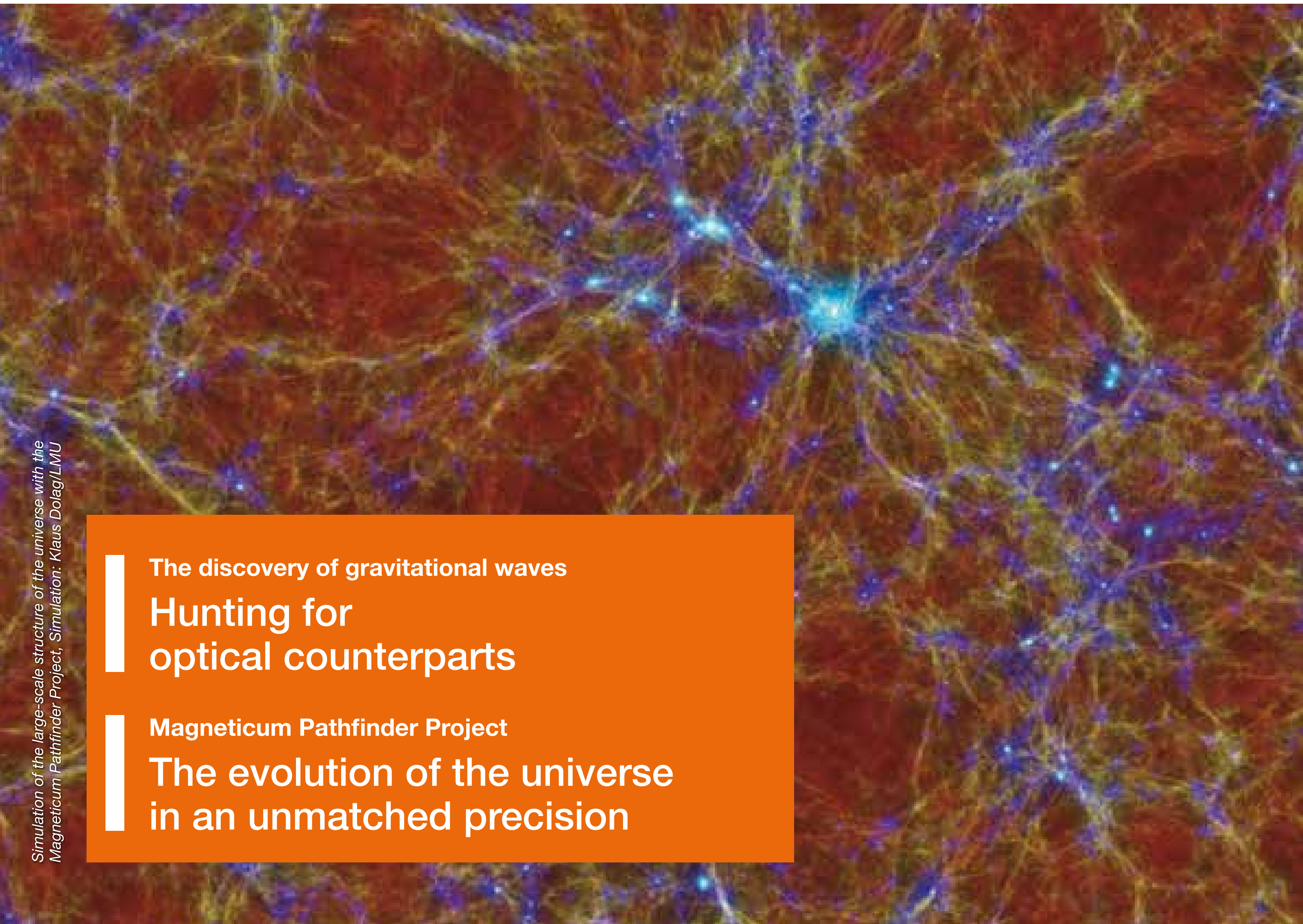
UniverseNews

Excellence Cluster Universe | Issue 1/2016



Simulation of the large-scale structure of the universe with the Magneticum Pathfinder Project, Simulation: Klaus Dolag/LMU

The discovery of gravitational waves

Hunting for optical counterparts

Magneticum Pathfinder Project

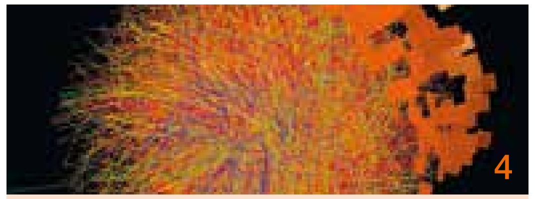
The evolution of the universe in an unmatched precision

Dear readers,

are there any connections between the discovery of gravitational waves and researchers in Garching? Indeed, there are. Heinz Billing at the MPA developed the first working prototype Michelson interferometer designed to search for gravitational waves in the 1970s. Without the knowledge gained here, the LIGO project would not have started when it did (S. 3).

Also today, Garching physicists provide decisive scientific contributions: Peter Fierlinger and his group at TUM created a space with a magnetic field even smaller than that in the depths of our solar system, a key prerequisite for many high-precision experiments in physics (S. 8). And LMU scientist Klaus Dolag's Magneticum Pathfinder simulations mark a new era in computer-based cosmology (S. 10).

We wish you an informative reading.
Petra Riedel, PR Manager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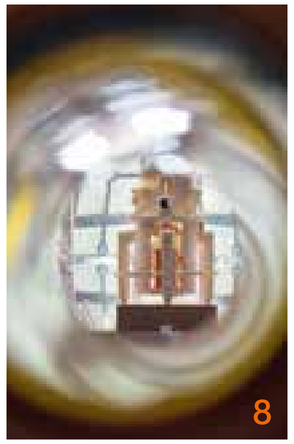
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Review

Photos: Riedel/TUM (2), Alexander Pinker/GMM

Irsee Symposium 2015
22 – 25 June 2015

For the third time now, the symposium 'Symmetries and phases in the universe' took place in the beautiful surroundings of Irsee Monastery. To give insights into the current state of research fields, the Excellence Cluster Universe invited international leading researchers including Prof. Carlos Frenk (Durham University), Prof. Joanna Dunkley (University of Oxford), Prof. Chris Quigg (Fermilab) and Prof. Dr. Reinhard Genzel (MPE) (photo).

