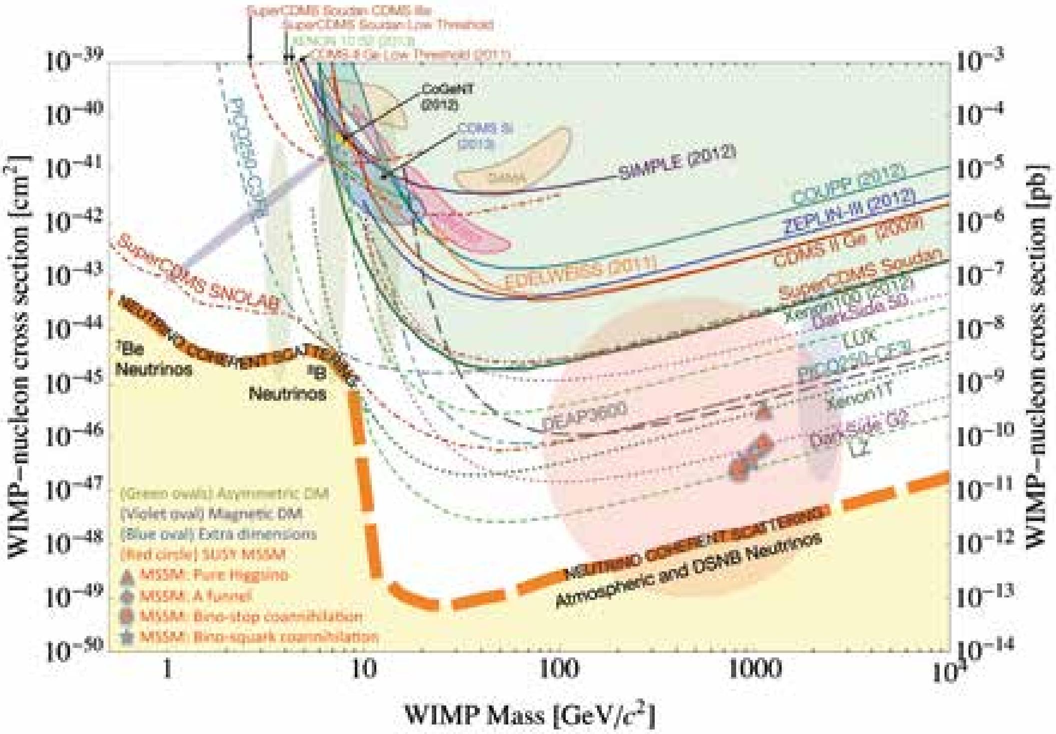
duration of stay:



anymore from the so-called “neutrino floor” (see figure), the background signals of solar, atmospheric and diffuse supernovae neutrinos. In order to be able to detect a dark matter signal, new methods need to be developed. This may involve entirely new detector concepts that do not rely on scattering of nuclei such that the small-mass dark matter region can be explored. Another possibility discussed at the MIAPP programme would make use of dark matter-induced bremsstrahlung. The photon emission from bremsstrahlung in nuclear recoils could be used to circumvent the kinematic limitations of current detectors. In one afternoon session it was furthermore presented how the detection of inelastic scattering signals from nuclear recoils would allow for the detection of a dark matter signal. According to these analyses, already the current threshold limit should allow for a detection of inelastic scattering. In order to be able to detect interactions under these difficult conditions it is necessary to thoroughly understand the theoretical basis of what is expected.

A crucial input to the interpretation of direct detection measurements in terms of dark matter particle properties is the dark matter density in the vicinity of Earth, which might be different from the average density in the Milky Way or in the entire Universe. The number of events expected to be detected with an experimental set-up can only be predicted on the basis of that knowledge. Along with the density it is also important to understand the local dark matter velocity distribution. It turns out to be surprisingly difficult to pin down

> **“I am very grateful to the organisers for providing me this great opportunity of joining this programme. The diversity of research topics covered in this programme have been amazing to me and will be very helpful for my following studies. I hope this kind of programme would help more people extend their research knowledge and collaborate.”**
> *(Dr. Peiwen Wu, Korea Institute for Advanced Study, Seoul, Republic of Korea)*



Sensitivity thresholds of different WIMP dark matter direct detection experiments. So far no dark matter particle has been detected within the green area (current detection limits). The increasing sensitivity (indicated by the solid lines – current experiments – and dashed lines - future experiments) will soon reach the neutrino “floor”, i.e. the neutrino background (yellow area). Then, in order to distinguish between solar, atmospheric and diffuse supernovae neutrinos new methods need to be developed. *Credit: J. L. Feng, S. Ritz, et al., “Cosmic Frontier” in the Proceedings of the APS DPF Community Summer Study (Snowmass 2013), http://www.slac.stanford.edu/econf/C1307292/, arXiv:1401.6085 [astro-ph].*

these two quantities from astronomical data or simulations. Determining the velocity distribution often depends on the underlying shape of the galaxy halo. A new method was presented at the MIAPP programme that allows a comparison of direct dark matter searches in a halo independent way.

The cross-disciplinary composition of the MIAPP programme and the accompanying topical workshop “Direct Dark Matter Detection: Experiment Meets Theory” in the first week of the programme helped to assess these and other open questions related to the determination of the particle nature of dark matter from new perspectives and different angles.

Jan Conrad, coordinator of the first MIAPP programme 2017, explains the idea behind the programme to Ina Haneburger ***(MIAPP programme manager)*****:**

“The existence of dark matter can be deduced from astrophysical observations. Most physicists are convinced that it is made up of new and unknown particles. As these particles could not be identified so far they must be rather inert. Although this is known for quite some years the sensitivity to measure these particles has been reached only recently. The hypothetical weakly interacting massive particles (WIMPs) are strong candidates as they would hardly interact with normal matter. One currently expects one collision per year with one ton of detector material. In consequence, detectors are built with big volumes of detector material to increase the probability to observe collisions. As well, ultra-pure materials are used for the production of the detectors in order to avoid background from radioactive decay within the detector which would render the chance to detect something close to impossible. Furthermore, most detectors are set up far below the Earth surface as collisions from cosmic rays within the Earth atmosphere would create an enormous background. Trillions of non-dark matter particle collisions would lead to an enormous background making it impossible to identify the rare events of dark matter particle collisions.

To identify the putative dark matter particle one has to understand the constraints of its particle nature (particle physicists). To further understand its interaction with normal matter nuclear physicists are needed. Dark Matter density and distribution are necessary ingredients as well (astrophysicists). At “usual” conferences these different disciplines do not meet. We therefore organised this meeting to bring them together.”

COORDINATORS OF THE PROGRAMME “ASTRO-, PARTICLE AND NUCLEAR PHYSICS OF DARK MATTER DIRECT DETECTION”


Photo: MIAPP

DR. RICCARDO CATENA

Chalmers University of Technology, Gothenburg, SWEDEN

- Dark matter direct detection
- Dark matter astronomy and astrophysics
- Dark matter model building

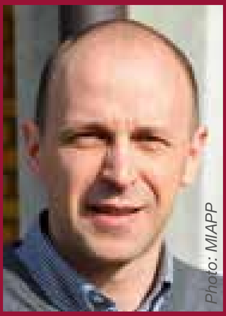


Photo: MIAPP

PROF. JAN CONRAD

Stockholm University, SWEDEN

- Dark matter direct detection with XENON, DARWIN
- Dark matter indirect detection with Fermi-LAT, HESS, CTA

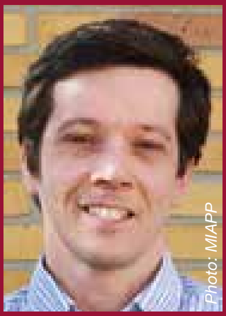


Photo: MIAPP

PROF. CHRISTIAN FORSSÉN

Chalmers University of Technology, Gothenburg, SWEDEN

- Ab initio nuclear theory
- Chiral effective field theory and nuclear interactions
- Quantum few- and many-body physics


Photo: MIAPP

PROF. ALEJANDRO IBARRA

Technical University of Munich, GERMANY

- Theoretical aspects of Dark matter detection (direct, indirect, colliders)
- Dark matter model building


Photo: MIAPP

DR. FEDERICA PETRICCA

MPI for Physics Munich, GERMANY

- Dark matter direct detection with CRESST
- Cryogenic detectors for rare event searches

Simulation of a galaxy hosting a superluminous supernova (SLSN). SLSNe are 10 - 100 times brighter than normal supernovae. Scientists are just beginning to understand what thrives these catastrophic events and how the conditions must be to lead to such a devastating death of a massive star. *Credit: Adrian Malec and Marie Martig; Swinburne University*

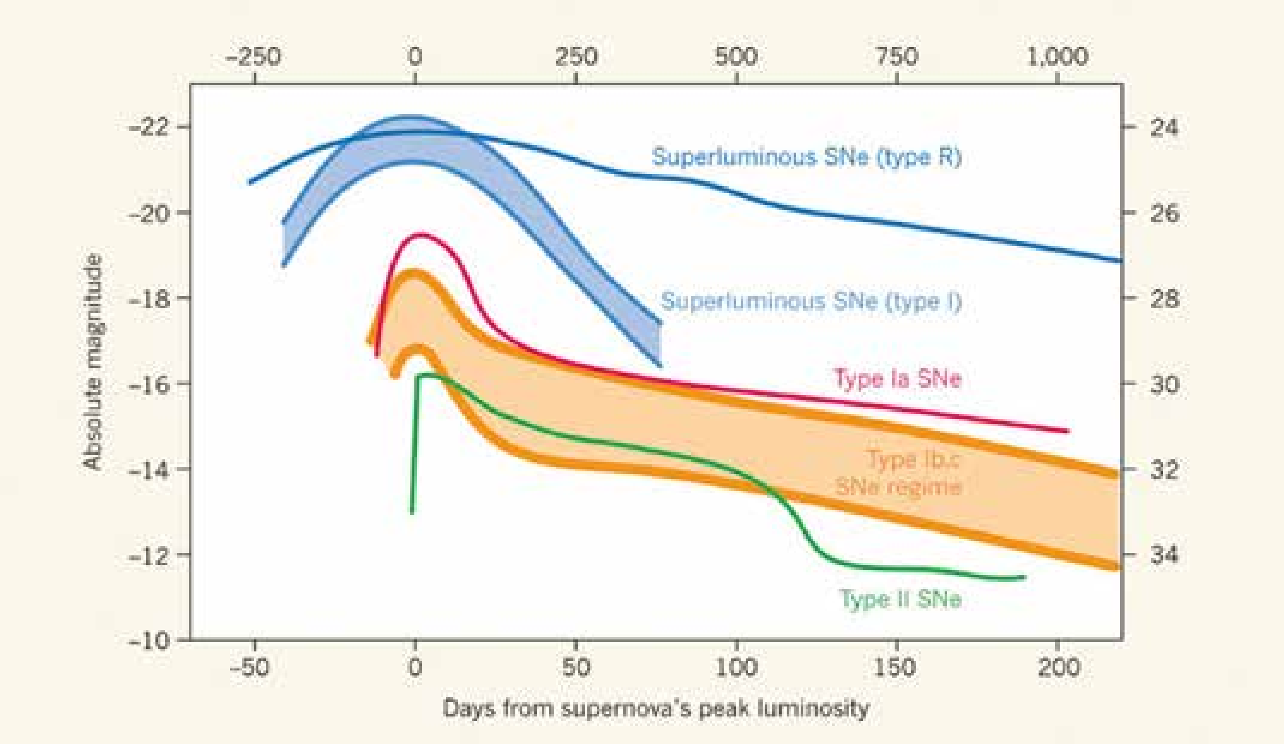
2nd - 26th May 2017

Superluminous Supernovae in the Next Decade

The violent death of a massive star is called a supernova. Enormous energies are released when the star explodes at the end of its life and unleashes its insides to the surrounding intergalactic medium. The dying star is usually as bright as a whole galaxy. However, in recent years with very efficient wide-area supernovae surveys a new class of extremely bright supernovae have been detected. These superluminous supernovae are 10 – 100 times brighter than "normal" supernovae. Their extreme brightness can't be explained within the common framework of stellar evolution and hence new theories have to be developed with respect to the nature of the progenitors and the explosion mechanisms. At the second MIAPP programme in 2017 experts from different fields were gathered to discuss the latest results and future prospects.

COORDINATORS: JEREMY MOULD, FERDINANDO PATAT, JEFF COOKE, LIFAN WANG, ALEXANDER HEGER

One would assume that the brightest things are the easiest to find, but superluminous supernovae (SLSNe) that are 10 – 100 times brighter than ordinary supernovae weren't discovered until about a decade ago. Then, due to technological improvements the first SLSNe have been detected in very efficient wide area surveys of the sky. "Superluminous supernovae are very rare, something like a thousand times more rare than normal supernovae. Therefore, one has to scan a big area of the sky for a long time to catch them", coordinator Jeff Cooke explains. Hence, observations at high redshift and very large distances are advantageous as they allow to observe a larger volume with the same camera and the same field of view. For statistical reasons it is of course more likely to observe SLSNe within a larger field of view and because they are super bright one can see them even if they are far away. As a matter of fact, SLSNe evolve very slow, i.e over hundreds of days. Therefore, long periods of observation times are needed to discover and analyse these events properly. It's only now that the number of detected SLSNe increases after the respective surveys have started to observe a wide area, really deep and over many years. With the available set of data, around 50 SLSNe nearby at low redshift and a dozen far way at high redshift, the scientists now start to figure out what these things are.



Comparison of the luminosity of superluminous and normal supernovae as a function of time. Superluminous supernovae evolve much slower, over hundreds of days, and hence longer periods of observing time are needed to study them. *Figure reproduced with kind permission of Stephen Smartt, Nature 491, 205–206 (08 November 2012).*

Superluminous supernovae are not only rare, weird events of massive stars that explode; they also have the potential to tell a lot about the chemical evolution of the Universe, how stars are formed in the early phases of the Universe (the period of reionisation of the Universe) and they can potentially be used as distance indicators. Hence, they are nice bright beacons with which all the material between them and the observer can be probed. Especially, since they're temporary events one can compare before, during and after the explosion, if all these data have been collected, and put everything together to draw a complete picture.

Classical supernovae (see also “The Physics of Supernovae”, page 23) are either type Ia supernovae involving a thermonuclear explosion of a mass gaining white dwarf in a binary system or, alternatively, are core collapse supernovae of a massive star. None of those two processes can possibly power the enigmatic event of a superluminous supernovae, as this simply wouldn't provide enough energy. Identification of a putative explosion mechanism needs examination of extreme physics in extreme situations like unusual densities, temperatures etc. One leading idea is that SLSNe are fuelled by a magnetar, which is a highly magnetised neutron star. In such a

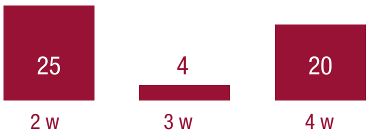
SUPERLUMINOUS SUPERNOVAE IN THE NEXT DECADE

60 registrations

49 participants
from 31 institutions
in 12 different countries

academic seniority:
27 faculty/staff
17 postdocs
5 PhDs

duration of stay:



> **“The MIAPP workshop provided the ideal forum to have all the necessary people working at various institutions all over the world to learn of, and participate in, a coordinated community effort for a multi-cycle Hubble Space Telescope proposal.”**
> *(Prof. Jeff Cooke, Swinburne University, Hawthorn, Australia)*

"Superluminous Supernovae in the Next Decade" programme participants in a discussion session. *Credit: Schürmann/TUM*

> **"I liked very much how the MIAPP workshops are organised. It is an ideal place for starting collaborations, projects and getting ideas for more research"**
> *(Prof. Pilar Ruiz-Lapuente, University of Barcelona, Spain)*

scenario a neutron star with a strong magnetic field would be formed out of a core-collapse supernovae. Next the magnetic energy would get converted into kinetic energy. Alternative theories suggest that SLSNe are examples of the long-theorised pair instability mechanism in extremely massive stars. In a massive star the extraordinary hot temperature in the outer envelope at still pretty low density would lead to the formation of electron positron pairs, which would lead to a reduction of pressure and to a collapse of the star followed by a catastrophic explosion. At this MIAPP programme

A joyful get-together in the "MIAPP garden". To foster scientific exchange and networking MIAPP organises social get-together like "Bavarian Brotzeit", Wine & Cheese events or BBQs.
Credit: Blauwitz/MIAPP

the different options were thoroughly discussed in order to reach a common consensus. As it is difficult to get the telescope time needed to observe all the important aspects of the superluminous supernovae events, there has been a larger effort at MIAPP to coordinate observations more systematically.

