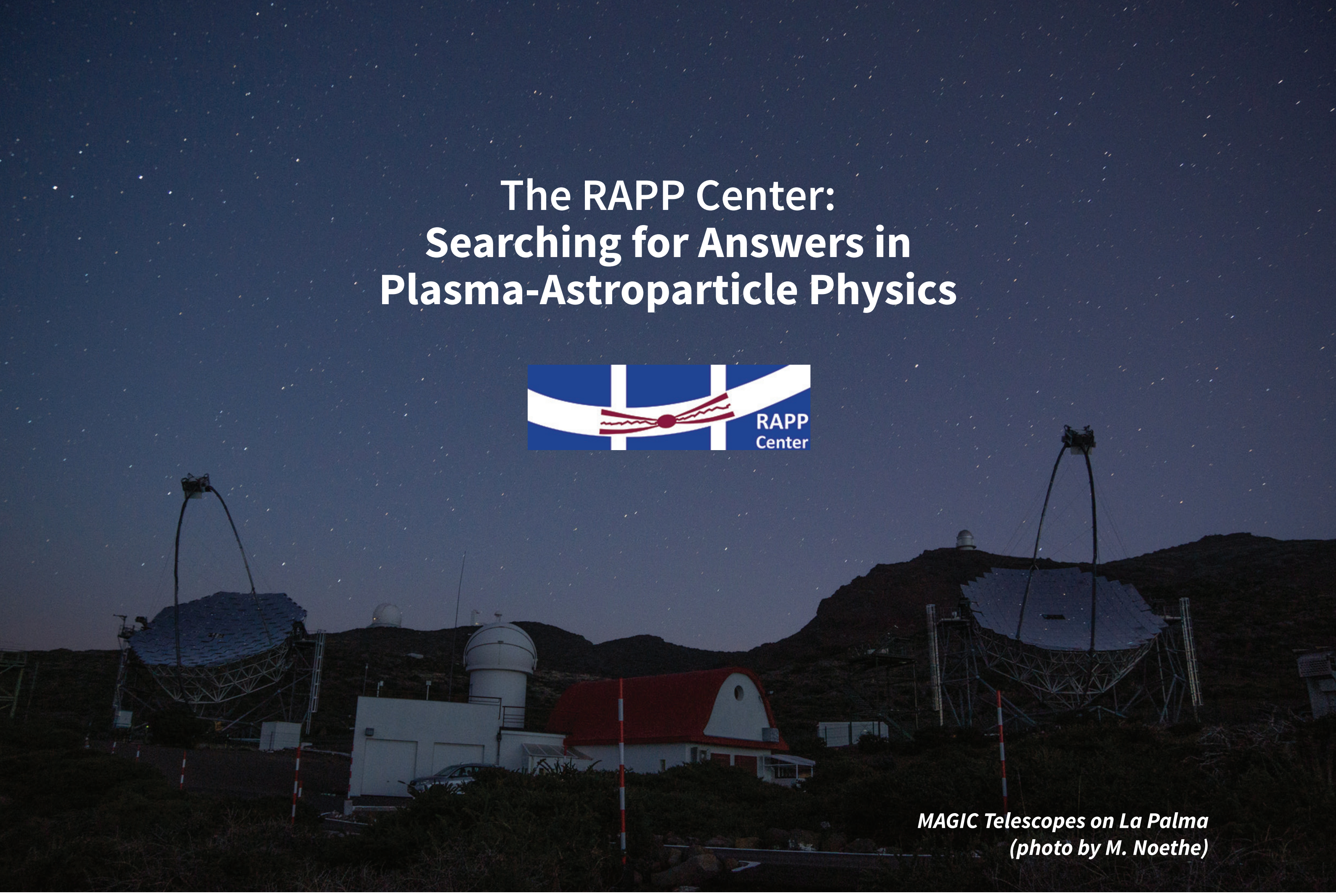
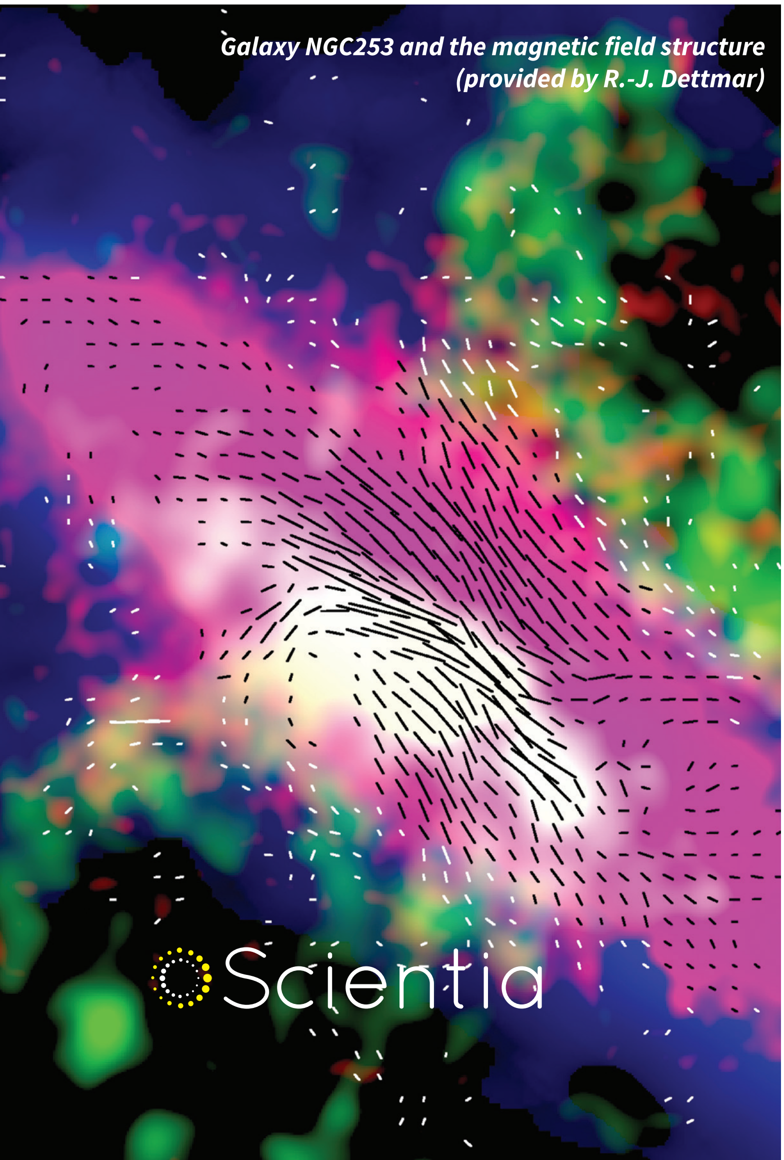
The RAPP Center: Searching for Answers in Plasma-Astroparticle Physics