It's the mass that does
25 November 2015

On November 25, 1915 at the Prussian Academy of Sciences, Albert Einstein presented for the first time his idea that gravity has the ability to bend light. On the occasion of the 100th anniversary of General Relativity, Einstein's theory was celebrated with the lecture 'It's the mass that does' by Prof. Harald Lesch (LMU) organized by the Excellence Cluster Universe and the Deutsches Museum. The TUM main auditorium was fully booked within two days.

Our moon
7 Oct. 2015 and 9 March 2016

Our moon is familiar to everyone and yet it is a strange, external object that holds a lot of unsolved mysteries that can give insights into the formation of the earth and the solar system. Many of the moon's numerously little-known details were revealed by Prof. Andreas Burkert (LMU) in his talk within the series 'Sciences for everyone' at the Deutsches Museum. Due to the great interest, Andreas Burkert had to give the talk twice.

Simulation: SXS, the Simulating eXtreme Spacetimes (SXS) project

Simulation of two black holes merge into one: The gravitational waves of such an enormously powerful event were observed for the first time by the detectors of the LIGO collaboration.

The discovery of gravitational waves

Hunting for optical counterparts

Only recently, the public learned about this sensational discovery. But some astrophysicists, including scientists from the Excellence Cluster Universe, got first indications of the event already a couple of days after September 14, 2015. They studied the sky for the cause of the gravitational wave signal that surprisingly has rushed into the LIGO detectors.

On September 14, 2015, at 9:50 Greenwich Mean Time, the two LIGO detectors in Hanford and Livingston, USA, both detected an unusual signal (LIGO: Laser Interferometer Gravitational-Wave Observatory). Three minutes later, it was recognized by a search process that promptly looks for gravitational wave signals of any morphology – as a candidate event of a phenomenon that was predicted by Albert Einstein but has never been directly detected before.

Two days later, the LIGO team provided information about the signal and its most probable area of origin to other research groups. On September 18, the team of the Dark Energy Survey, which also includes scientists from the Excellence Cluster Universe, began to scan this area for optical counterparts. The Dark Energy Survey camera (DES), one of the world's most powerful digital cameras that primarily serves the observation of dark energy, should screen the specified area for signs of two phenomena.

Red supergiants are known to core collapse to black holes and producing gravitational radiation, but without visible supernovae. The DES camera therefore examined the sky area in question, which included the Small Magellanic Cloud, for a missing object. But by comparison with existing catalogs it showed that all of the 144 red giants were detected.

In addition, the DES team looked for signs of a merger containing at least one neutron star. Such an event should appear in the visible range of light as a red transient that disappears within a few days. The researchers scanned the area in question at the 4^{th} and 5^{th} day after the event, and compared these images to those from days 7 and 24. "But there was nothing of significance," says Prof. Jochen Weller from the LMU, who is also a member of the Excellence Cluster.

The absence of electromagnetic radiation in this and other follow-up observations is not surprising. When the LIGO collaboration finally announced the first detection of gravitational waves on February 11, 2016, they also made known their analyses that the wave is consistent with the inspiral and merger of two black holes with masses of each around 30 times the mass of the sun. Such an event does not produce any electromagnetic signature.

The discovery is based on more than 40 years of research: The first working prototype Michelson interferometer designed to search for gravitational waves was developed by the group of Prof. Heinz Billing at the Max Planck Institute for Astrophysics (MPA) in Garching.

The astrophysical importance is far reaching. Gravitational waves offer, for example, a new window for tests of general relativity at high speeds, strong gravitational fields and in the nonlinear regime.

Numerous ideas and theories are in discussion. Dr. Shantanu Desai, until recently a scientist at the Excellence Cluster Universe and between 2004 and 2008 a member of the LIGO collaboration, for good reasons is interested in an effect that occurs when light passes large masses and is known as "Shapiro delay". Accordingly, for a distant observer, the light slows down near a mass distribution along the line of sight. This is a consequence of Einstein's equivalence principle. "Gravitional waves should also undergo Shapiro delay," the astrophysicist says. "From this measurement, they were able to rule out any frequency-dependent violations of Shapiro delay to about one part in 10^9." The effect is, of course, negligible small: The time of arrival of GW20150914 was delayed by about 1800 days due to a gravitational potential along the line of sight, as Shantanu Desai has calculated with a colleague in a recently published paper. "This is an interesting detail for itself", Shantanu Desai explains, "but in the case of a gravitational wave signal that comes with an electromagnetic or neutrino counterpart, the differential Shapiro delay can be used to rule out or confirm alternate theories of gravity." Physicsts are now waiting for further LIGO news.

Most precise measurement of mass and charge of light nuclei and anti-nuclei

The symmetry of the universe

Why did antimatter disappear almost completely from our universe, whereas matter did not? Scientists are attempting to solve this mystery at the particle accelerator of the Large Hadron Collider (LHC) at CERN. The ALICE team has published the most precise measurement of the characteristics of light atomic nuclei and anti-nuclei ever made. Physicists from the Excellence Cluster Universe of the Technical University of Munich (TUM) are working on new detectors for the ALICE experiment, which will allow measurements with even greater precision in the future.

What did the universe look like shortly after it came into being? The ALICE experiment (A Large Ion Collider Experiment) at the Large Hadron Collider at CERN in Switzerland concerns itself with this question. At the largest particle accelerator in the world, researchers let lead nuclei and protons collide at the highest beam energies to date. The temperatures thereby created are 100,000 times higher than those in the centre of the Sun.