> **“For me the main advance was coming together of people with lots of data from all big surveys and seeing that results on emerging samples converge to similar results.”**
> *(Prof. Avishay Gal-Yam, Weizmann Institute of Science, Rehovot, Israel)*

Hubble Space Telescope observing time is especially valuable for the understanding of SLSNe as it allows for a study in the ultraviolet light. As superluminous supernovae are brightest in the ultraviolet with important information contained in UV spectral lines, one can deduce a lot of information to constrain models and theory. Hubble is the dominant instrument that can perform observations in the ultraviolet and it is ending its life soon as the detectors are degrading. It is therefore a race against the time to collect enough data before the possibility to gather those ends in smoke. Hence, a joint proposal for Hubble Space Telescope time was handed in as a result of the MIAPP programme to get spectra in the ultraviolet and to observe their spectral evolution. Alternatively, for SLSNe at large distance and, therefore, high redshift the UV-spectra are redshifted to visual light because of the expansion of the Universe and the giant telescopes at the ground can be used for spectroscopic studies. More and more superluminous supernovae are now found at high redshift. This allows for an investigation of the nature of SLSNe through the course of cosmic time.

COORDINATORS OF THE PROGRAMME “SUPERLUMINOUS SUPERNOVAE IN THE NEXT DECADE”


Photo: MIAPP

PROF. JEREMY MOULD

Swinburne University,
Hawthorn, AUSTRALIA

- Galaxy evolution and dynamics
- Cosmological parameters
- Galaxies and cosmology and the late stages of stellar evolution


Photo: C. Migliore

DR. FERDINANDO PATAT

ESO, Garching,
GERMANY

- Nearby supernovae
- Type Ia progenitors
- Spectropolarimetry of SNe
- Optical spectroscopy and photometry


Photo: MIAPP

PROF. JEFF COOKE

Swinburne University,
Hawthorn, AUSTRALIA

- High redshift supernovae
- Fast transients
- High redshift galaxies and cosmic reionisation
- Interstellar and intergalactic gas


Photo: Wang

PROF. LIFAN WANG

Texas A&M University,
College Station, USA

- Near field cosmology
- Cosmic distance scale
- Supernovae
- Polarimetry
- Astronomical site surveys

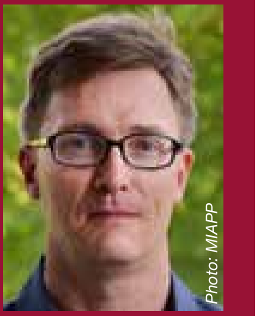
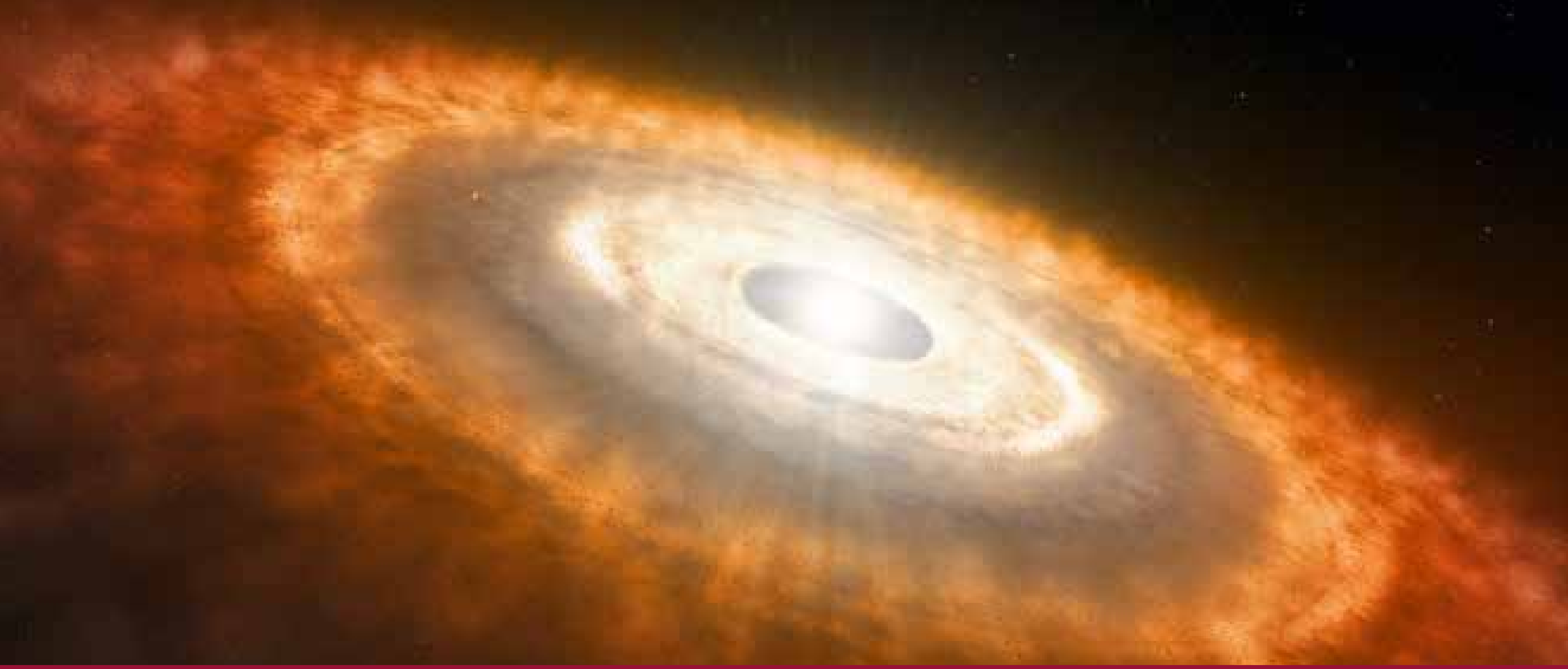


Photo: MIAPP

PROF. ALEXANDER HEGER

Monash University,
Melbourne, AUSTRALIA

- Supernovae
- First stars
- Massive stars
- Gamma-ray bursts
- Stellar rotation
- Nucleosynthesis
- Type I X-ray bursts



Artists impression of a young star surrounded by its protoplanetary disk. The particles of the gas and dust in the disk eventually aggregate and grow bigger and bigger, resulting in the formation of planets. Why and how these planets form was the focus of the third MIAPP programme 2017. *Credit: ESO/L. Calçada*

29th May - 23rd June 2017

Protoplanetary Disks and Planet Formation and Evolution

Where do planets originate from? It is believed that planets are formed when a molecular cloud collapses and a young star is born. The leftover gas and dust forms a disk-like structure – the protoplanetary disk. Over the next million years, the particles inside this disk begin to aggregate and grow larger and larger, eventually leading to the formation of new planets. The composition and evolution of these disks, greatly influences how planets are formed. At the third MIAPP programme experts in disk physics and planet formation came together in order to discuss and work on the relevant issues that determine the formation and evolution of planets in their disks.

COORDINATORS: WILHELM KLEY, BARBARA ERCOLANO, LEONARDO TESTI, CHRISTOPH MORDASINI

In our Milky Way stars are born continuously. They form out of dense clouds of interstellar gas and dust, which become gravitationally unstable and collapse. The conservation of angular momentum of the matter in the cloud inevitably leads to the formation of a disk-like structure orbiting around the newborn stellar core. This disk then becomes the birthplace of planets. Thus, most of the stars born in the Milky Way and in the billions of galaxies in our Universe are surrounded by orbiting planets, which were formed in protoplanetary disks. However, the processes how planets are formed within these disks are extremely complex and not well understood. They rely heavily on the physical properties of the disks. Investigating protoplanetary disks is, thus, the key to understand the formation of planetary systems around stars. With thousands of such planetary systems now discovered showing a stunning and entirely unexpected variety of physical properties the detailed study of protoplanetary disks has become a key research field in modern astrophysics.

For decades protoplanetary disks have been elusive. The dust contained in them makes them opaque at visual light and therefore hides the disks and the processes happening inside. For a long time disks could not be observed directly. More recently, then, at least indirect evidence about their existence and and first knowledge of their physical properties could be

In the last week of the programme the topical workshop “Formation and Evolution of Planets and their Disks“ was held at the Leibniz-Rechen-Zentrum (LRZ) in Garching. Here, additional topics could be addressed that were not in the focus of the main programme. *Credit: Blauwitz / MIAPP*

derived from from the spectral energy distribution of their light emission at different wavelengths using telescopes on the ground and in space observing from very short x-ray wavelengths over the ultra-violet, visual and infrared light to sub-millimeter, millimeter and centimeter wavelengths. This already provided a wealth of information and the interpretation of these data was one of the goals of the MIAPP programme. However, most recently, direct observations of protoplanetary disks with unprecedented spatial resolution have become available through the use of the new ALMA observatory at 5000 m elevation in the Atacama Desert in Chile. These observations have revealed stunning features, like gaps, holes and rings within the protoplanetary disk that very likely are caused by young planets orbiting within the disk around their young host stars. Within inhomogeneous regions of the disks planets might be formed as they most likely indicate regions with concentrated or trapped dust. Especially, extended non-axisymmetric features that have been observed in several protoplanetary disks were at the focus of the discussion at this MIAPP programme. These structures could putatively be formed by the presence of a planet, a massive companion or even the passage of another star. In addition, to the above mentioned features, several disks seem to lack dust in their centre, appearing as a hole devoid of dust. This property of the so called transitional disks is discussed as a signpost for planet formation. At MIAPP it was stressed that in order to draw that conclusion additional studies are critical. One problem that emerged was the determination of the gas mass in the disk as often only the dust signatures that can be observed directly while gas features remain elusive. At MIAPP exciting new data were presented, including new images and surveys obtained with the ALMA observatory.

“I really enjoyed to be part of this programme. The talks had always an informal format which allowed people to ask anytime and to have a great interaction with the speaker. Another great aspect of this programme is that many young researchers had the chance to talk about their work. One of the best programmes I have attended so far!”
(Dr. André Izidoro, São Paulo State University, Brazil)

Numerical hydrodynamical simulations of the formation and evolution and of the spectral light emission of protoplanetary disks are crucial for the analysis of the wide variety

PROTOPLANETARY DISK AND PLANET FORMATION AND EVOLUTION

109 registrations

65 participants
from 30 institutions
in 14 different countries

academic seniority:
27 faculty/staff
26 postdocs
12 PhDs

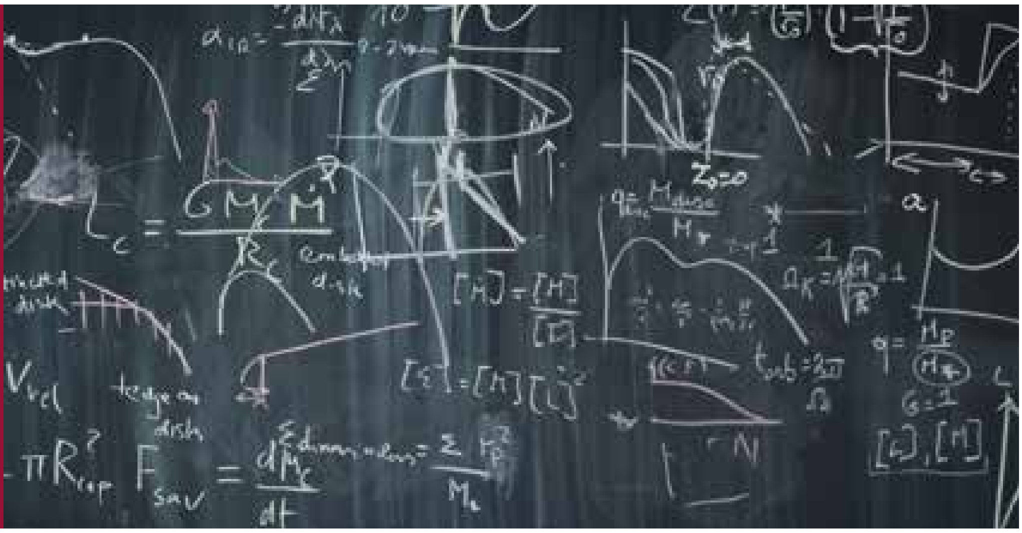
duration of stay:

of large observational data sets and were therefore in the focus of the MIAPP programme. With their help one can deduce the mass in dust and gas, the spatial distribution and temporal evolution of the disks. Coupling observation with theoretical disk models often allows to gain physical insights, such as the mass accretion process building up the disk. The analysis of the mass accretion rate onto the disk as well as the inferred dust mass as a function of the mass of the young protostar can contribute to the understanding of the evolutionary history.

Crucial properties of the disk such as temperature and turbulence velocities greatly influence if and how planets are formed. Only moderate turbulences allow the particles to come close enough together to form aggregates. Furthermore, self-gravity and turbulences may further influence the generation of instabilities, out of which protoplanets form. New magnetohydrodynamic models have been presented at MIAPP that allow conclusions about these mechanisms. It is believed that planets grow in a bottom up process, i.e. through an endless sequence of sticking collisions that start with micrometer sized dust particles all the way to 1000 km sized planets. Dust-gas interactions strongly influence the early growth stages. The growth of planetisimals, i.e. precursors of planets that accrete material through their self-gravity, is therefore a balancing act between the pressure gradient of the gas that leads to rapid inflow of dust and the disruptive forces of individual collisions. Hence, special dust-concentration mechanisms, such as streaming instabilities, vortices and dust self-gravity, are relevant for the early stages in planet formation. Therefore, one needs to understand dust-gas dynamical processes in more detail in order to be able to determine their influence on the overall disk structure. Furthermore, the dust size distribution is of crucial importance for the interpretation of disk observations in continuum wavelength and also plays a major role in the chemical modeling of the disk.

> **"I started new projects, new collaborations, and I also wrote a whole new paper during my stay."**
> *(Prof. Giuseppe Lodato, Università degli Studi di Milano, Italy)*

Numerous most recent detections have given new insights into the extraordinary diversity of exoplanetary systems in our Milky Way. Planets come in very different masses and sizes and show interesting dynamics in their orbits. Full planetary systems with up to seven planets have been found as well as planets in binary star systems. The wealth of new observational data on exoplanets now allows



The blackboard in the MIAPP auditorium after an intense discussion of the physical properties of protoplanetary disks and the comparison of observations with theoretical models.
Credit: Haneburger/MIAPP

statistical analyses of the different planet populations and their occurrence rate. Planets vary a lot in their sizes and dynamical disk properties. They do not form in isolation but rather in planetary systems. The concomitant development of planets in the same protoplanetary disk may result in complex feedbacks among the newborn planets. It is however so far not clear, whether planets, especially the so called super-Earth planets with masses 1 - 10 times the mass of the Earth, form in situ at or close to their observed location or further out and then migrate to their actual position.

Just shortly before the MIAPP programme, in January 2017, another system has drawn a lot of attention, as it became clear that Trappist 1 consists of seven planets. At MIAPP new ideas regarding the accretion of material onto growing planets were presented. This might also be of importance for massive Jupiter-type planets as it is not understood how they can grow this big in the limited lifetime of a protoplanetary disk. Future analyses of exoplanets, their structure and their atmospheres will further contribute to the understanding to their origin and how they evolve. New research projects developed at MIAPP confronting the outcome of large surveys on protoplanetary disks (with ALMA) and the latest results of adaptive optics observations with the imager SPHERE at the ESO VLT on complex structures in disks with theory will greatly contribute to the knowledge about protoplanetary disks and how they evolve.

“I loved this MIAPP programme. The way in which it was structured allowed me both to listen to very interesting talks and discussions from leading experts in the field and to continue my work inspired by all the inputs that I received. I was able to start new collaborations both with previous collaborators and new ones. I feel like I am at pace with all the latest discoveries in the field.”