MAGIC Telescopes on La Palma
(photo by M. Noethe)



Galaxy NGC253 and the magnetic field structure
(provided by R.-J. Dettmar)

FACT Telescope on La Palma
(photo by M. Noethe)

Scientia

THE RAPP CENTER: SEARCHING FOR ANSWERS IN PLASMA-ASTROPARTICLE PHYSICS

The Ruhr Astroparticle and Plasma Physics (RAPP) Center was established in 2015 by Professor Julia Tjus and her colleagues within the University Alliance Ruhr – a collaboration between the three universities of the Ruhr area: Ruhr-Universität Bochum, Technische Universität Dortmund and Universität Duisburg-Essen. The Center is unique in the German research landscape, as it systematically combines theory and observations in particle, plasma and astrophysics in order to explore and understand the mysteries of the cosmos by tracking and detecting low- and high-energy elementary particles.

Astroparticle physics strives to explore and understand the extremely energetic particles that reach us from the depths of the cosmos. Because these particles are often charged, their paths are highly distorted by the magnetic fields that exist on large scales in and between galaxies in the Universe, making it difficult to trace high-energy cosmic rays to their sources. The description of cosmic ray signatures requires the combination of astrophysics, particle physics and plasma physics. The latter is used to properly describe the interaction of charged cosmic rays with magnetic fields, while particle physics is needed to understand cosmic ray interactions and signatures of dark matter. In fact, the theory and experiments adopted by astroparticle physicists use information from the entire electromagnetic spectrum in order to understand how cosmic rays travel through and influence the interstellar and intergalactic media, and also how particle interactions work at the highest energies.

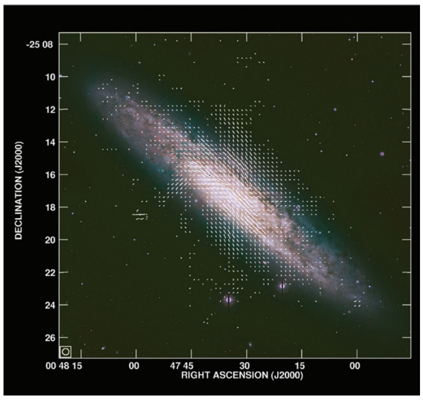
The interpretation of these multimessenger data requires a proper treatment of the basic physics involved. The intersection of particle, astro- and plasma physics can enable researchers to explore the different states of matter, with each discipline offering information on different physics regimes. Combining these pieces of information will lead to a more comprehensive view of the Universe. The RAPP Center is the first of its kind in Germany to systematically combine these methods. In doing so, scientists in the RAPP Center seek to contribute significantly to answering four of the central physics questions of this century, interconnected through the interaction and transport of cosmic rays:

- What is the origin of cosmic rays?
- What is the nature of neutrinos and dark matter?
- How does the interaction of cosmic rays influence the interstellar medium – from molecular clouds to protoplanetary disks?
- How are magnetic fields generated and maintained in the Universe?

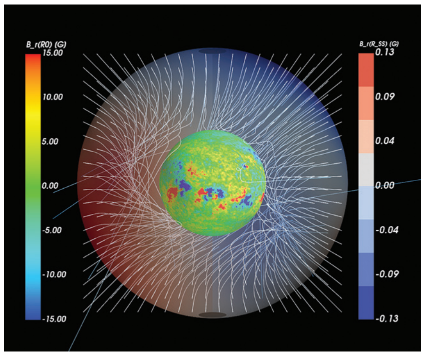
These questions share a common basis in that they take advantage of knowledge from the three subdisciplines of physics – plasma, astro- and particle physics – to find answers on a fundamental physics level.

A Center for Astro-, Particle and Plasma Physicists

In 2007, three German universities – Ruhr-Universität Bochum, Technische Universität Dortmund and Universität Duisburg-Essen – formed the University Alliance Ruhr (UAR). In 2010, the Alliance became home to the Mercator Research Center Ruhr (MERCUR) – a joint initiative for funding research projects. This created the basis for the emergence of



Multiwavelength view and the magnetic field structure of the galaxy NGC253 (provided by V. Heesen)



Cosmic ray transport in the solar magnetic field (published in: M. Kroll, PhD thesis, Ruhr-Universität Bochum, 06/2017)

the Ruhr Astroparticle and Plasma Physics Center (RAPP), which was established to provide a strong foundation for research efforts in plasma, astro- and particle physics in the Ruhr area. The close proximity of the three founding universities (within a range of only 20 kilometers) allows researchers to work together closely and collaborate on research and funding projects. In this context, the