A state similar to the Big Bang

“A state is created that is very similar to the one after the Big Bang,” explains Prof. Laura Fabbietti from the TUM Physics Department and principle investigator of the Excellence Cluster Universe. She and Dr. Torsten Dahms who leads a junior research group at the Excellence Cluster head the two experimental ALICE groups at the TUM.

This state of matter, the so-called quark-gluon plasma, probably formed one microsecond after the Big Bang, a point in time when the universe was expanding at great speed. The quark-gluon plasma is stable only for 10^{-23} seconds, but, during this very short time, the researchers have the opportunity to investigate the beginning of the universe.

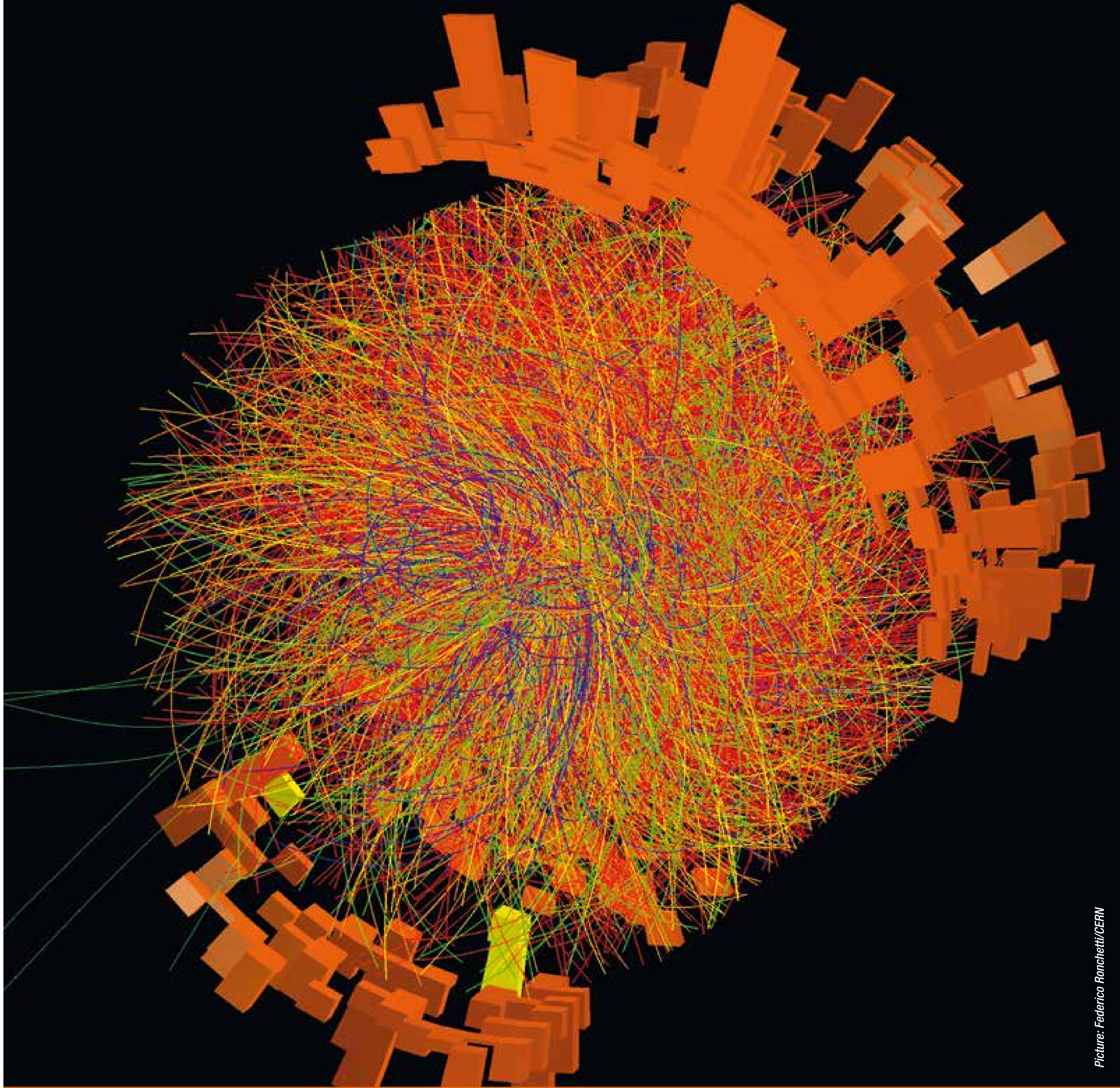
The matter-antimatter mystery

Furthermore, the ALICE physicists also want to better understand why there is matter in our universe, but apparently no antimatter. Equal quantities of matter and antimatter should have been produced at the moment of the Big Bang, and immediately should have annihilated. However, there is some matter left, the matter the visible universe is made of, but antimatter is rarely found anywhere. So what is the reason for this imbalance?

Most accurate measurements

“ALICE is attempting to find a difference by means of high-precision measurements of the characteristics of particles and their antiparticles which are produced in particle collisions at the LHC,” explains Torsten Dahms. In the current study, the researchers investigated the mass-to-charge ratio of helium-3 nuclei and deuterium nuclei and their respective antiparticles. Charge and mass are determined by measuring the particle traces and the particle’s specific energy loss within the Time Projection Chamber (TPC), the heart of the ALICE detector system. The results published in Nature Physics are the most accurate measurements to date and did not find a difference in mass and amount of charge.

To make the investigations even more precise, the researchers are currently working on improvements of the ALICE detector. “At the moment, we are able to record 500 collisions per second,” explains Fabbietti. “Soon it should be 50,000 collisions.” The TUM groups, which head the GEM-TPC upgrade project for ALICE as part of an international collaboration, are working on an upgrade of the TPC read out device, which is to become much faster. The installation of the new detector system is planned for the year 2018.