(Dr. Giovanni Picogna, Ludwig-Maximilians-Universität München, Germany)

COORDINATORS OF THE PROGRAMME “PROTOPLANETARY DISKS AND PLANET FORMATION?”


Photo: MIAPP

PROF. WILHELM KLEY

University of Tübingen,
GERMANY

- Planet formation and evolution
- Binary star systems
- Computational astrophysics


Photo: MIAPP

PROF. BARBARA ERCOLANO

Ludwig-Maximilians-University
Munich, GERMANY

- Star and planet formation
- Protoplanetary discs
- Computational astrophysics


Photo: MIAPP

DR. LEONARDO TESTI

ESO, Garching,
GERMANY

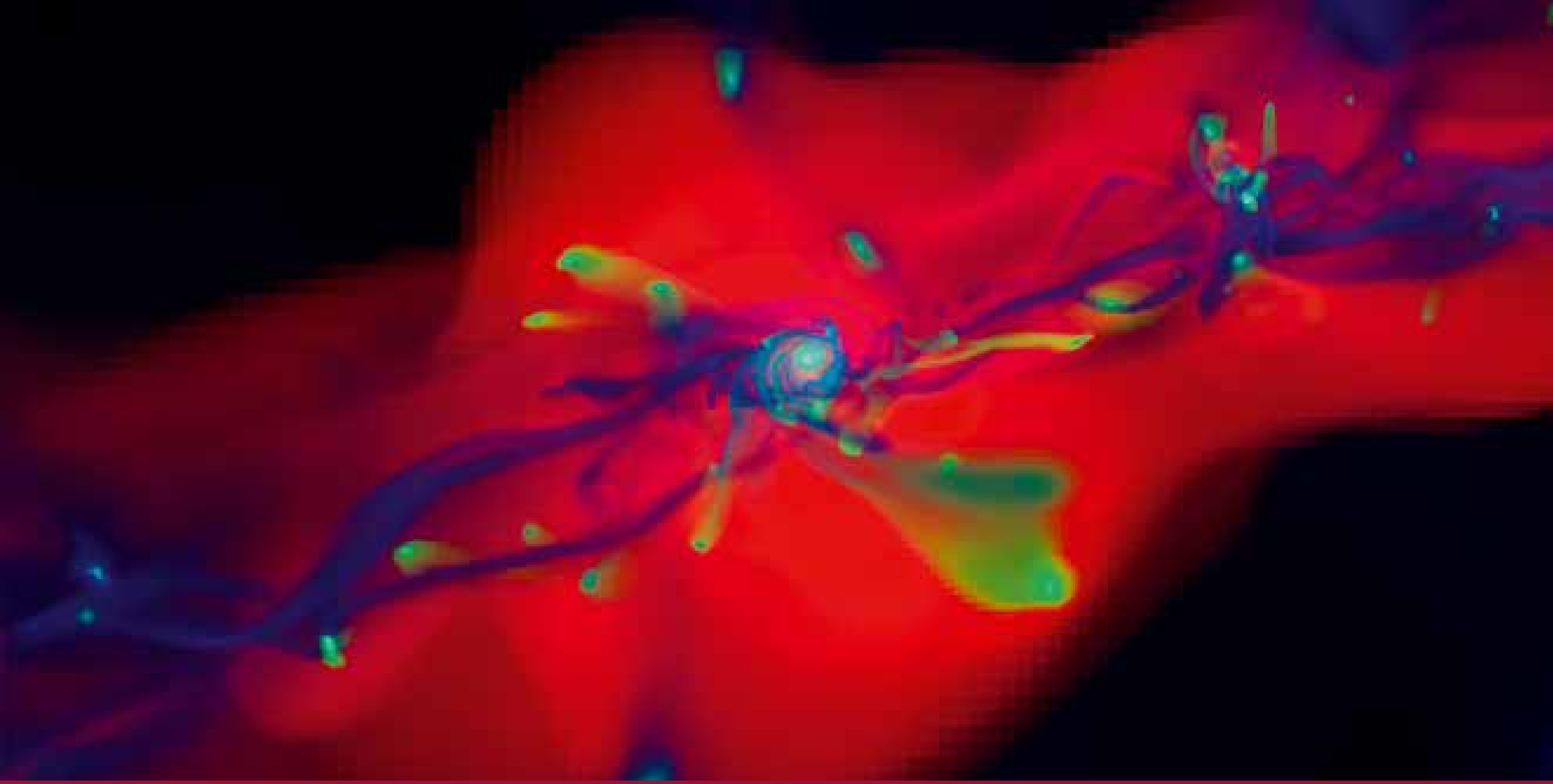
- Formation of stars and brown dwarfs
- Planet forming disks and their evolution
- Disk population


Photo: MIAPP

PROF. CHRISTOPH MORDASINI

University of Bern,
SWITZERLAND

- Planet evolution
- Planetary population synthesis
- Orbital migration
- Evolution of protoplanetary disks



Simulation of a galactic disk of a young galaxy in the early Universe. Cold gas streams (blue) transport new material to the protogalactic disk that serves as material for star formation. The disk is surrounded by shock-heated gas (displayed in red). Metal-rich gas is accreted from smaller nearby galaxies (green).

Credit: Agertz, Teyssier & Moore, 2009, Monthly Notices of the Royal Astronomical Society: Letters, Volume 397, Issue 1, pp. L64-L68

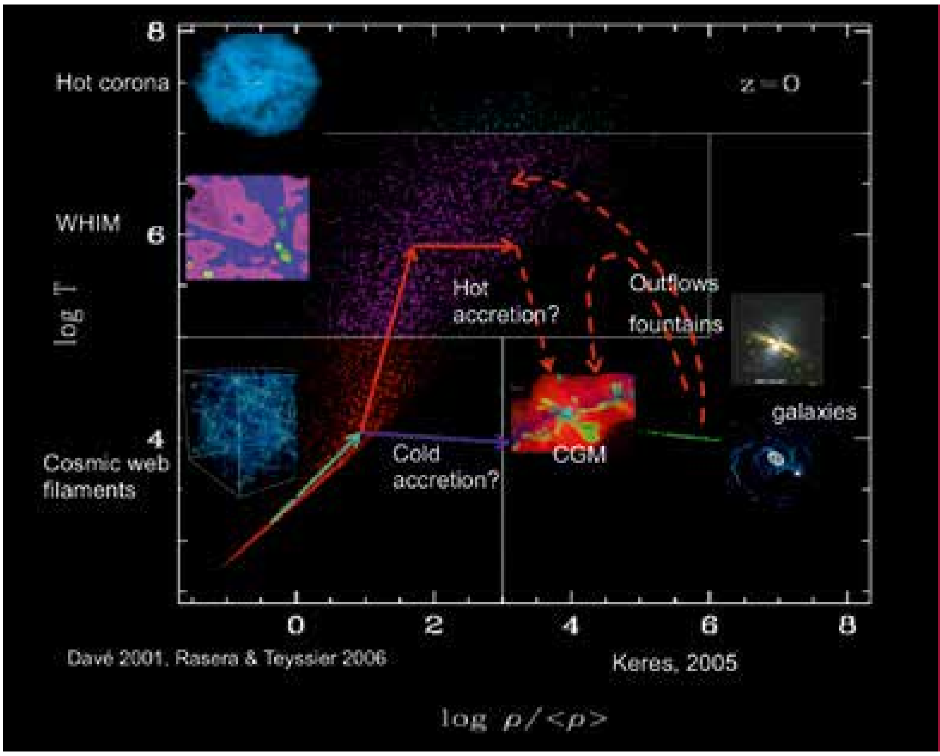
26th June - 21st July 2017

In & Out. What rules the Galaxy Baryon Cycle?

Nowadays, the Milky Way seems to be a steady place that constantly evolves at a rather modest rate of star formation. But the galaxies in the Universe are believed to have been much more vivid in the past with a 10 times increased star formation rate. One attempt to understand this dramatic evolution is to consider galaxies as ecosystems that depends on massive in- and outflow of material, the galaxy baryon cycle. The fourth MIAPP programme 2017 therefore aimed at answering “what rules the galaxy baryon cycle”, providing a full overview of the state of the art and to tackle the different observational and theoretical aspects.

COORDINATORS: PAOLA POPESSO, GABRIELLA DE LUCIA, CÉLINE PEROUX, MARCELLA BRUSA, AMÉLIE SAINTONGE

As we know from the observations of galaxies at very large distances, many billions of light years away, the young Universe provided an extremely active environment filled with galaxies which formed new stars at an extremely high rate ten times the star formation rates of today. But what changed for instance for a galaxy such as our Milky Way in order to become a rather steady place peacefully evolving at a very moderate birth rate of stars of only one solar mass per year? The answer is that galaxies do not live and evolve in isolation. Galaxies are surrounded by matter, the pristine gas of hydrogen and helium which was formed in the Big Bang and the neighbouring galaxies which have formed in parallel, and they accrete this matter because of their own gravity. At the same time galaxies also eject matter through galactic winds caused by the violent explosions called supernovae which happen when stars die. As a consequence, galaxies like the Milky Way are ecosystems where everything is interconnected. The status of the ecosystem depends on the in- and outflow of gas that serves as the fuel for star formation and subsequent stellar death with nucleosynthesis and chemical evolution. This so called galaxy baryon cycle describes the accretion and loss of matter, composed out of baryons, i.e. the atoms originally produced in the Big Bang and in the subsequent chemical



The baryon cycle of galaxies in the context of temperature (y-axis) and density (x-axis). The circum galactic medium (CGM), i.e. the region around the galaxy is the major reservoir of baryons. Further material might be accreted from cold or hot reservoirs such as the cosmic web, the warm-hot intergalactic medium or even hot coronas. The baryons within the CGM then serve as source for star and planet formation. Of course, baryons could also get “lost” in a sense that they are no longer available for star and planet formation as they may have been expelled to the intergalactic medium.

Credit: reproduction with kind permission by Céline Peroux/LAM

evolution processes. The galaxy baryon cycle can be divided into three interconnected phases: The flow of cool gas into the system; the conversion of these baryons into stars and the ejection of gas that is enriched with heavy elements. Understanding what rules the cold gas accretion rate into the galaxy, the efficiency of converting baryons into stars as well as the role of outflowing gas in preventing the infall of new accreted material has reached increasing importance in galaxy formation studies.

The cold gas reservoir out of which stars are born in a galaxy at the presently observed rate of star formation would be consumed within a billion years. Thus, in order to maintain star formation at the even higher rate over ten billion years requires the gas reservoirs to be refilled by an efficient accretion process. Can this accretion process be observed? At the MIAPP programme a wide variety of new observational evidence for accretion was presented. The major source is the the so-called circumgalactic medium. Already in the late 1990s it was suggested that the majority of baryons within a galaxy are hidden there. And indeed, only a minor fraction of baryons is bound in stars while most of them are present in the surrounding gas. Particularly, the warm-hot circumgalactic medium contains a large fraction of baryons. It mainly consists of ionised hydrogen and helium. Baryons can be attracted by hot or cold accretion and then, upon further cooling, may serve as material for star formation. Due to the different spatial scales and physical stages involved in the accretion process multiple observational techniques have to be applied. For example in order to be able to draw conclusions about the baryonic content UV- and X-ray observations have to be combined. UV-spectroscopy is more sensitive but only applicable at lower temperatures while X-ray observations can be made at higher temperatures though at a lower sensitivity. Most of the discussion at the MIAPP programme focused on the observation of neutral hydrogen and heavy elements, “metals”, through near-UV spectroscopic observations of the gas around galaxies. The metal rich gas,

> **“Discussions work well on the scale of a MIAPP and there is time to think about what you’ve heard. So attending a MIAPP I find a much better way of broadening & deepening my knowledge than attending a large-scale, week-long meeting.”**
> *(Prof. James Binney, Rudolf Peierls Centre for Theoretical Physics, Oxford, United Kingdom)*

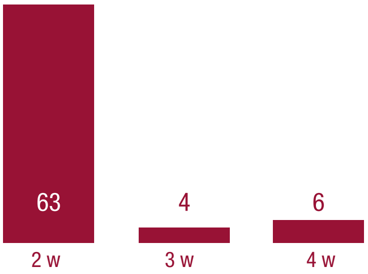
IN & OUT. WHAT RULES THE GALAXY BARYON CYCLE?

120 registrations

73 participants
from 42 institutions
in 8 different countries

academic seniority:
38 faculty/staff
24 postdocs
11 PhDs

duration of stay:




Student session. Every second week the students presented a wrap-up of the last two weeks. As well they could ask senior participants to clarify aspects that did not become clear. *Credit: Haneburger/MIAPP*

which is observed, has very likely been expelled due to supernovae explosions. It will cool down and fall back onto the galactic disk thereby creating a fountain. Such a gas circulation would be sufficient to provide the galactic disk with enough recycled material to maintain star formation and to advance the chemical evolution of the galaxy.

New observations also allow to constrain the evolution of the gas content within a galaxy throughout cosmic time and the efficiency in converting it into stars. Data gained with the new imager MUSE at the ESO VLT and the ALMA radio telescope in the Atacama desert in Chile presented at MIAPP stressed that star formation is not uniform but rather shows significant variations within a galaxy. Furthermore, data from these two instruments indicated that the molecular gas structure is influenced by the local environment such as star clusters or black holes. For instance, the mass accretion in the centre of a galaxy due to a massive black hole, a so called Active Galactic Nucleus, will


Science speed dating. Within five minutes the speed dating participants had to get to the heart of their scientific work and could find out whether they had some overlapping interest and/or complementary expertise. The idea was to stimulate the formation of new collaborations. “The science speed dating was great fun and very useful.” (Dr. Claudia Lagos, The University of Western Australia, Perth, Australia). *Credit: Jessica Werk / University of Washington*

alter velocity and chemistry of the gas and dramatically change the galaxy evolution.

While the observations providing clear evidence of matter accretion and galactic winds are striking, they do not allow to develop a complete coherent and compelling picture of the role of the baryon cycle. Detailed and comprehensive hydrodynamic simulations are needed, which consider the interaction between galaxy dynamics, mass accretion, star formation, stellar death, chemical evolution and galactic winds in the complex galaxy ecosystem. A variety of simulations was presented during the programme and the comparison with observations was heavily debated in a steep learning process where assumptions in the data reductions and observational biases were worked out and at the same time methodical weaknesses in the simulations were emphasized. The participants agreed that this intense exchange resulted in a significant step forward towards the understanding of the big picture of the role of the baryon cycle.

The fourth MIAPP programme 2017 was designed to be a platform for the different communities working at different wavelengths of the electromagnetic spectrum and with diffferent methods to study the gas flows into, within, and out of galaxies, and the processes, which drive their evolution. In order to actively involve younger scientists, students were asked to provide a summary of the programme in the second and the fourth week. In this very interactive discussions senior scientists were also asked to explain results and conclusions in more detail. At the science speed dating participants could present their science in a one to one situation and possibly could find out that they have the same scientific interests and could combine their expertises in order to tackle the problem.

> **“Scientific highlight: Learning about the various different approaches to trace gas flows in galaxies both observationally and theoretically. Bringing together of various experts enabled a broader overview of the status of understanding. It was particularly revealing to find out how different people define apparently similar quantities in very different ways (e.g., mass outflow rates).”**
> *(Dr. Christopher Harrison, European Southern Observatory, Garching, Germany)*

COORDINATORS OF THE PROGRAMME “IN & OUT. WHAT RULES THE GALAXY BARYON CYCLE?”