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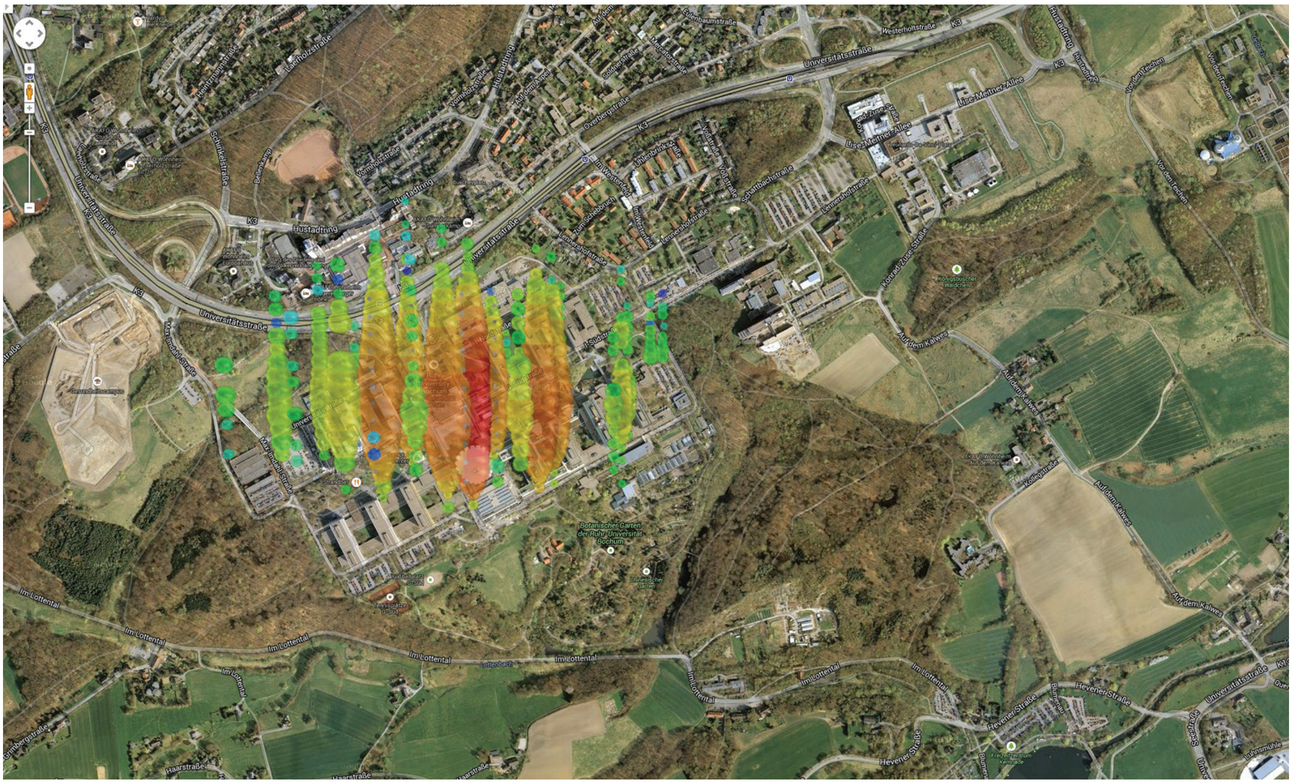


Bert over Bochum: a representation of the neutrino event named “Bert” detected by IceCube, shown projected to scale onto the Ruhr-Universität Bochum campus (map from Google Maps)