Picture: Federico Ronchetti/CERN

After the restart of the LHC: The particle tracks of one of the first heavy-ion collisions recorded by ALICE in November 2015

A glance at the COMPASS setup at the Super Proton Synchrotron at CERN:
With this experiment, physicists succeeded in discovering a new mysterious particle state.

COMPASS: Observation of a new combination of light quarks

Exotic particle status puzzles theorists

Scientists from the COMPASS collaboration at CERN have observed a new exotic combination of light quarks. The discovery was made in an experiment that shoots pions at close to the speed of light towards a liquid hydrogen target. Now, the ball is in the theoretical physicists'court to find an explanation for the new particle status. Scientists from the Excellence Cluster Universe of the Technical University of Munich (TUM) had a leading role in the data analysis of the new finding.

The Standard Model of particle physics defines quarks as the fundamental components of atomic nuclei. A proton consists of one 'up' and two 'down' quarks, a neutron of one 'down' and two 'up' quarks. With this, the quark particle garden is far from being complete: apart from the two lightest quarks, there are four heavier ones: strange, charm, bottom, and top quarks, plus the corresponding antiparticles, the antiquarks.

All these quarks existed shortly after the Big Bang and played an important role in the early universe. Nowadays, heavy quarks cannot be observed in nature anymore and can only be created in particle physics experiments. Quarks are 'glued' together via special adhesive particles, the gluons, which mediate the strong nuclear force, the strongest of the four fundamental forces of nature.

The strong force is described by a theory called Quantum Chromodynamics (QCD), which had been developed in the late 1980s. QCD explains the basic principles on which formation of all matter is based and prescribes which particle configurations occur in nature predicting a whole set of possible quark combinations.

Some of them are well known: combinations of three quarks (baryons), such as protons and neutrons, and combinations of one quark and one antiquark (mesons), such as pions. According to QCD, some truly exotic combinations, for example molecule-like tetra-quarks or even penta-quarks, are also possible.

Understanding the combination rules for quarks has always been a big challenge for theoretical and experimental particle physics, because an extraordinary phenomenon is hindering scientific exploration of the processes that combine quarks together: the force between two quarks increases as the quarks move away from each other, contrary to all other fundamental forces of nature, that always fall off with distance.

In its most recent publication, the COMPASS collaboration announces the existence of an extraordinary meson, which is made out of light quarks and has a mass of 1,42 GeV/c^2. As numerous investigations have explored this mass range in the last 50 years, the discovery of the new particle at the COMPASS spectrometer at the Super Proton Synchrotron (SPS) at CERN is indeed a big surprise. It was only possible thanks to the largest worldwide dataset currently available for such investigations.

The new particle called $a_1(1420)$ was found during data analyses of experiments, in which pions were shot at a liquid hydrogen target with an impulse of 190 GeV/c. As this new particle is about 1,000 times rarer than the known mesons, a new, much more complex method of analysis had to be developed, led by scientists from the Excellence Cluster Universe of the Technical University of Munich (TUM).

Various theoretical explanations for the new particle where proposed, some of which interpret $a_1(1420)$ as a molecule composed of known mesons (also known as a tetra-quark-state). Other explanations are based on postulating different long-range effects of the strong force, but fail to fully explain the experimental findings. "This new particle $a_1(1420)$ is obviously a new member of the club of unexplained states", says Prof. Stephan Paul from the Excellence Cluster Universe of the TUM. Now the QCD experts have to solve another difficult problem.

In search of dark matter particles

CRESST is ready to detect lightweights

Scientists have searched for the particles of dark matter in numerous experiments – so far, in vain. With the CRESST experiment, the search can be considerably expanded: Momentarily the CRESST detectors are being refaced and are then able to detect particles whose mass lies below the current measurement range. As a consequence, the chance of tracing dark matter is hightened.

Astrophysical observations leave hardly any doubt that in the universe another so far unknown form of matter exists. The amount of this invisible dark matter is five times larger than the matter we can see and which makes up our earth, the sun and all of the visible universe. "So far, physicists have assumed that dark matter consists of heavy particles, which we call WIMPs," says Federica Petricca, spokesperson of the CRESST experiment and a researcher at the Max Planck Institute for Physics (MPP). "Therefore, most experiments currently look into a mass range from 10 to 1000 GeV/c^2." (WIMPS: Weakly Interacting Massive Particles, CRESST: Cryogenic Rare Event Search with Superconducting Thermometers).

The lower limit of 10 GeV/c^2 roughly corresponds to the mass of a carbon atom. New theoretical models have recently been developed with the potential of solving long-standing problems, like the difference between the simulated and the observed dark matter profile in galaxies. Several of these models hint towards dark matter candidates below the mass of the traditional WIMP.

The scientists of the experiment CRESST have aimed to reduce the energy threshold of their detectors, and thus to increase the sensitivity for lighter particles. They have been successful: In a long-term experiment with one detector, the researchers achieved an energy threshold of 307 eV.

More sensitive detectors

"With that, this detector is best suited for measurements of particles with masses between 0.5 and 4 GeV/c^2, improving its sensitivity by 100 times", says Dr. Jean-Côme Lanfranchi, group leader of the CRESST group at the chair for experimental astroparticle physics at the Technical University of Munich (TUM). "We can now detect particles that are considerably lighter – for example dark matter particles with a mass comparable to a proton, that is 0.94 GeV/c^2."

On the basis of these newly gained insights, the scientists will now equip the experiment with the novel detectors. The next measurement cycle of CRESST is expected to begin in spring 2016 and last for one to two years.