Photo: MIAPP

DR. PAOLA POPESSO

Technical University of Munich, GERMANY

- Evolution of the star formation activity in group galaxies
- Environmental quenching


Photo: MIAPP

DR. GABRIELLA DE LUCIA

INAF-Astronomical Observatory of Trieste, ITALY

- Structure and formation of dark matter halos
- Theoretical models of galaxy formation and evolution


Photo: MIAPP

DR. CELINE PEROUX

LAM – Laboratoire d’Astrophysique de Marseille, FRANCE

- Cosmic web
- Cold gas accretion
- Galactic winds
- Galaxy formation and evolution


Photo: MIAPP

DR. MARCELLA BRUSA

University of Bologna, ITALY

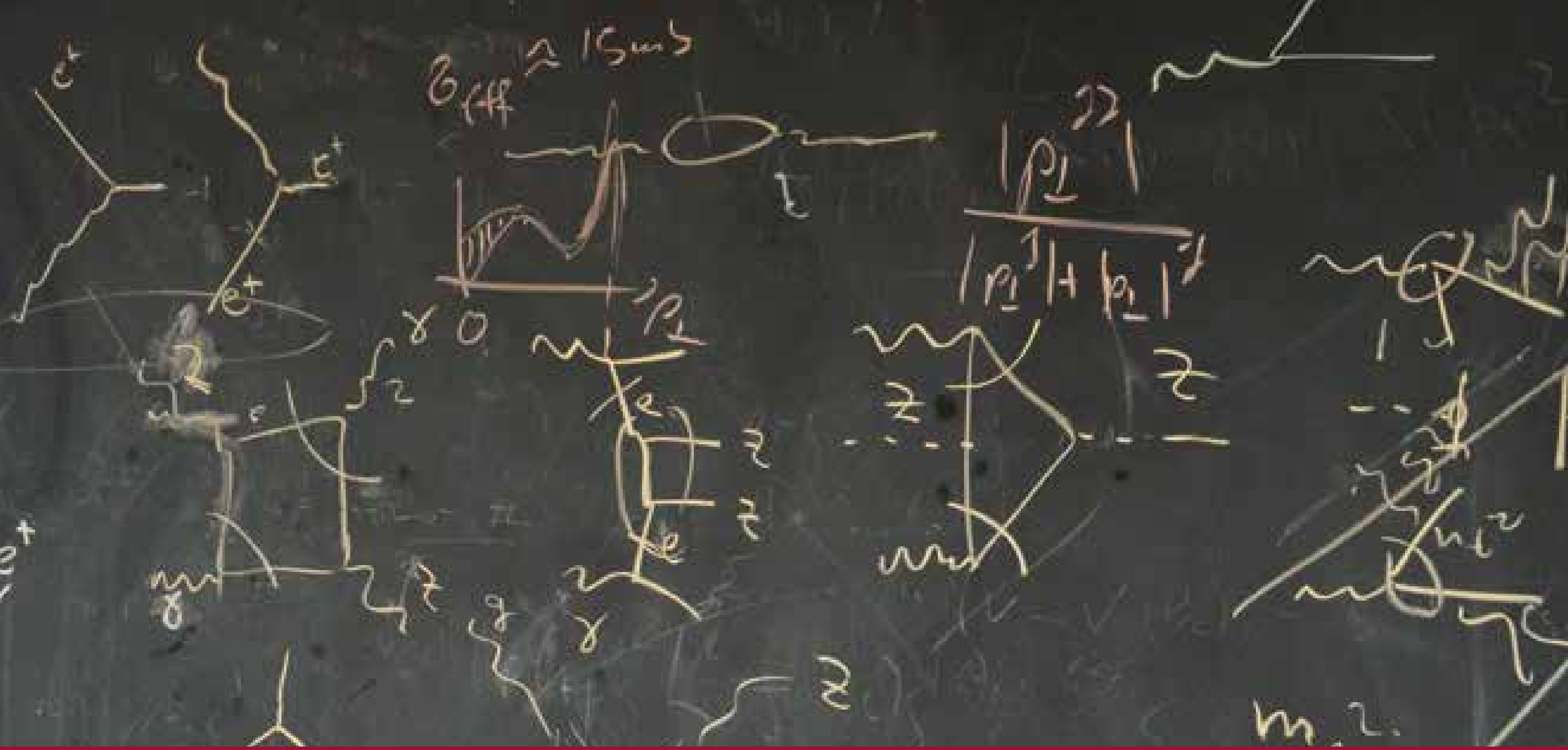
- Active Galactic Nuclei (AGN) surveys
- AGN-host galaxy co-evolution
- AGN feedback and outflows


Photo: The Royal Society

DR. AMELIE SAINTONGE

University College London, UK

- Molecular gas, dust
- Star formation in galaxies at low and high redshift



Several scattering processes depicted as Feynman diagrams. Feynman diagrams are pictorial representations of interactions between subatomic particles that help to visualise these often complex processes. “Translating” these representations into the underlying mathematical expressions and solving them is the focus of perturbative calculations and can often be enormously difficult. *Credit: Haneburger/MIAPP*

24th July - 18th August 2017

Automated, Resummed and Effective: Precision Computations for the LHC and Beyond

The Large Hadron Collider (LHC) at CERN is the most powerful particle collider in the world. Protons are brought into collision to gain more information about Standard Model particles such as the Higgs boson, but also hopes are high to find evidence for physics beyond the Standard Model. Computations of the collision process and quantitative predictions of what should be observed are crucial, so that experimentalists can watch out for signs of new physics. The question how such complex calculations can be done efficiently and precisely brought together theoretical particle physicists from many countries to this MIAPP programme.

COORDINATORS: THOMAS BECHER, MARTIN BENEKE, RIKKERT FREDERIX, KIRILL MELNIKOV, MATTHEW SCHWARTZ

At the LHC protons are accelerated to an energy of about 7000 times their rest mass and subsequently brought into collision. The protons are destroyed in this collision and their energy is converted into a complex final state of elementary particles, among them the decay fragments of very short-lived, “exotic” particles of the Standard Model of Particle Physics, such as the Higgs boson or the top quark. For every collision event, the sophisticated detectors register the energy and momenta of hundreds of particles. When comparing the results of millions of these collisions with theoretical predictions, deviations between the two can hint towards new phenomena. This might be an anomalous property of one of the known particles or the signature of an entirely new particle. The discovery of either would revolutionise the current understanding of the fundamental laws of Nature. Of course, such comparisons rely on the quality of the theoretical predictions, especially when the expected signature is tiny. Theoretical physicists all over the world have taken up the challenge to improve the computational methods and techniques to the sophisticated level required to extract the most information possible from the unprecedented, precise measurements at the LHC.

One of the peculiar properties of the Standard Model and, especially, the strong interaction is that the fundamental rules are exactly known, and even simple, but that the phenomena are complex and the mathematical equations are not simple to solve. In high-energy collisions, perturbation theory is the basic method. The interactions of the elementary particles are pictorially represented by Feynman diagrams, but as the demand for precision and the order in perturbation theory increases, the number of diagrams and their complexity increases quickly, calling for "automation". Even though Feynman diagrams represent "only" manifold integrals, their singularity structure is too complicated to solve them with standard numerical tools. Even worse, in certain important kinematical configurations of a final state at LHC the perturbation expansion fails and an infinite number of Feynman diagrams has to be "resummed", at least in some approximation. The difficulties are both of analytical and conceptual nature, and of making calculations efficient, as the final numerical evaluation often requires large-scale computing resources. "Automation", "Resummation" and "Effective" therefore defined the key words of the fifth 2017 MIAPP programme.

> **"The highlights were certainly the discussions between the fixed order community and the resummed/effective community. It led to a deeper understanding what the others are doing in detail. Some questions arise only after a while of reflection, therefore it is extremely helpful to have the colleagues in the office next door."**
>
> *(Prof. Stefan Weinzierl,*
> *Johannes Gutenberg-Universität Mainz, Germany)*

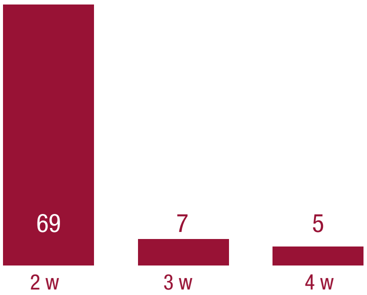
AUTOMATED, RESUMMED AND EFFECTIVE: PRECISION COMPUTATIONS FOR THE LHC AND BEYOND

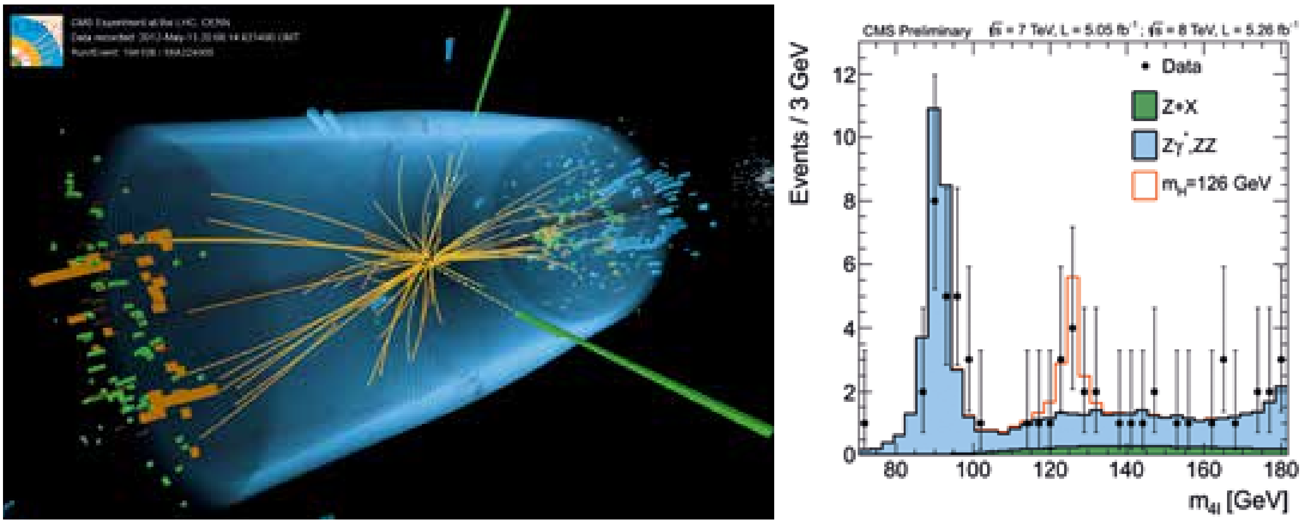
115 registrations

81 participants
from 42 institutions
in 14 different countries

academic seniority:
44 faculty/staff
35 postdocs
2 PhDs

duration of stay:





Collisions at particle colliders like the LHC are analysed to find hints for physics beyond the Standard Model. In 2012 such analyses led to the discovery of the Higgs particle. The left image depicts a collision event recorded in the CMS detector which showed the characteristics of a Standard Model Higgs decaying to two photons (dashed yellow lines and green towers). In order to get an idea for what one is looking for, sound simulations are needed. When the data are later analysed (for example as can be seen on the right, dots: data, shaded histograms: background, un-shaded histogram: signal expectation) and the prediction and measured data coincide, one explanation could indeed be that a so-far unknown decay/particle (here the Higgs boson) has been observed. *Credit: © 2012 CERN, for the benefit of the CMS Collaboration*

For ten years computer codes exist that are able to calculate many scattering processes automatically one order beyond the lowest order in perturbation theory. These codes generate all Feynman diagrams, transform them into the respective mathematical expressions, evaluate them and result in distributions that allow to compare the experimental results with these predictions. For more elaborate processes or when pushing the precision of the calculation to the next order, no automated code exists to date. During the MIAPP programme several groups presented their attempts to build new codes that are able to calculate more sophisticated processes. In this developing stage, different subtraction schemes to tame the singularities of the individual integrals are explored and discussed. Numerical methods can be one solution to this problem, but require efficient analytical methods to decompose a Feynman integral into a multitude of simpler terms that can be solved numerically. Experts in numerical methods participated at the MIAPP programme in order to foster exchange and scientific cross-talk.

Soccer matches among the participants were organised to exercise body and soul as a complement to the brain. *Credit: Haneburger / MIAPP*

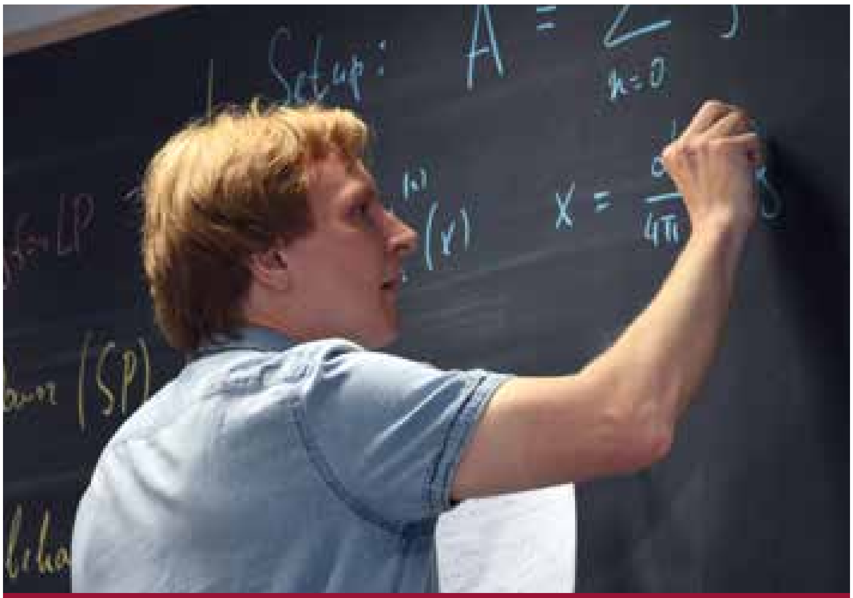
“For me, the highlights were the discussion of collinear factorisation violation using the SCET Glauber formalism during the first week and the discussions around formal accuracy of parton showers that went on during the third week. Both led to further discussions around the questions of non-global-logarithm sensitive observables and analytic understanding of Monte Carlo phase space integration that are in the process of being turned into concrete research projects.”

(Dr. Marat Freytsis, University of Oregon, Eugene, USA)

The simplest and most universal method to address resummation are the so-called parton shower calculations. Parton shower generators are computer programmes that simulate the complex final state of an high-energy collision by the splitting of virtual quarks and gluons into pairs of quarks and gluons. Since parton showers are routinely used by the experimental collaborations, a major present problem is the upgrade of these algorithms to next-to-leading order accuracy. The theoretical foundations of parton showers were reviewed and debated at the MIAPP programme. An alternative to parton showers is analytic but process-dependent resummation on which much progress has been made in recent years using the framework of effective quantum field theories. The advances in understanding the factorisation of energy scales of more complicated final states have considerably enlarged the power of analytic resummation, and a great effort is now put into the automation of resummation. The MIAPP programme was the first to cover all these different areas of research and particular emphasis was put on promising topics somewhat aside the current mainstream, such as automated electroweak calculations, parton showers with resonances, power corrections to high-energy processes, and Glauber and double-parton scattering.

This MIAPP programme was also characterised by a light schedule with only three seminars per week, a few extra discussion sessions and much time for work. The coordinators insisted on blackboard presentations only, which invited spontaneous discussions. Established collaborations met at the programme to pursue their work and some new collaborations emerged.

In the end it was clear that the quest for precision at LHC will remain a worthwhile theoretical effort for some time. Bringing together experts from the different communities in precision collider physics helped to understand the beauty and the traps of the "competing" methods and to improve each owns approach. The effort to turn Feynman diagrams into precise numerical predictions is complemented by the amazing mathematical structure inherent to these expressions. Quite a few participants therefore also attended the subsequent MIAPP programme, devoted to this topic.