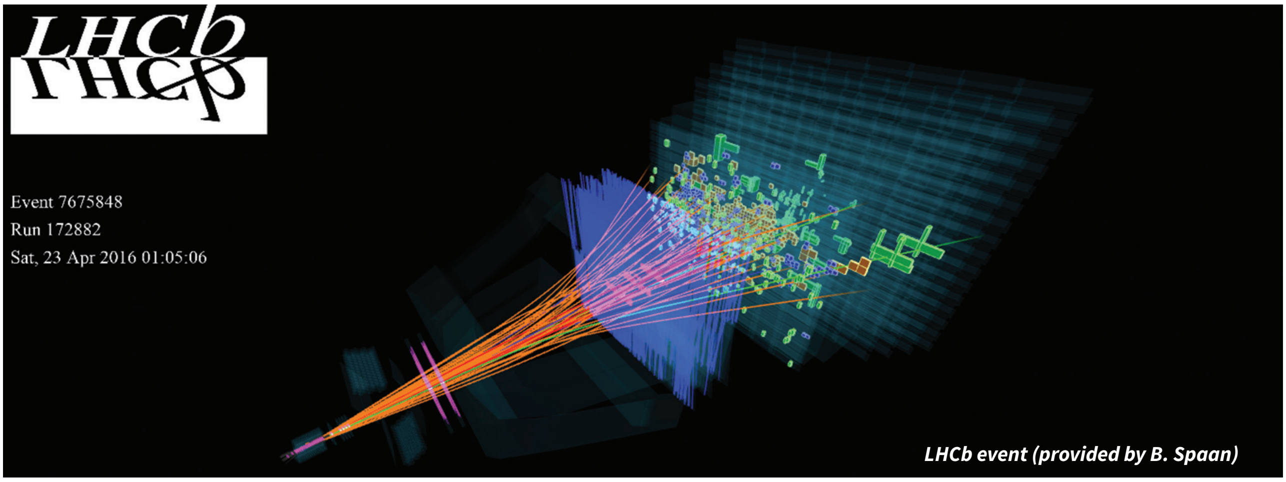
RAPP Center naturally came into existence as the brainchild of six professors from the University Alliance Ruhr – Professors Dettmar, Rhode, Schlickeiser, Spaan, Tjus and Wurm – who today are six of the 23 principal investigators of the Center.

The principle investigators are involved in a large number of large-scale experiments, among them the Large Hadron Collider at CERN, located in Geneva, Switzerland, and the planned Square Kilometer Array, set to become the world’s largest telescope array for the detection of radio waves, to be built in South Africa and Australia. A further example is the IceCube Neutrino Observatory located at the South Pole. IceCube is the world’s largest neutrino detector and comprises one cubic kilometer of instrumented ice, which makes for a rather literal name. Neutrinos, produced in the Earth’s atmosphere or originating from the cosmos, pass through IceCube and sometimes (but rather rarely) interact with the ice. Thus, the sheer volume of one cubic kilometer makes it just large enough to detect the very small signals from cosmic neutrinos. Given that neutrinos are extremely difficult to detect, the size of the instrumented volume increases the probability that some neutrinos will interact with it before exiting at the other side. Professors Rhode and Tjus have been working on IceCube (and its smaller predecessor AMANDA) since 1998 and 2003, respectively, contributing to the development of different analysis techniques like unfolding and stacking by adding information from the theoretical modelling of neutrino sources.

Cosmic Interactions: From Source to Signal

There is a strong connection between the fields of plasma and astrophysics, as the creation of magnetic fields in the Universe relies on the dynamics of plasma in the Universe – defined as a quasi-neutral gas composed of approximately the same number of particles with positive and negative charge. It is believed that the dynamics of this particle ensemble, possibly through interactions between the general background plasma and high-energy cosmic rays, is responsible for creating large- and small-scale magnetic fields in the Universe. Therefore, only the combination of plasma and astrophysics will be able to answer this fundamental question. Astroparticle physics was developed from particle physics, in that it studies elementary particles coming from astronomical sources. This field is also closely related to astrophysics, because it studies these particles in the context of cosmology.