The central parts of all CRESST detectors are crystals of calcium tungstate. When a particle hits one of the three crystal atoms (calcium, tungsten or oxygen), the detectors simultaneously measure energy and light signals from the collision which in turn deliver information about the nature of the impinging particle.

In order to catch even the smallest possible temperature and light signals, the detector modules are cooled to virtually absolute zero (-273.15 degrees C). To eliminate disturbing background events, the CRESST scientists employ materials with little natural radioactivity. To shield the experiment from cosmic rays, it is located in the world's largest underground laboratory in the Italian mountain Gran Sasso.

International team

Participants of the CRESST collaboration include the MPP, the Universities of Tübingen and Oxford, the Technical Universities of Munich and Vienna, the Institute of High Energy Physics in Vienna and the Gran Sasso National Laboratory of the Istituto Nazionale di Fisica Nucleare in Italy.

Prototype of the future CRESST detectors: The new crystal (centre) is rectangular and smaller than previous. To reduce background signals, the bronze crystal holdings have been replaced by components made of the crystal material.

Dr. Jean-Côme Lanfranchi and Prof. Stefan Schönert from the chair of experimental astroparticle physics at the TUM in front of the CRESST experiment in the Gran Sasso underground laboratory in Italy.

Record-breaking magnetic shielding for high precision experiments

The weakest magnetic field in the solar system

Magnetic fields easily penetrate matter. Creating a space practically devoid of magnetic fields thus presents a great challenge. An international team of physicists led by Prof. Peter Fierlinger from the Excellence Cluster Universe at the TUM has now developed a shielding that dampens low frequency magnetic fields more than a million-fold. Using this mechanism, they have created a space that boasts the weakest magnetic field of our solar system. The physicists now intend to carry out precision experiments with neutrons there.

Magnetic fields exist everywhere in the universe. Here on the earth, we are permanently exposed to both natural and artificial magnetic fields. In Central Europe the earth's ever-present magnetic field measures 48 microtesla. On top of this come local magnetic fields generated by transformers, motors, cranes, metal doors and the like.

A group of scientists headed by Prof. Peter Fierlinger, physicist at the Technical University of Munich (TUM) and researcher at the Excellence Cluster Universe, has now successfully created a 4.1 cubic metre space at the Garching research campus in which permanent and temporally variable magnetic fields are reduced over a million-fold. This is accomplished using a magnetic shielding comprising various layers of a highly magnetisable alloy.

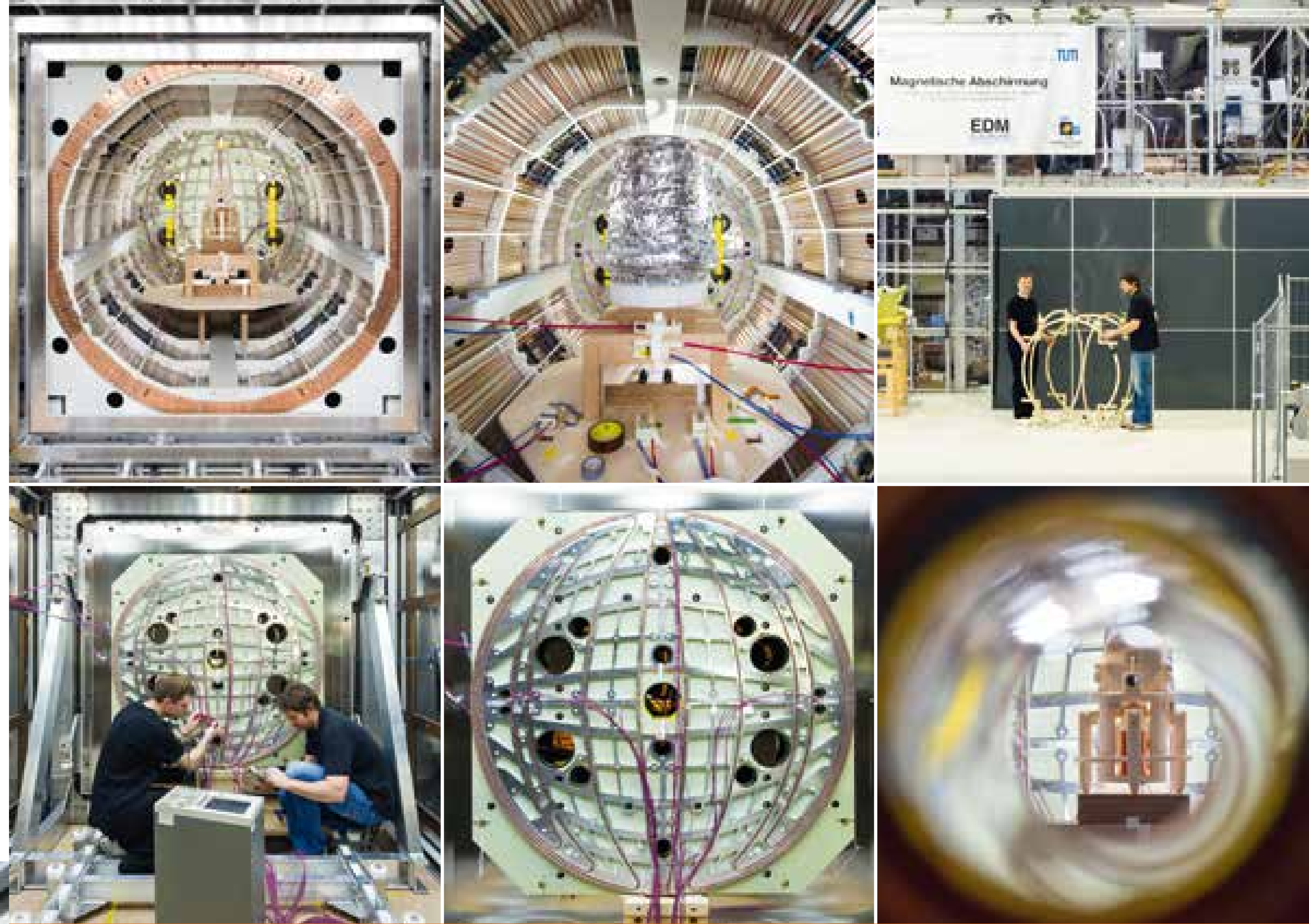
Improved attenuation

The ensuing magnetic attenuation results in a residual magnetic field inside the shield that is even smaller than that in the depths of our solar system. The approach improves the attenuation of previous set-ups more than ten-fold.