Prof. Alexander Penin from the University of Alberta giving his blackboard presentation on logarithms in power corrections. *Credit: Haneburger/MIAPP*

> **"The MIAPP provided me with the place and the atmosphere to focus on some problem that I had been struggling with for some time. During my stay at the MIAPP I managed to take a huge step forward and could solve most of the roadblockers. The stimulating atmosphere at the MIAPP and the discussions with the other participants were instrumental in order to make this possible. "**
> *(Prof. Claude Duhr, CERN, Geneva, Switzerland & Catholic University Louvain, Belgium)*

COORDINATORS OF THE PROGRAMME "AUTOMATED, RESUMMED AND EFFECTIVE: PRECISION COMPUTATIONS FOR THE LHC AND BEYOND"


Photo: MIAPP

PROF. THOMAS BECHER

University of Bern,
SWITZERLAND

- Collider physics
- Effective quantum field theories
- Resummation


Photo: Eckert/TUM

PROF. MARTIN BENEKE

Technical University
of Munich,
GERMANY

- Collider physics
- Effective quantum field theories
- Heavy-quark physics
- Particle dark matter physics


Photo: MIAPP

DR. RIKKERT FREDERIX

Technical University
of Munich,
GERMANY

- Collider physics
- Perturbative computations
- Event generation


Photo: MIAPP

PROF. KIRILL MELNIKOV

Karlsruhe Institute
of Technology (KIT),
GERMANY

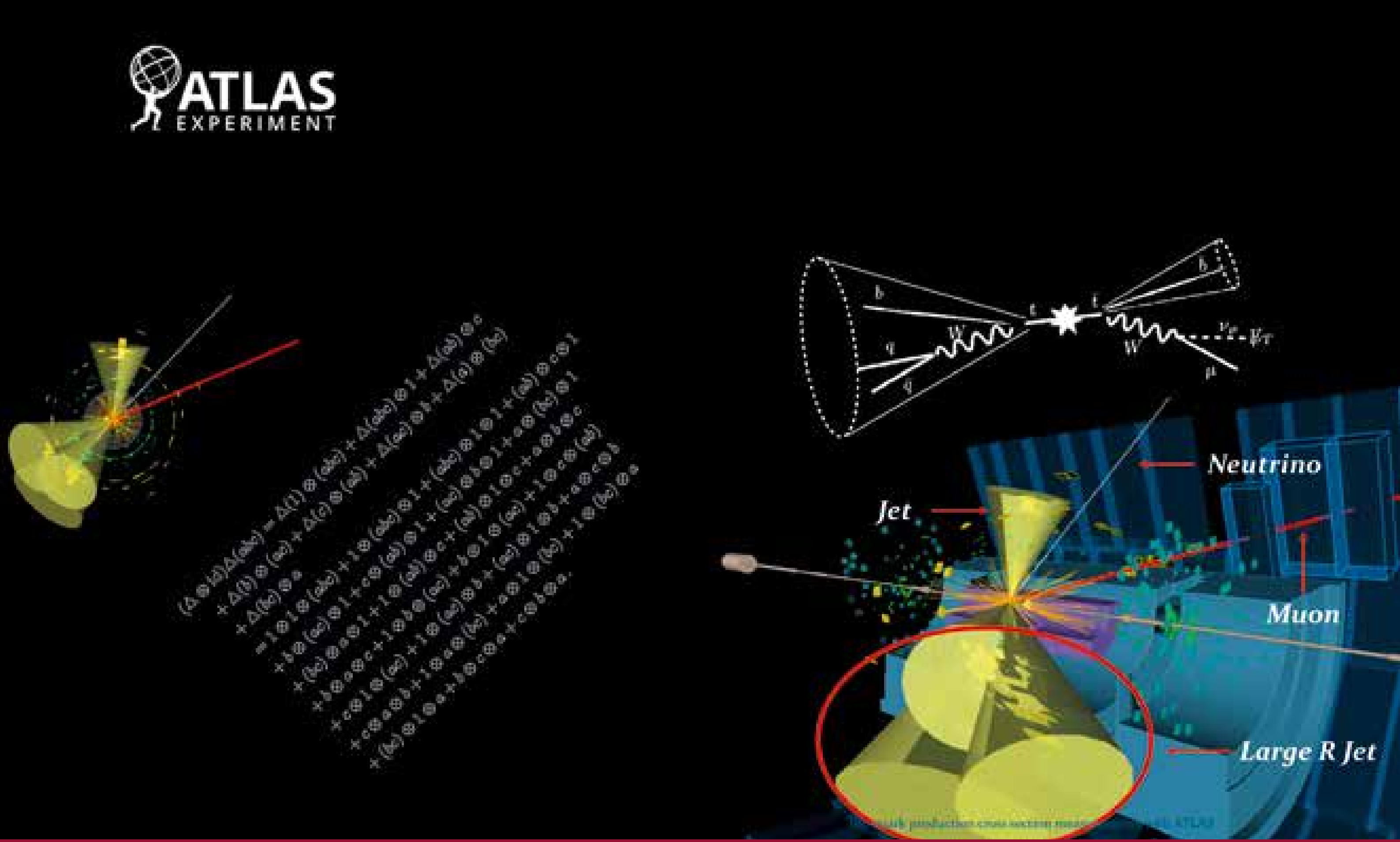
- Collider physics
- Heavy-quark physics
- Higher-order computations


Photo: MIAPP

PROF. MATTHEW SCHWARTZ

Harvard University,
Cambridge,
USA

- Collider physics
- Jet physics
- Effective quantum field theories



Scattering amplitudes describe the interaction of elementary particles. In order to be able to compute complex decay processes new methods need to be developed. The sixth MIAPP programme 2017 was designed to foster crosstalk between pure mathematics and theoretical physics in order to extract new insights and methods stimulated by the different perspectives. *Credit: ATLAS Experiment © 2018 CERN. Re-used with permission and Claude Duhr, Mathematical aspects of scattering amplitudes, arXiv:1411.7538v1; collage: MIAPP*

21st August - 15th September 2017

Mathematics and Physics of Scattering Amplitudes

Traditionally physicists have used scattering amplitudes mostly as a tool to compare quantum field theories to observations. Recent years however have seen an explosion of progress in our understanding of scattering amplitudes as interesting objects on their own right. Large classes of amplitudes, whose computation would have seemed unthinkable even ten years ago, can now be derived with pen and paper on the back of an envelope using a set of ideas broadly referred to as "on-shell methods". This has enabled the determination of scattering amplitudes of direct interest to experiments, while at the same time opening up novel approaches to the foundations of quantum field theory, amongst other things revealing surprising and deep connections with areas of mathematics ranging from algebraic geometry to combinatorics to number theory. The sixth 2017 MIAPP programme hosted theoretical physicists and mathematicians to explore and deepen these connections further.

COORDINATORS: STEPHAN STIEBERGER, LANCE DIXON, CLAUDE DUHR, LIVIA FERRO

Quantum mechanical particles behave in a purely probabilistic way. These probabilities are determined by the absolute square of sums of complex numbers – also called amplitudes – which can be calculated using the rules of quantum mechanics. These amplitudes are an important link between experiment and the underlying theory. The most important amplitude calculations are those used to predict the scattering of particles.

With their help theorists can predict which results can be expected from a certain experimental set up at particle colliders. Traditionally, scattering amplitudes have been calculated using a so-called perturbative expansion: one starts from the solvable, linear part of a quantum field theory and adds successive non-linearities as small perturbations to the solvable part. This expansion has a pictorial representation: the famous Feynman diagrams. First introduced in 1948, they have been the main tool to calculate the behaviour of subatomic particles by determining their scattering amplitudes. Nevertheless, their mathematical complexity soon gets rather difficult to handle.

The number of Feynman diagrams contributing to a given amplitude grows exponentially with the number of particles involved. A process describing the (so-called tree-level) scattering of two force carriers of the strong force (gluons) into two other gluons involves just

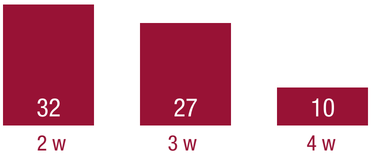
MATHEMATICS AND PHYSICS OF SCATTERING AMPLITUDES

112 registrations

69 participants
from 34 institutions
in 12 different countries

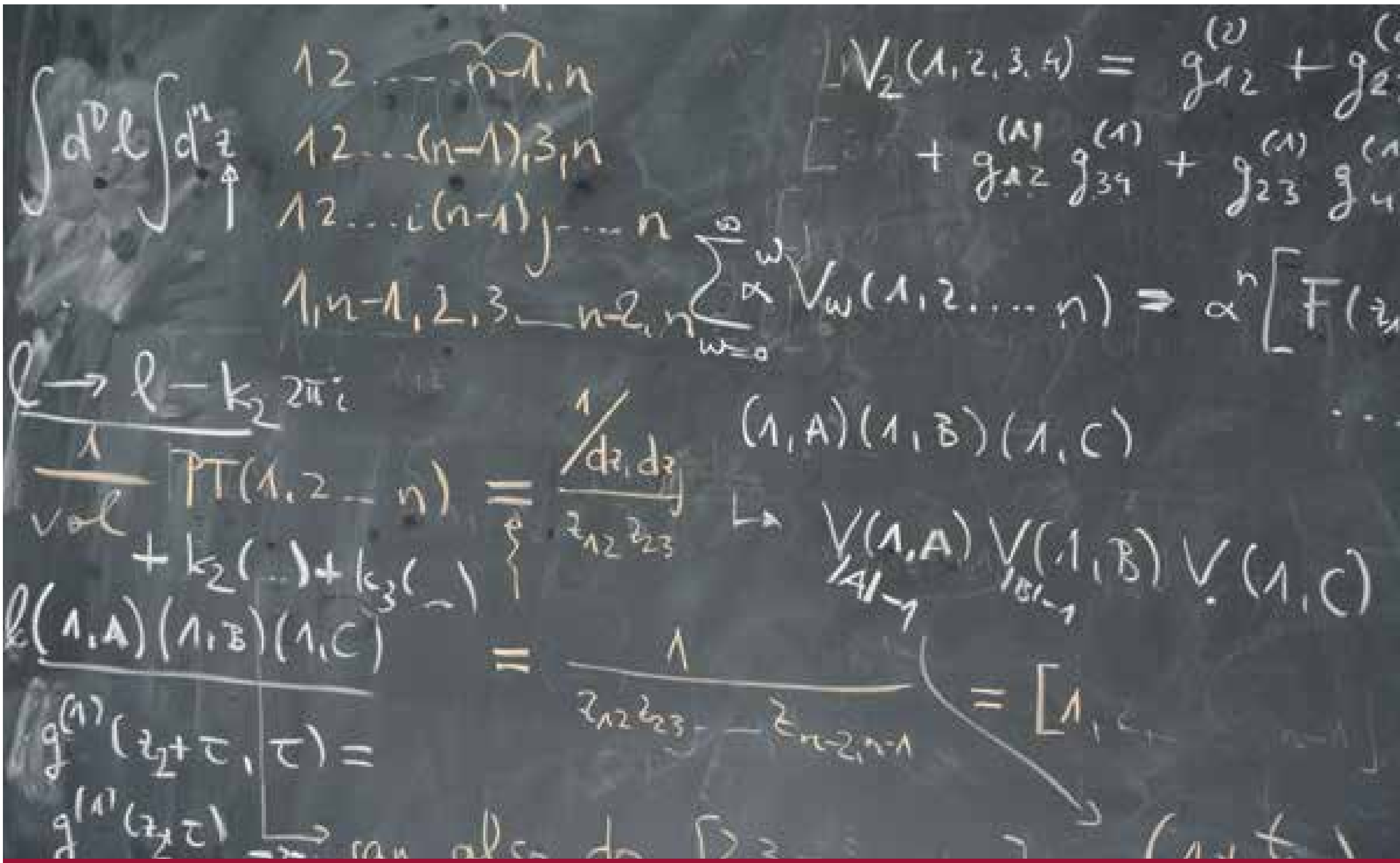
academic seniority:
32 faculty/staff
27 postdocs
10 PhDs

duration of stay:



> **“Very happy with the visit, learned a lot of new ideas and had both illuminating and inspiring discussions. A good venue as well – one is bound to bump into each other. Furthermore, the focus was on discussions rather than on talks, a format that I am especially fond of.”**
> *(Prof. Herbert Gangl, Durham University, United Kingdom)*

Discussion session after the talk of Prof. Dirk Kreimer, Mathematical Institute of the Humboldt-Universität zu Berlin, Germany. The crossdisciplinary backgrounds of the participants largely contributed to a refined understanding of the mathematical structure of scattering amplitudes. *Credit: Yang Zhang / ETH Zurich.*



MIAPP blackboard after an afternoon of intense discussion. *Credit: Haneburger / MIAPP.*

four Feynman diagrams — a calculation which can be done by any graduate student worth her or his salt. The leading order scattering amplitude of two gluons into four gluons already requires the evaluation of 220 Feynman diagrams, and the process with eight gluons in the final state needs a staggering million diagrams to be determined. The resulting scattering amplitude, however, can be strikingly simple. An early example in 1984 was the Parke-Taylor formula for a specific scattering configuration (maximally helicity violating amplitudes). What would take pages of Feynman diagram calculations, can be extracted from a one-line formula. This seems to indicate that Feynman diagram calculations are mostly just complicated ways of summing terms to zero. The textbook formulation of quantum field theory is plagued by a redundancy that undercuts any fundamental meaning to the terms used to define Feynman diagrams. By applying any old field redefinition, we can map one theory into an infinite set of different theories describing identical physics. This one-to-infinity mapping has its disadvantages. First of all, these redundancies spawn a correspondingly redundant set of Feynman diagram representations of the same scattering. Secondly, a poor choice of field basis may obscure or altogether conceal certain underlying structures of the theory. The most famous example is the still to be understood mystery that the scattering of gravitons appears to be the square of the corresponding gauge-theory scattering amplitude. This motivates the use of new variables

“I think the MIAPP is a great addition to the research infrastructure in our field and should continue and grow!”
(Prof. Jan Plefka, Humboldt-University Berlin, Germany)

Participants of the fourth week of the programme "Mathematics and Physics of Scattering Amplitudes".
Credit: Anne Klitsch / ESO

> **"I found the part of the meeting I participated in extremely stimulating because it forced me to consider aspects of loop integrations I had been avoiding for years. The idea of bringing in people closer to pure mathematics was a very good choice because those invited actually managed to present material in a manner that was clear and understandable. So I actually learned a lot and I was forced to think about new issues - the perfect result of a programme."**
> *(Prof. Poul Damgaard, Copenhagen University, Denmark)*

where the simplest is the spinor-helicity formalism but many more have been developed and discussed during the programme.

In order to calculate the scattering amplitude beyond the leading order, one has to sum up all terms resulting from the Feynman diagram and subsequently needs to solve the integral over internal loop momenta. This may sound pretty much straight forward but turns out to be rather complex. The equations may contain so-far unknown integrals. Accordingly, one of the hot topics of the sixth MIAPP programme was elliptic integrals and elliptic polylogarithms. Various versions of these functions have appeared in two-loop QCD computations for the Large Hadron Collider (LHC) and in one-loop superstring amplitudes. A complete theory is still lacking. These objects are also being studied by mathematicians. During the programme, a new collaboration has been formed that analyses how to connect the elliptic polylogarithms that appear in pure mathematics and string theory to Feynman integrals.

Intensive time was also spent on the ambi-twistor string approach to loop amplitudes and its relation to conventional string theory. Another approach to multi-loop amplitudes, at least in planar N=4 super-Yang-Mills theory, is to bootstrap them by writing down an ansatz for the amplitude as a linear combination of functions from a suitable function space, and then fixing unknown parameters using properties in various factorisation limits. There was a large group of people interested in geometric approaches to scattering amplitudes, both physicists and mathematicians. It led to many discussions on the so-called amplituhedron construction which is of huge interest to both communities. In particular, the mathematicians Nicholas Early and Hugh Thomas explained the more mathematical aspects of it and had plenty of interesting discussions with physicists.

This programme led to a more refined understanding of the mathematical structure of scattering amplitudes, for example: From the perspective of the integrand, and its geometric description in terms of the amplituhedron; how integrability is manifested at this level and at the level of integrated amplitudes; how Cosmic Galois Theory is reflected in certain amplitudes; and how elliptic polylogarithms encountered in one-loop string amplitudes can also be relevant for multi-loop field theory amplitudes. There was also work on relating amplitudes in different theories to each other, going beyond the gauge-gravity, Freddy Cachazo, Song He, and Ellis Yuan (CHY) and ambitwistor-based relations. New formulae were found for graviton scattering in terms of gluon scattering. Differential equations were applied to various field-theory relations, and extensions of the tree-level string-theoretic Kawai, Lewellen, Tye (KLT) relations were extended to the loop level. It might take a while longer before one can discern which of these developments will have the most impact.