At the same time, high-energy cosmic rays exceed energies that terrestrial particle accelerators can achieve – the highest energy detected for a cosmic particle can be compared with the energy of a tennis ball served at 200 kilometers per hour. The field of astroparticle physics seeks to understand how these particles can be accelerated to such extreme energies and what sources in the Universe are responsible. As acceleration processes are expected to arise due to non-uniformities in magnetic fields, plasma physics also plays an important role here. These highest-energy particles can reveal properties of elementary particles at an energy scale that cannot be probed using



LHCb event (provided by B. Spaan)

LOFAR station in Jülich (photo by E. Jütte)

man-made accelerators. The interplay between astro- and particle physics is therefore crucial to both understanding the sources of cosmic rays through their interactions and learning from high-energy cosmic rays about fundamental particle properties – in particular, those concerning interactions at the highest energies, neutrino production and dark matter.

The three participating universities have a long tradition in investigating the aspects discussed above, with more than a decade of collaboration with each other across the three involved subdisciplines of physics. As an example, Technische Universität Dortmund joined forces with the Ruhr-Universität Bochum to contribute to the construction of the large-scale Cherenkov Telescope Array to investigate astrophysical processes. At the same time, researchers in Dortmund focus on developing statistical data evaluation methods, while those in Bochum model possible cosmic-ray astrophysical sources by using data from gamma and neutrino astronomy. For example, a multiwavelength model that predicts the simultaneous detection of gamma-ray signatures and cosmic ray ionization signals was developed at the Ruhr-Universität Bochum. Ionization processes are of fundamental relevance for the formation of larger dust grains in the Universe, leading to the formation of planets, which is studied at Universität Duisburg-Essen by Professor Wurm. Another example of the connection of the subdisciplines is the research of unit instabilities, turbulence, and transport in cosmic magnetic fields that principle investigators in Bochum have been studying over the past eight years, funded by the German Science Foundation. These examples show the long tradition of collaboration between the principle investigators at the boundary of the physics subdisciplines of plasma, astro- and particle physics. The foundation of the RAPP Center was a natural step to further enhance and foster these activities.

As Professor Tjus points out, the expertise available at the universities of Bochum, Dortmund, and Duisburg-Essen in the areas of particle, astro- and plasma physics is of high value towards finding answers to these important questions. Moreover, the technology required to explore these phenomena now finally exists. 'Traditionally, optical astronomy was, of course, the way to understand the Universe. Today, we have a large variety of frequencies that can be used to study distant galaxies or objects within the Milky Way, from radio wavelengths up to X-rays, and to even higher energies,' Professor Tjus explains. 'In astroparticle physics, information from cosmic rays, neutrinos, and high-energy photons is added to get a whole picture of the high-energy Universe. In the RAPP Center, we go even one step beyond this approach, trying to use fundamental physics input from basic research in plasma and particle physics in order to be able to explain the Universe from the lowest to the highest energies.'

As the first center in Germany where astro-, particle and plasma physicists join forces to understand cosmic interacting matter in the Universe, the RAPP Center hosted its first conference with over 100 participants in September 2016. As it stands today, the Center is an excellent choice for those who, like Professor Tjus and her colleagues, want the best of the three worlds: 'As a student, I was most interested in astrophysics and particle physics, so it was great not to have to choose between the two. In the recent years, I have learned how exciting plasma physics is and how important it is to explain our signatures. Yet, the combination of all these subdisciplines requires a large team of researchers already experienced in the topics in question – something that has developed naturally during the past decade through the collaboration of the different chairs involved in the RAPP Center. Just imagine, we try to describe particle interactions at the sub-nanometer scale, after they have propagated over millions of light years. These two worlds, the cosmological and the microscopic quantum world, cannot even be described by the same fundamental theory at this point, but it is still working quite well to combine them the way it's done in astroparticle physics. So far, it has often been neglected that the transport and interaction of these cosmic rays happen in a magnetized background plasma. During my time as a professor in Bochum I have learned how important this treatment is. However, the combination of all three research areas cannot be achieved by one single scientist. It requires the combination of experts from all of these disciplines. At the RAPP Center, we naturally host such an environment, in which 20 principle investigators have gathered to understand the signatures of interacting cosmic matters in the Universe.'