Reducing electromagnetic noise is a key prerequisite for many high-precision experiments in physics – but also in biology and medicine. In fundamental physics, the highest degree of magnetic shielding is essential when making precision measurements of miniscule effects in phenomena that drove the early development of our universe. Peter Fierlinger's team is currently developing an experiment to determine the charge distribution in neutrons – referred to by physicists as the electric dipole moment. Neutrons are nuclear particles that have a tiny magnetic moment but are electrically neutral. They comprise three quarks, whose charges cancel each other out. However, scientists suspect that neutrons have a tiny electric dipole moment. Unfortunately, past measurements were not sufficiently precise. The new, nearly magnetic field free space provides the requisite conditions for improving measurements of the electric dipole moment by a factor of 100. This opens the door to a realm of the theoretically predicted scale of the phenomenon.

A view into the space with the weakest magnetic field in the solar system: Prof. Peter Fierlinger (TUM) (l.) and the PhD student Michael Sturm (TUM).

Photo: Astrid Eckert



Interior and exterior views of the room in which permanent and temporally magnetic variable fields are reduced over a million-fold. The new, nearly magnetic field free space provides the conditions for the measurement of the electric dipole moment of the neutron.

Physics beyond the limits of the Standard Model

"This kind of measurement would be of fundamental significance in particle physics and swing wide open the door to physics beyond the Standard Model of particle physics," explains Peter Fierlinger. The Standard Model describes the characteristics of all known elementary particles to a high degree of precision. Yet, there are still phenomena that cannot be adequately explained: Gravity, for example, is not even considered in this model. The Standard Model also fails to predict the behaviour of particles at very high energies as they prevailed in the early universe. And, it provides no explanation for why matter and antimatter from the Big Bang did not annihilate each other completely, but rather a small amount of matter remained from which we and our surrounding, visible universe are ultimately formed. Physicists therefore attempt to create short-lived conditions as were prevalent in the early universe using particle accelerators like the Large Hadron Collider (LHC) at CERN. They smash particles into each other at high energies, in particular to create new particles.

Alternatives to high-energy physics

The experiments of the TUM scientists complement those in high-energy physics: "Our high-precision experiments investigate the nature of particles at energy scales that will likely not be reached by current or future generations of particle accelerators," says doctoral candidate Tobias Lins, who worked on the magnetic shield setup in Peter Fierlinger's laboratory. Exotic and hitherto unknown particles could alter the properties of known particles. Thus, even small deviations in particle characteristics could provide evidence for new, previously unknown particles.

In addition to Fierlinger's group, physicists of the Physikalisch-Technische Bundesanstalt Berlin, the TUM Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II), the University of Illinois at Urbana-Champaign, USA, the University of Michigan, USA, and IMEDCO AG in Switzerland contributed to the experimental setup and measurements. Funding was provided by the German Research Foundation (DFG) and the Excellence Cluster Universe.

Magneticum Pathfinder opens a new era of cosmological simulations

The evolution of the universe in an unmatched precision

The world's most elaborate cosmological simulation of the evolution of our universe was accomplished by theoretical astrophysicists of the Ludwig-Maximilians-Universität Munich (LMU) in cooperation with scientists of the Excellence Cluster Universe's datacentre C^2PAP and experts of the Leibniz Supercomputing Centre. The most comprehensive simulation within the 'Magneticum Pathfinder' project pursues the development of a record number of 180 billion tiny spatial elements in a previously unreached spatial area of 12.5 billion light years. For the first time, a hydrodynamic cosmological simulation is large enough to be directly compared with large-scale astronomical surveys.

Within modern cosmology, the Big Bang marks the beginning of the universe and the creation of matter, space and time about 13.8 billion years ago. Since then, the visible structures of the cosmos have developed: billions of galaxies which bind gas, dust, stars and planets with gravity and host supermassive black holes in their centres. But how could these visible structures have formed from the universe's initial conditions?

To answer this question, theoretical astrophysicists carry out cosmological simulations. They transform their knowledge about the physical processes forming our universe into mathematical models and simulate the evolution of our universe on high-performance computers over billions of years.

Simulation of the large-scale structures

A group of theoretical astrophysicists from the LMU led by Klaus Dolag has now, as part of the Magneticum Pathfinder project, performed a new, unique hydrodynamic simulation of the large-scale distribution of the universe's visible matter. The most recent results regarding the three most important cosmic ingredients of the universe are taken into account – the dark energy, the dark matter and the visible matter.

The scientists incorporated a variety of physical processes in the calculations, including three that are considered particularly important for the development of the visible universe: first, the condensation of matter into stars, second, their further evolution when the surrounding matter is heated by stellar winds and supernova explosions and enriched with chemical elements, and third, the feedback of supermassive black holes that eject massive amounts of energy into the universe.

The most comprehensive simulation covers the spatial area of a cube with a box size of 12.5 billion light years. This tremendous large section of the universe was never part of a simulation before. It was divided into a previously unattained number of 180 billion resolution elements, each representing the detailed properties of the universe and containing about 500 bytes of information.

Comparison with astronomical surveys

For the first time, these numerous characteristics make it possible to compare a cosmological simulation in detail with large-scale astronomical surveys. "Astronomical surveys from space telescopes like Planck or Hubble observe a large segment of the visible universe while sophisticated simulations so far could only model very small parts of the universe, making a direct comparison virtually impossible," says Klaus Dolag. "Thus, Magneticum Pathfinder marks the beginning of a new era in computer-based cosmology."