COORDINATORS OF THE PROGRAMME “MATHEMATICS AND PHYSICS OF SCATTERING AMPLITUDES”


Photo: Anne Klitsch

PROF. STEPHAN STIEBERGER

Max Planck Institute for Physics,
Munich, GERMANY

- Non-perturbative effects in superstring theory
- Perturbative string theory: string amplitudes
- Gauge and gravity theories from/in string theory


Photo: Anne Klitsch

PROF. LANCE DIXON

SLAC, Stanford University,
USA

- Perturbative QCD for colliders
- Scattering amplitudes in QCD and supersymmetric theories
- Standard Model backgrounds to searches for new physics


Photo: Anne Klitsch

PROF. CLAUDE DUHR

CERN, Geneva, SWITZERLAND
& Catholic University Louvain,
BELGIUM

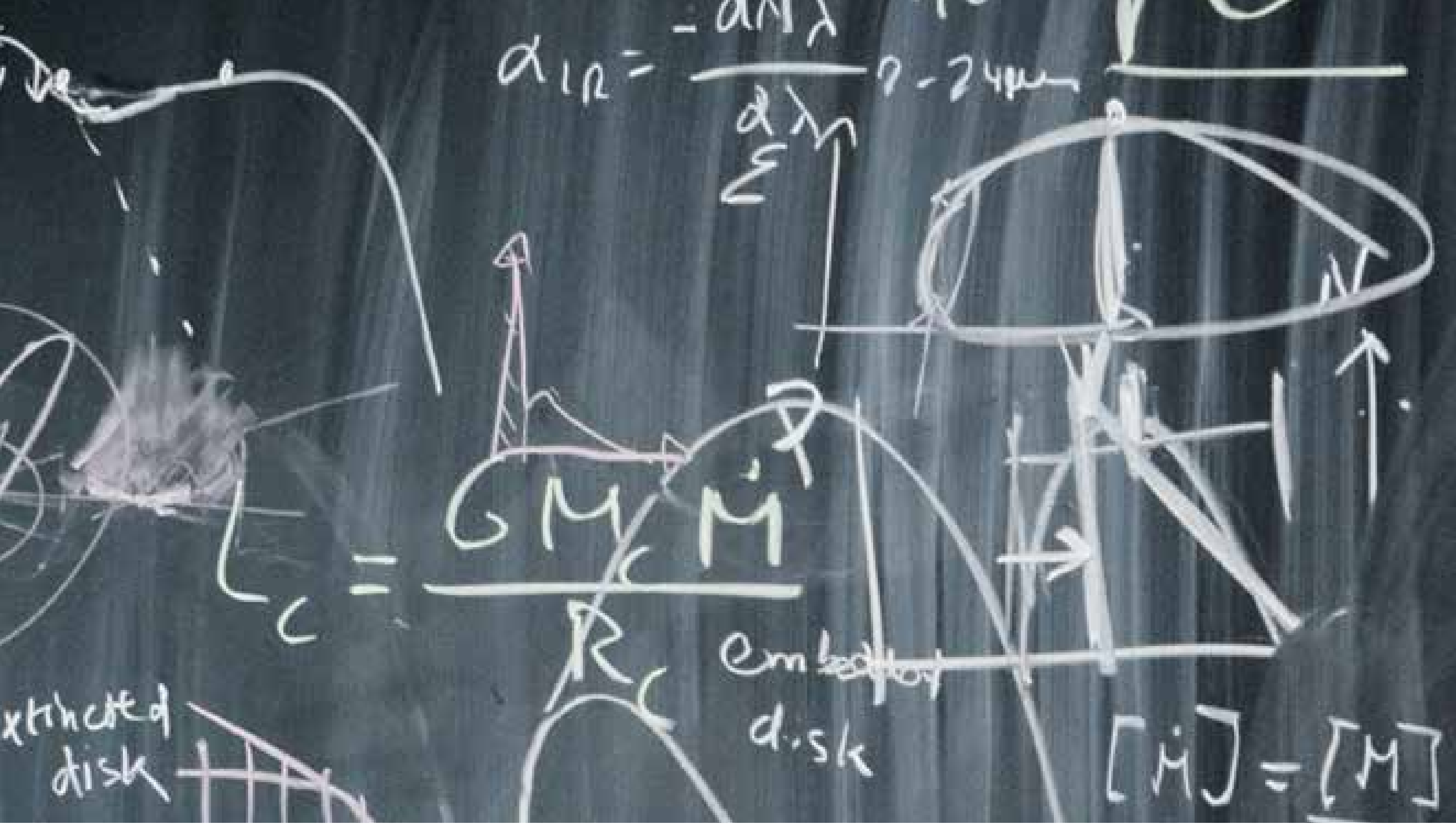
- Scattering amplitudes and higher order computations in gauge theories
- Multi-loop computations in QCD & N=4 Super Yang Mills theory
- Mathematical properties of Feynman integrals.

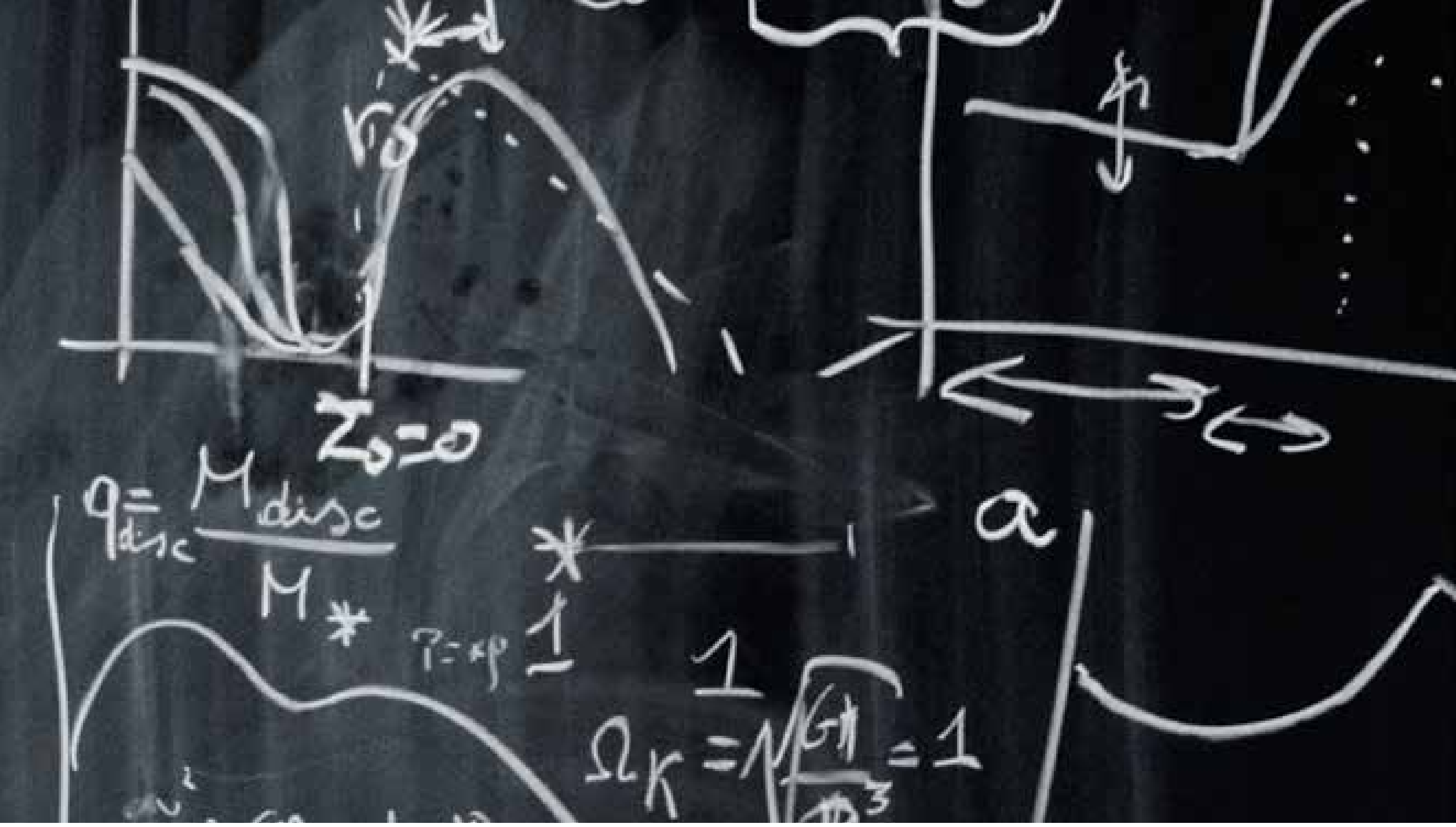

Photo: Anne Klitsch

PROF. LIVIA FERRO

Ludwig-Maximilians-
Universität München,
GERMANY

- Scattering amplitudes in supersymmetric theories
- Geometric formulations of scattering amplitudes
- Quantum integrability in gauge theories


$\alpha_{IR} = \frac{-d\lambda F_\lambda}{d\lambda}$ 2-24μm
$L_c = \frac{GM_c\dot{M}}{R_c}$
extincted disk
embedded disk
$[\dot{M}] = [M]$



FACTS & FIGURES

The MIAPP building at the Forschungszentrum Garching. In front of the building is the MIAPP “beer garden”.
Credit: Haneburger / MIAPP

What is MIAPP?

The Munich Institute for Astro- and Particle Physics (MIAPP) is part of the interdisciplinary research project Cluster of Excellence „Origin and Structure of the Universe“. The Cluster joins about 45 different working groups with around 200 scientists from physics institutes in Garching and Munich. It already had an elaborate programme for visiting researchers but wanted to promote the interaction and scientific exchange by providing a designated meeting place. Consquently, MIAPP was founded in 2012 starting with its first programmes in 2014. The institute is generously funded by the German Research Foundation allowing to rent and maintain the MIAPP building, a small staff as well as to support the long stays of MIAPP participants.

MIAPP organises six four-week programmes and several shorter topical workshops per year, featuring

The MIAPP seminar room provides space for approx. 45 people and is equipped with a long blackboard as well as a projector and screen. *Credit: Haneburger/MIAPP*

The MIAPP lounge area is a nice place for spontaneous gatherings and informal discussions. *Credit: Haneburger / MIAPP*

recent and exciting topics from astrophysics, cosmology, particle and nuclear physics. Physicists from all over the world can suggest a programme. Out of the many proposals submitted, the MIAPP committees select the most appealing programmes according to criteria such as timeliness, quality of the proposal and feedback by the target community.

In order to set MIAPP apart from ordinary conferences, participation at MIAPP programmes requires at least a stay of two weeks. During their time at MIAPP every of the 45 attendees per week is provided with a well-equipped desk to allow for focussed, individual work. The majority of desks is located in the MIAPP building, in offices ranging from single offices to offices with five desks. Together with the common areas this ensures an open atmosphere as one can easily find the colleague/expert next door who could provide valuable input or feedback. Social gatherings such as wine and cheese, Bavarian Brotzeit or BBQs, are the ideal platform for a pleasant chat with colleagues. To strengthen oneself, coffee and snacks are available in the MIAPP kitchen during the day. Here, a fully equipped kitchen is at the participants' disposal.

Every participant gets a desk assigned. Office sizes range from single offices to larger offices with up to five desks. Every desk is equipped with a telephone, desk lamp, LAN cable, base cabinet and office supplies.
Credit: Haneburger/MIAPP

Around 400 researchers come to MIAPP every year, most of them from institutes around the world, while about one fifth comes from a local partner institution. The scientific schedule and content of each programme is organised by the proposers. In order to preserve the spirit of MIAPP and to set MIAPP apart from an ordinary conference venue a loose schedule with at most one session a day and plenty of time for collaborative work is recommended. The spectrum of sessions ranges from plenary talks or discussion sessions over mini-workshops to chalk and talk sessions. The scientific coordinators select a well-balanced mix of experts, established scientists and young researchers. In order to allow talented young researchers to join a MIAPP programme up to five PhD stipends, covering part of their travel costs, are awarded to excellent graduate students.

The MIAPP team (from left to right): Prof. Dr. Andreas Weiler (director), Prof. Dr. Rolf Kudritzki (director), Susann Blauwitz (adminsitrative coordinator), Dr. Ina Haneburger (programme manager), Sandra Schmid-Willers (administrative coordinator), Prof. Dr. Martin Beneke (director) and Theresa Kämper (adminstrative coordinator).

Credit: Schürmann / TUM and Haneburger / MIAPP

The MIAPP Team

The local organisation of the MIAPP programmes is in the hands of a small team, headed by the three MIAPP directors. Prof. Dr. Martin Beneke and Prof. Dr. Andreas Weiler are particle physicists from the Technical University of Munich, while Prof. Dr. Rolf Kudritzki is from the University Observatory of the Ludwig-Maximilians-University Munich. The directors coordinate MIAPPs operation and are in charge of all scientific aspects of the organisation. Programme Manager, Dr. Ina Haneburger, manages all administrative aspects and assists the coordinators in the scientific preparations as well as the follow-up reporting, assessment and documentation. The team is completed by the three administrative coordinators Susann Blauwitz, Theresa Kämper and Sandra Schmid-Willers. They are in charge of the hands-on organisation of every programme. Sandra, Susann and Theresa furthermore accompany the scientific coordinators from the selection of the programmes to the final implementation and are the first line response for all requests of the MIAPP participants. They guide the coordinators through the selection process of participants, set up the webpage and prepare all documents needed for the programmes. In the run-up of the programmes they furthermore assist with finding suitable accommodation and visa issues. After the start of the programmes the local team helps with any request on site and is read to assist. Most importantly they take care of the physical well-being of the participants by preparing coffee breaks and social get-together. As well, it is them who handle financial support. System administrator Michael Nies from the Excellence Cluster Universe helps with all issues related to computers and internet access. Two accountants from the Excellence Cluster, Gabriele Hartmann and Kinga Szigli, together with managing director PD Dr. Sonja Dames takes care of the smooth transaction of the financial support.

Together this well-established team works hard to ensure successful programmes and unforgettable stays at MIAPP.