Group picture of RAPP Center members at the inauguration ceremony in September 2016

Meet the Researchers

Professor Julia Tjus

Professor Julia Tjus is the speaker of the RAPP Center and head of the Plasma Astroparticle Physics Group at Ruhr-Universität Bochum. She received her PhD in 2007 for her thesis entitled 'On the phenomenology of potential astrophysical neutrino sources', which was awarded the prize for the best thesis in physics at TU Dortmund that year. In 2013, she became a full professor and has since attracted numerous grants and awards for her work. As an example, she was awarded the Young Scientist Award of the International Union of Applied and Pure Physics (Section C4) in 2015. Her career currently follows both of her main research interests, namely the connection between astrophysics, plasma physics and particle physics. Her group is an active member of the IceCube and Cherenkov Telescope Array (CTA) collaborations.

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Professor Wolfgang Rhode

Professor Wolfgang Rhode, is the Co-Speaker of the RAPP Center and a professor at the Department of Physics at Technische Universität Dortmund (TU Dortmund). He received a PhD in philosophy in 1990 from the University of Freiburg and another one in physics in 1993 from the University of Wuppertal. He then continued his career in astroparticle physics. His main research interests are astroparticle physics, i.e. neutrino astronomy and gamma-ray astronomy, in addition to the utilization of computer science in physics and aspects of natural philosophy. Currently, he is involved in several national and international research collaborations, including IceCube and CTA.

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Professor Bernhard Spaan

Professor Bernhard Spaan is a German research physicist and professor at TU Dortmund.He received his PhD in 1988 for his thesis on 'Investigations on rare decays of τ-leptons and on the mass of τ-neutrinos', which was awarded the Benno-Orenstein Prize in 1989. He continued his career in experimental particle physics with the experiments ARGUS, BaBar and now LHCb. In 1996, he joined Technische Universität Dresden as professor for experimental hadron physics. Since 2004, he has been full professor of experimental particle physics at TU Dortmund. Between 2008 and 2014, he was also dean of the Department of Physics of TU Dortmund.

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Professor Gerhard Wurm

Professor Gerhard Wurm is an astrophysicist and professor in the Department of Experimental Physics at Universität Duisburg-Essen. During his PhD studies, he joined a collaboration at the University of Jena, where he studied dust in star forming regions'. He continued his career at the University of Colorado, Boulder where he worked at the Laboratory for Atmospheric and Space Physics. Later on, he joined the Institute for Planetology of the University of Münster and finally joined Universität Duisburg-Essen in 2009.

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Professor Ralf-Jürgen Dettmar

Professor Ralf-Jürgen Dettmar has been a professor of astronomy at the Ruhr-Universität Bochum since 1994. In 1986, he received his PhD from the University of Bonn with a thesis project conducted at the Max-Planck-Institute for Radio Astronomy. Between 1986 and 1994, he was a postdoc at the University of Bonn, a fellow at Lowell Observatory in Flagstaff, AZ (USA), and worked for the European Space Agency (ESA) at the Space Telescope Science Institute in Baltimore. His research interests are centered on the evolution of galaxies and, more precisely, the interstellar medium in spiral galaxies.

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Professor Reinhard Schlickeiser

Professor Reinhard Schlickeiser is the Chair of the Theoretical Physics Department at Ruhr-Universität Bochum. He received his PhD from the Christian-Albrechts-University Kiel. After numerous collaborations with German and international universities, he became a full professor in 1998. Throughout his career, he has guided 36 PhD students to successfully complete their research and published almost 400 papers in peer reviewed journals, which have attracted over 22,000 citations. Out of all of his PhD students and postdocs, 15 are today permanent professors, research professors, or lecturers at universities worldwide. He is also an editor for four scientific journals and published a book titled 'Cosmic Ray Astrophysics'.

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www.rapp-center.de