This achievement is preceded by ten years of research and development, accompanied by experts of the Leibniz Supercomputing Centre (LRZ) of the Bavarian Academy of Sciences, one of the most powerful scientific computer centres in Europe. "One of the biggest challenge for such a complex problem is to find the right balance between optimizing the simulation code and the development of the astrophysical modelling," explains Klaus Dolag. "While the code permanently needs to be adjusted to changing technologies and new hardware, the underlying models need to be improved by including better or additional descriptions of the physical processes which form our visible universe."

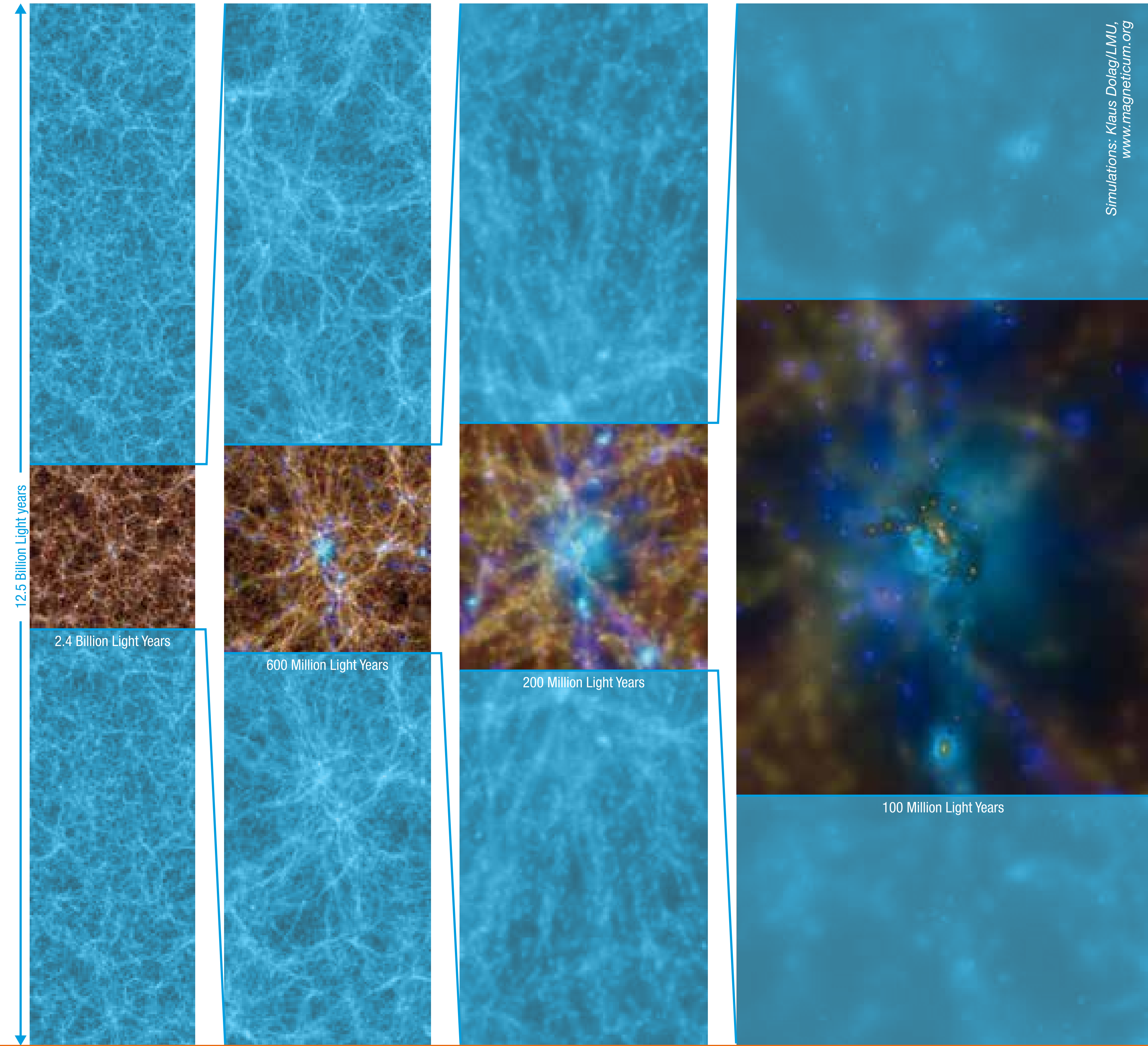
The realization took two years

The realization of this largest simulation within the Magneticum Pathfinder project took about two years. The research group of Klaus Dolag was supported by the physicists of the datacentre C^2PAP which is operated by the Excellence Cluster Universe and located at the LRZ. Within the framework of several one-week workshops, the Magneticum Pathfinder team got the opportunity to use the LRZ' entire highest-performance supercomputer SuperMUC for its simulation. "I do not know any datacentre that would have allowed me to use the entire computing capacity for such a long time," says Klaus Dolag.