Committees 2016 / 2017

SCIENTIFIC ADVISORY BOARD:

- Prof. Lance Dixon, Stanford University (Chair)
- Prof. Richard Ellis, California Institute of Technology
- Prof. Francis Halzen, University of Wisconsin-Madison
- Prof. Jeremy Mould, Swinburne University of Technology
- Prof. Yosef Nir, Weizmann Institute of Science

FORMER MEMBERS SAB:

- Prof. Riccardo Barbieri, Scuola Normale Superiore Pisa (until 2015)
- Prof. Scott Tremaine, Institute for Advanced Study Princeton (until 2015)

PROGRAMME COMMITTEE:

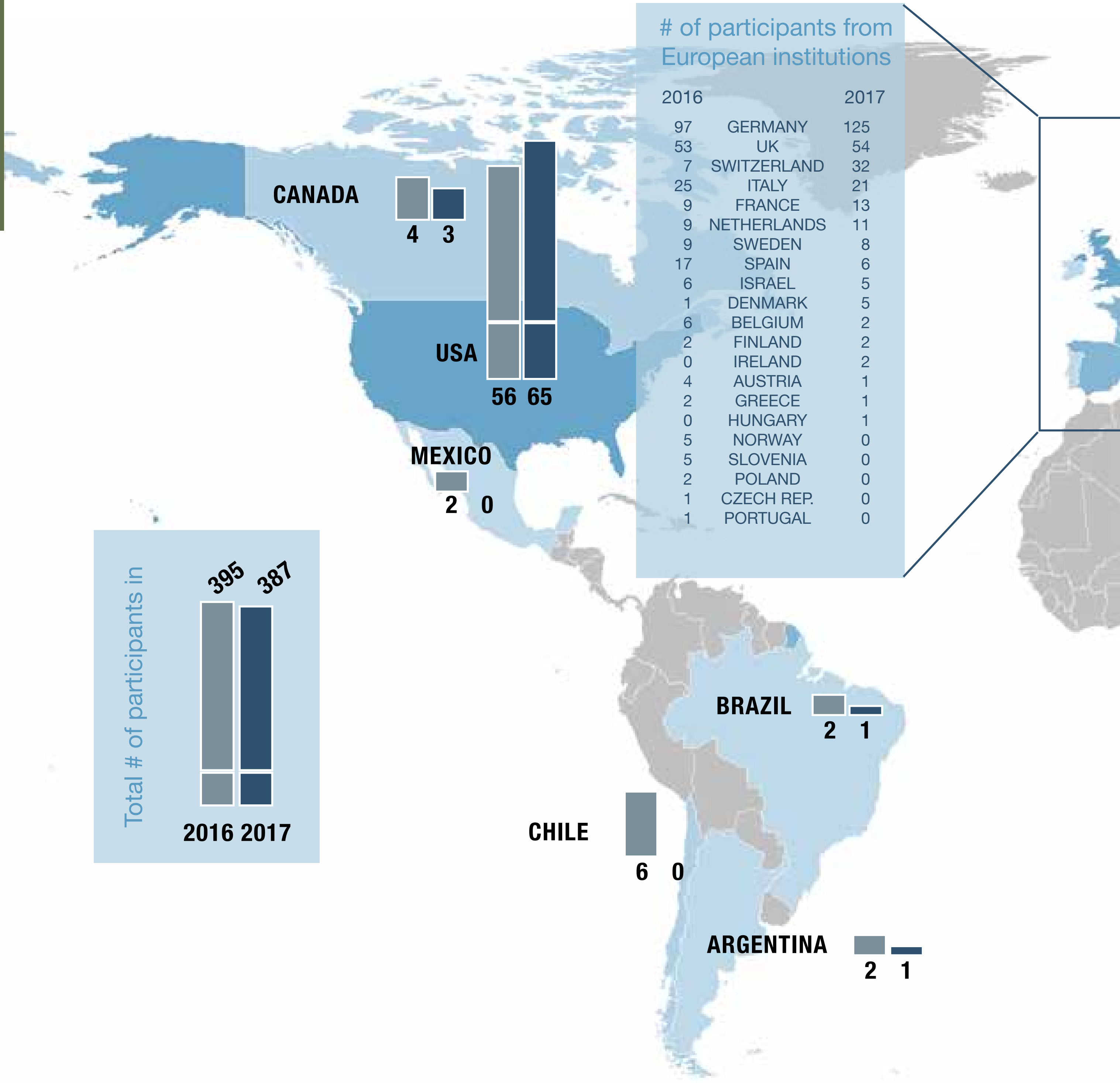
- Prof. Amy Barger, University of Wisconsin-Madison
- Prof. Gerhard Buchalla, Ludwig-Maximilians-Universität München
- Prof. Laura Covi, Georg-August-Universität Göttingen (Chair until 2014)
- Prof. Barbara Ercolano, Ludwig-Maximilians-Universität München
- Dr. Laura Greggio, INAF-Astronomical Observatory of Padua (Chair)
- Prof. Reiner Krücken, TRIUMF, Vancouver
- Prof. Johann Kühn, Karlsruher Institut für Technologie (KIT)
- Dr. Bruno Leibundgut, ESO Garching
- Prof. Dieter Lüst, Ludwig-Maximilians-Universität München
- Prof. Michael Ramsey-Musolf, University of Massachusetts Amherst
- Prof. Hans-Walter Rix, Max-Planck-Institut für Astronomie, Heidelberg
- Prof. Stefan Schönert, Technische Universität München
- Dr. Stella Seitz, Ludwig-Maximilians-Universität München
- Prof. Geraldine Servant, Universität Hamburg & DESY
- Prof. Kim Venn, University of Victoria

FORMER MEMBERS PC:

- Prof. Sigfried Bethke, Max-Planck-Institut für Physik, München (until 2014)
- Prof. Andrzej Buras, Technische Universität München (until 2014)
- Prof. Helene Courtois, IPNL, University Lyon (2015)
- Prof. Günther Hasinger, University of Hawaii (until 2014)
- Prof. Robert Kennicutt, University of Cambridge (until 2014)
- Dr. Georg Raffelt, Max-Planck-Institut für Physik, München (until 2014)
- Prof. Simon White, Max-Planck-Institut für Astrophysik, München (until 2014)

The Scientific Advisory Board and Programme Committee meet every year in late November or early December to select the MIAPP programmes for the year after next.

Statistics 2016 & 2017



of participants from European institutions

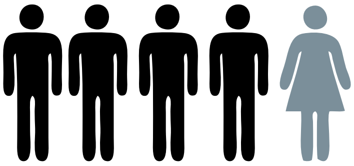
2016		2017
97	GERMANY	125
53	UK	54
7	SWITZERLAND	32
25	ITALY	21
9	FRANCE	13
9	NETHERLANDS	11
9	SWEDEN	8
17	SPAIN	6
6	ISRAEL	5
1	DENMARK	5
6	BELGIUM	2
2	FINLAND	2
0	IRELAND	2
4	AUSTRIA	1
2	GREECE	1
0	HUNGARY	1
5	NORWAY	0
5	SLOVENIA	0
2	POLAND	0
1	CZECH REP.	0
1	PORTUGAL	0

Number of registrations and participants

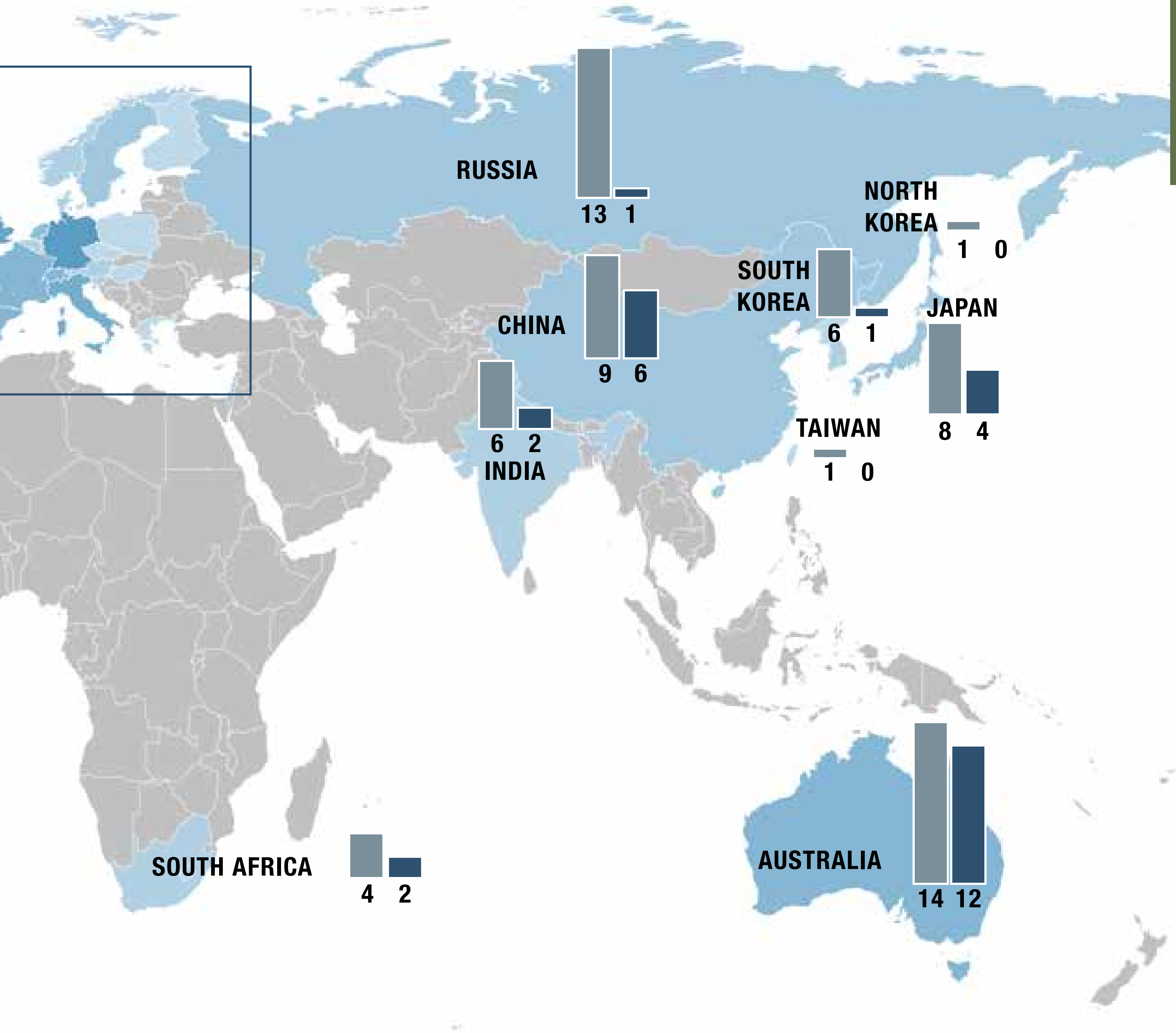
1218 registrations

782 participants

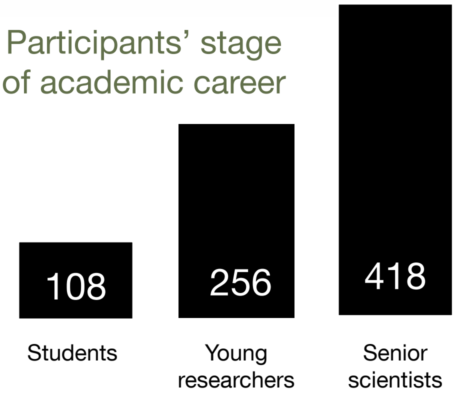
Participants’ gender



80 % male, 20 % female



Participants' stage of academic career



Average duration of participation

2.4 weeks

MIAPP Posters 2016

TOPICAL WORKSHOP

ASPECTS OF HIGHER SPIN THEORY

23-25 May 2016, Garching

TOPICAL WORKSHOP

BARYOGENESIS

Status of Experiment and Theory

6 - 8 June 2016, Garching

TOPICAL WORKSHOP

SUPERNOVAE: THE

12-16. September 2016, G

Munich Institute for Astro- and Particle Physics

MIAPP Programmes 2016

Images on this page: Munich Skyline + Matterhorn (collage: MIAPP, Matterhorn viewed from the Gornergratbahn, Riffelberg / Zermatt, Switzerland by Andrew Bossi, Wikimedia Commons collection, Munich: istock); Supernovae (NASA, ESA. Before and after Hubble Space Telescope images of the outlier "Type Iax" supernova 2012 in NGC 1309 [McCully et al. 2014, Nature, 512, 54]); Detector (©Belle II Collaboration); Higher Spin (collage: MIAPP; Chess board by Petras Gagilas from Erith, Kent, UK; Flickr; Spinning tops made by David Earle)

Activities in 2016

MIAPP programmes:

Programme	Dates
Cosmic Reionisation B. Ciardi, M. Haehnelt, D. Stark, S. Zaroubi	4 – 29 April 2016
Higher-Spin Theory and Duality J. Erdmenger, S. Giombi, I. Klebanov, I. Sachs, M. Vasiliev	2 – 27 May 2016
Why is there more Matter than Antimatter in the Universe? M.J. Ramsey-Musolf, B. Garbrecht, S. Huber, J. Shu	30 May – 24 June 2016
The Chemical Evolution of Galaxies B. Davies, M. Bergemann, F. Bresolin, A. Font, R.-P. Kudritzki	25 July – 19 August 2016
The Physics of Supernovae C. Fransson, S. Jha, K. Maguire, S. Woosley	22 August – 16 September 2016
Flavour Physics with High-Luminosity Experiments S. Paul, M. Ciuchini, B. Golob, P. Krizan, T. Mannel	24 October – 18 November 2016

MIAPP topical workshops:

Workshop	Dates
Aspects of Higher Spin Theory J. Erdmenger, S. Giombi, I. Klebanov, I. Sachs, M. Vasiliev	23 – 25 May 2016
Bayogenesis - Status of Experiment and Theory M.J. Ramsey-Musolf, B. Garbrecht, S. Huber, J. Shu	6 – 8 June 2016
Supernovae: The Outliers K. Maguire, C. Fransson, S. Jha, M. Modjaz, S. Woosley	12 – 16 September 2016
B2TiP MIAPP workshop C. Bobeth, T. Kuhr and B2TiP coordinators	15 – 17 November 2016

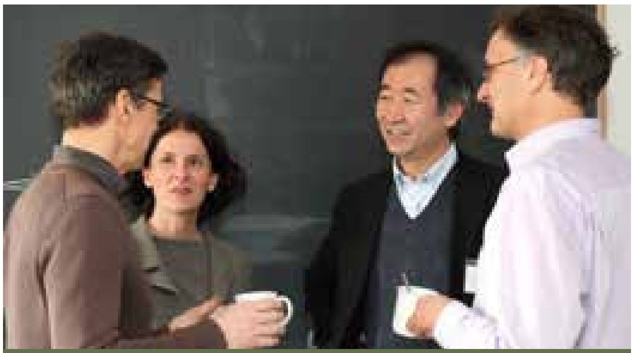
External workshops:

1st Atmospheric Neutrino Workshop (ANW'16)

7 – 9 February 2016

S. Böser, T. Gaisser, T. Kajita, T. Katori, E. Lisi, E. Resconi

The follow-up workshop of the second MIAPP programme 2014 focussed on how to solve the problem of neutrino mass hierarchy with the help of atmospheric neutrinos. Researchers from the leading experiments of neutrino searches participated; among them Nobel Laureate Prof. Takaaki Kajita, professor at the University of Tokyo and director of the Japanese Institute for Cosmic Ray Research. The Nobel Laureate of 2015 introduced the prospects of the future detector Hyper-Kamiokande that is supposed to be about 20 times larger than its predecessor. Furthermore, within the three-day workshop the participants discussed the physical issues and challenges related to the analysis of atmospheric neutrinos and the respective experiments. "The very pleasant and relaxed atmosphere at our international visiting research centre MIAPP has ensured that everybody felt comfortable and immediately got into discussion." commented organiser Elisa Resconi on the success of the workshop.



Prof. Stefan Schönert (TUM) and Prof. Elisa Resconi (TUM), discussing with Nobel Laureate Prof. Takaaki Kajita (University of Tokyo) and MIAPP director Prof. Martin Beneke (TUM) (from left). *Credit: Riedel/TUM*

Towards the Construction of the Fundamental Theory of Flavour

8 – 11 March 2016

G. Buchalla A. Buras, A. Ibarra, G. Isidori, M. Ratz

In March 2016, TUM Emeritus of Excellence, Prof. Andrzej Buras, organised a workshop on the theory of flavour physics. Andrzej Buras has been a member of the Excellence Cluster Universe in the first funding period as well as a member of the MIAPP Programme Committee.

Participants of the 1st Atmospheric Neutrino Workshop 2016. *Credit: Riedel / TUM*

Towards accurate lightcones for cosmology

18 – 20 October 2016

Pablo Fosalba, Stefan Hilbert, Jens Jasche, Alexander Knebe, Frazier Pearce

In October 2016, Dr. Stefan Hilbert, Junior Research Group leader of the Excellence Cluster Universe and Dr. Jens Jasche, Research fellow of the Cluster, organised a workshop in order to discuss systematic approaches for developing, testing, and validating lightcone and lensing simulation software and their outputs in order to reach a new level of accuracy in these model predictions.

Activities in 2017

MIAPP programmes:

- **Astro-, Particle and Nuclear Physics of Dark Matter Direct Detection** 6 – 31 March 2017
  R. Catena, J. Conrad, C. Forssén, A. Ibarra, F. Petricca
- **Superluminous supernovae in the next decade** 2 – 26 May 2017
  J. Mould, F. Patat, J. Cooke, L. Wang, A. Heger
- **Protoplanetary Disks and Planet Formation and Evolution** 29 May – 23 June 2017
  W. Kley, B. Ercolano, L. Testi, C. Mordasini
- **In & Out. What rules the Galaxy Baryon Cycle?** 26 June – 21 July 2017
  P. Popesso, G. De Lucia, C. Peroux, M. Brusa, A. Saintonge
- **Automated, Resummed and Effective: Precision Computations for the LHC and Beyond** 26 July – 18 August 2017
  T. Becher, M. Beneke, R. Frederix, K. Melnikov, M. D. Schwartz
- **Mathematics and Physics of Scattering Amplitudes** 21 August – 15 September 2017
  S. Stieberger, L. Dixon, C. Duhr, L. Ferro

MIAPP topical workshops:

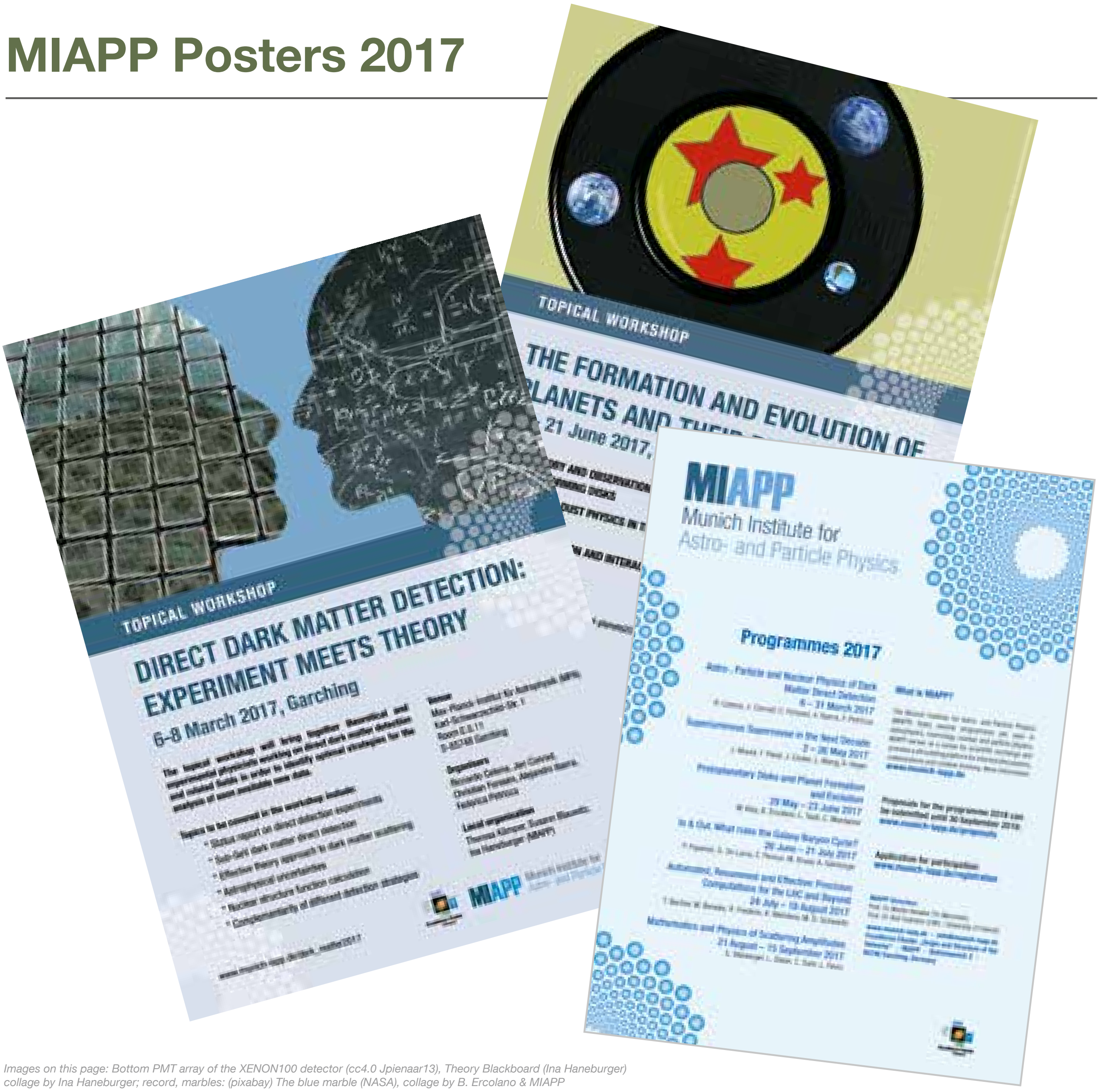
- **Direct Dark Matter Detection: Experiment meets Theory** 6 – 8 March 2017
  R. Catena, J. Conrad, C. Forssén, A. Ibarra, F. Petricca
- **The Formation and Evolution of Planets and their Disks** 19 – 21 June 2017
  W. Kley, B. Ercolano, L. Testi, C. Mordasini

CRESST collaboration meeting at MIAPP 13 – 15 November 2017

Stefan Schönert, Michael Willers

In November 2016, Prof. Stefan Schönert (TUM) and his group organised a CRESST collaboration meeting in the MIAPP building. Prof. Schönert is PI of the Cluster of Excellence and member of the MIAPP programme committee. He and his group are part of the CRESST collaboration, which is an experiment running at the Gran Sasso underground laboratory aiming at the detection of dark matter.

MIAPP Posters 2017



TOPICAL WORKSHOP

THE FORMATION AND EVOLUTION OF PLANETS AND THEIR …

21 June 2017,

TOPICAL WORKSHOP

DIRECT DARK MATTER DETECTION: EXPERIMENT MEETS THEORY

6-8 March 2017, Garching

MIAPP

MIAPP

Munich Institute for Astro- and Particle Physics

Programmes 2017

Images on this page: Bottom PMT array of the XENON100 detector (cc4.0 Jpienaar13), Theory Blackboard (Ina Haneburger) collage by Ina Haneburger; record, marbles: (pixabay) The blue marble (NASA), collage by B. Ercolano & MIAPP

Activities in 2018

MIAPP programmes:

The High Energy Universe: Gamma Ray, Neutrino, and Cosmic Ray Astronomy E. Resconi, S. Gabici, F. Halzen, A. Olinto, P. Padovani	26 February – 23 March 2018
The Interstellar Medium of High Redshift Galaxies A. Ferrara, R. Ellis, F. Walter	9 April – 4 May 2018
Near-Earth Objects: Properties, Detection, Resources, Impacts and Defending Earth A. Burkert, C. Colombo, R. Jedicke, D. Koschny, R. Wainscoat	14 May – 8 June 2018
The Extragalactic Distance Scale in the Gaia Era L. Macri, R. Kudritzki, S. Suyu, W. Gieren	11 June – 6 July 2018
Probing the Quark-Gluon Plasma with Collective Phenomena and Heavy Quarks T. Dahms, L. Fabbietti, J.-P. Lansberg, J.-Y. Ollitrault	27 August – 21 September 2018
Interface of Effective Field Theories and Lattice Gauge Theory N. Brambilla, A. Kronfeld, P. Petreczky, A. Vairo	15 October – 9 November 2018

MIAPP topical workshops

Exploring the Perfect Liquid T. Dahms, L. Fabbietti, J.-P. Lansberg, J.-Y. Ollitrault	6 – 8 September 2018

External workshops:

$b \to s\ell\ell$ 2018: 6th Workshop on Rare Semileptonic B Decays D. Straub, T. Kuhr, D. van Dyk	20 – 22 February 2018

Cluster members Dr. David Straub (TUM), Prof. Thomas Kuhr and Dr. Danny van Dyk (TUM) organised this follow-up workshop of the sixth programme 2016 in order to take a closer look at the interplay of the LHCb and Belle II experiments. It was also the sixth in a series of meetings of experts on both experimental and theoretical studies of semi-leptonic flavour-changing neutral current b hadron decays.

MIAPP Posters 2018 - 2019

MIAPP
Munich Institute for
Astro- and Particle Physics

Programmes 2018

The High Energy Universe: Gamma Ray, Neutrino, and Cosmic Ray Astronomy
26 February - 23 March

The Interstellar Medium of High Redshift Galaxies
9 April - 4 May

Near-Earth Objects: Properties, Detection, Resources, Impacts and Defending Earth
14 May - 8 June

The Extragalactic Distance Scale in the Gaia Era
11 June - 6 July

Probing the Quark-Gluon Plasma with Collective Phenomena and Heavy Quarks
27 August - 21 September

Interface of Effective Field Theories and Lattice Gauge Theory
15 October - 9 November

What is MIAPP?

www.munich-iapp.de

Proposals for the 2019 programme can be submitted until 30 September 2017.
www.munich-iapp.de/proposals

Application for participation:
www.munich-iapp.de/registration

TOPICAL WORKSHOP

Exploring the Perfect Liquid
6 - 8 September 2018, Garching

- PROBING INITIAL CONDITIONS AND QGP PROPERTIES WITH FLOW
- COLLECTIVE PHENOMENA IN SMALL SYSTEMS
- THE CHIRAL MAGNETIC EFFECT AND HE QUEST FOR THE QCD CRITICAL INT
- AVY QUARKS AS PROBES OF MASS ENDENT QCD ENERGY LOSS
- ATE OF QUARKONIA AT THE LHC

Venue

Organizers

Local organization
MIAPP

TOPICAL WORKSHOP

b→sll 2018: 6th Workshop on Rare Semileptonic B Decays
20-22 February 2018, Garching

- Toward precision measurements
- Probes of lepton flavour universality
- Hadronic matrix elements of (non-)local operators
- Precision determinations of Wilson coefficients
- Complementarity of Belle II and LHCb

Venue

Organizers

Local organisation

MIAPP
Munich Institute for
Astro- and Particle Physics

Programmes 2019

Beyond the Standard Model with Precision Flavour Experiments
29 April - 24 May

The Weak Scale at a Crossroads: Lessons from the LHC and Beyond
27 May - 21 June

Dynamics of Large-Scale Structure Formation
1 - 26 July

Galaxy Evolution in a New Era of HI Surveys
29 July - 23 August

Precision Gravity: From the LHC to LISA
26 August - 20 September

Deciphering Strong-Interaction Phenomenology through Precision Hadron-Spectroscopy
7 - 31 October

What is MIAPP?

www.munich-iapp.de

Proposals for the 2020 programme can be submitted until 30 September 2018.
www.munich-iapp.de/proposals

Application for participation:
www.munich-iapp.de/registration

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Activities in 2019

MIAPP programmes:

Beyond the Standard Model with Precision Flavour Experiments J. Albrecht, W. Altmannshofer, T. Kuhr, D. Straub, J. Zupan	29 April – 24 May 2019
The Weak Scale at a Crossroads: Lessons from the LHC and Beyond T. Cohen, C. Csaki, M. McCullough, A. Weiler	27 May – 21 June 2019
Dynamics of Large-scale Structure Formation M. Garny, R. Scoccimarro, A. Sánchez, R. Sheth, R. Wechsler	1 – 26 July 2019
Galaxy Evolution in a New Era of HI Surveys A. Baker, J. van Gorkom, L. Staveley-Smith, M. Verheijen, M. Zwaan	29 July – 23 August 2019
Precision Gravity: From the LHC to LISA J. J. Carrasco, I. Mandel, D. O’Connell, R. Porto, F. Schmidt	26 August – 20 September 2019
Deciphering Strong-Interaction Phenomenology through Precision Hadron-Spectroscopy S. Paul, N. Brambilla, S. Eidelman, C. Hanhart, L. Maiani	7 – 31 October 2019

MIAPP topical workshops

Nine Billion Years of Neutral Gas Evolution A. Baker, J. v. Gorkom, L. Staveley-Smith, M. Verheijen, M. Zwaan	29 – 31 July 2019

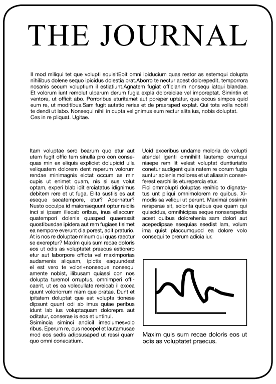
... many more in preparation.

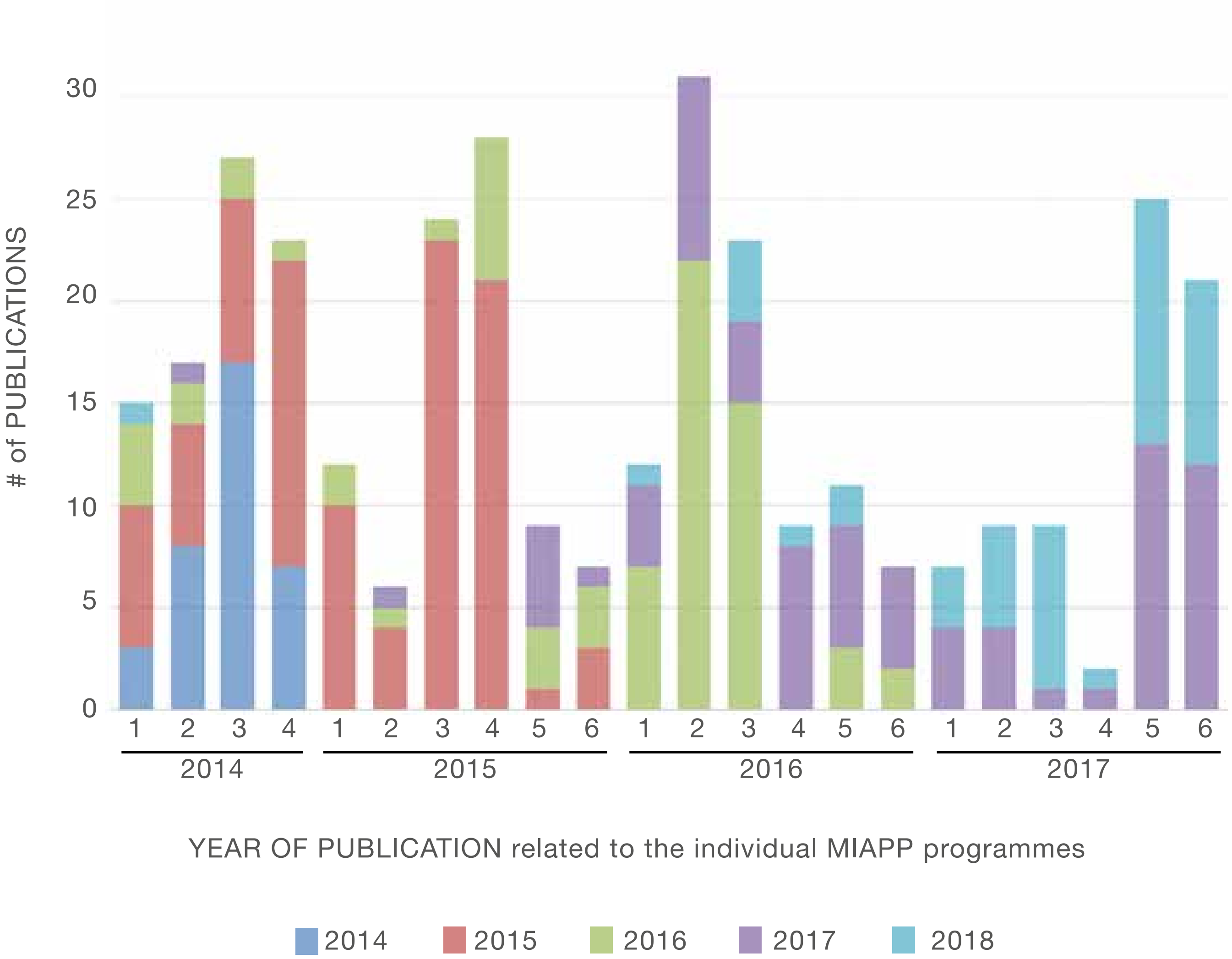
Publications

Papers explicitly acknowledging MIAPP: 337
(reference date: 04 May 2018)

- in refereed journals: 293
- non-refereed: 44

- 2014-related: 80
- 2015-related: 89
- 2016-related: 93
- 2017-related: 75





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Bresolin F., R.-P. Kudritzki, et al., 2016. Young Stars and Ionized Nebulae in M83: Comparing Chemical Abundances at High Metallicity. The Astrophysical Journal 830, 2, 64.

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2014-4: Cosmology after Planck

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2015-4: Anticipating 14 TeV: Insights into Matter from the LHC and Beyond

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MIAPP / Excellence Cluster Universe
Technische Universität München
Boltzmannstraße 2
85748 Garching, Germany
Phone: +49.89.35831.7200
Fax: +49.89.3299-4002
Internet www.munich-iapp.de
E-Mail: info@munich-iapp.de

Editors
Prof. Dr. Martin Beneke
Prof. Dr. Rolf Kudritzki
Prof. Dr. Andreas Weiler
Dr. Ina Haneburger

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