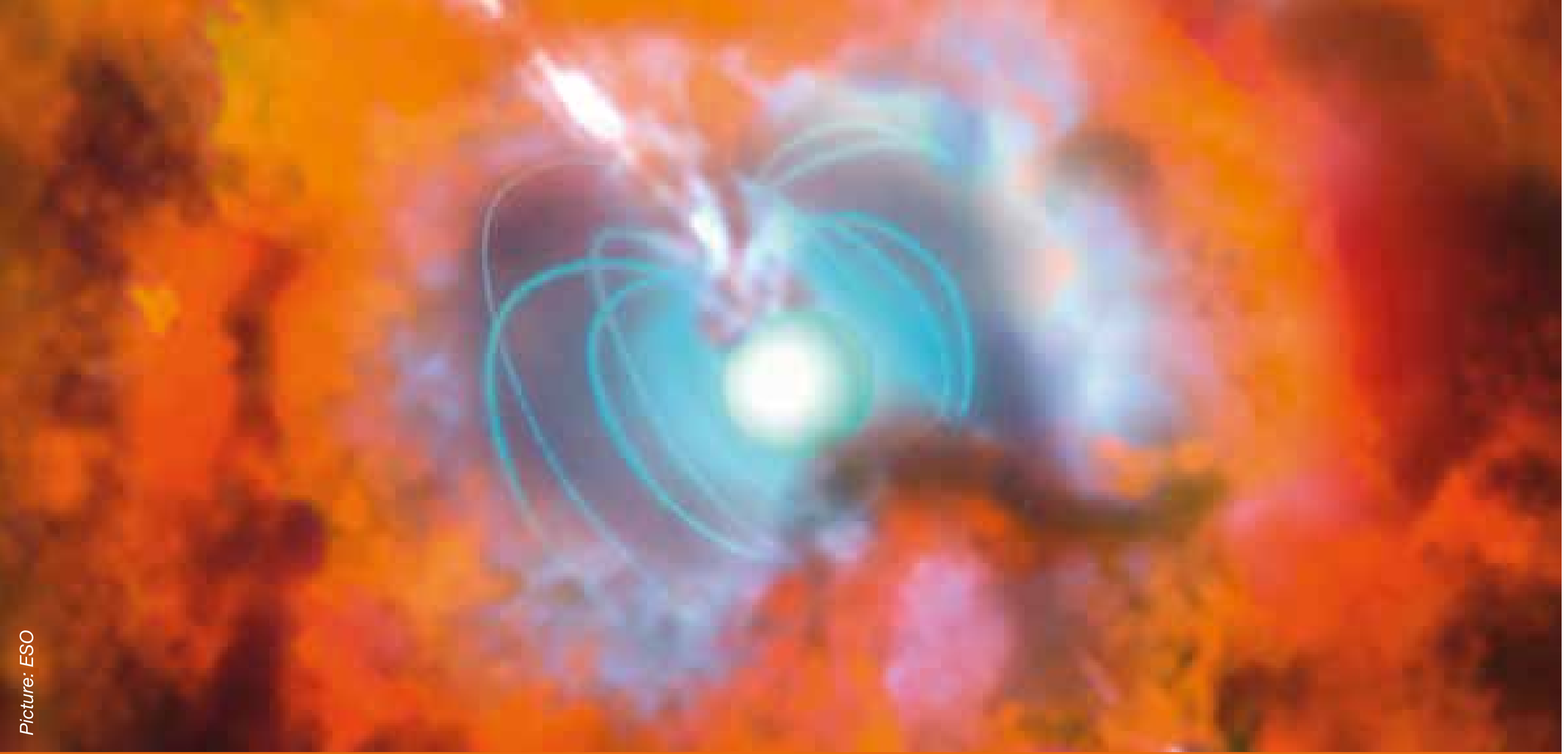
Overall, the Magneticum Pathfinder simulation utilised all 86,016 computing cores and the complete usable main memory – 155 out of a total of 194 Terabytes – of the expansion stage 'Phase 2' of the SuperMUC which was put into operation recently. The entire simulation required 25 million CPU hours and generated 320 Terabytes of scientific data.

Data centre for cosmological simulations

These data are now available for interested researchers worldwide. The Munich-based astrophysicists are already engaged in further projects: Among others, Klaus Dolag is currently closely working with scientists from the Planck collaboration to compare observations of the Planck satellite with the calculations of Magneticum Pathfinder. The extensive development work for the hydrodynamic simulations of the Magneticum Pathfinder project was in particular supported by the Bavarian Competence Network for Technical and Scientific High Performance Computing (KONWIHR), the Astrolab at the LRZ and the Excellence Cluster Universe with its datacentre C^2PAP.



The Magneticum Pathfinder project: The world's most elaborate cosmological simulation of the evolution of the universe shows the large-scale distribution of matter with its galaxy groups and clusters and the extensive network of galaxy filaments.



Picture: ESO

This artist's impression shows a supernova and an associated gamma ray burst driven by a rapidly spinning neutron star with a very strong magnetic field — an exotic object known as a magnetar.

New insights into very long lasting gamma ray bursts

The strongest magnetic fields power the biggest explosions

Astronomers from the Max Planck Institute for Extraterrestrial Physics in Garching and the Karl Schwarzschild Observatory have for the first time demonstrated a link between a very long-lasting burst of gamma rays and an unusually bright supernova explosion. The results show that the supernova was not driven by radioactive decay, as expected, but was instead powered by a decaying super-strong magnetic field around an exotic object called a magnetar. The results appeared in the Nature journal.

For a long time the cause of gamma ray bursts (GRBs), very short and very sharp pulses of high-energy electromagnetic radiation first discovered in 1973, remained a mystery. In recent years, astronomers were able to increasingly enlighten the nature of this phenomenon by using dedicated gamma and X-ray satellites, in particular including the Swift satellite that is designed to quickly locate short-lived gamma-ray bursts so that other telescopes can be aligned to the object while the afterglow is still on-going.

GRBs usually only last for a few seconds, but in very rare cases the gamma radiation continues for hours. A particularly long-lasting and very bright GRB was observed by the Swift satellite on December 9, 2011 and named GRB 111209A.

As the afterglow from the burst faded, it was studied using both the GROND instrument on the 2.2-metre telescope at La Silla and the X-shooter instrument on the Very Large Telescope (VLT) at Paranal. The observations were found to be characteristic of a supernova, so the event was later named SN 2011kl.

Astronomers have observed that only for about one in 100,000 supernovae a gamma ray burst occurs. “The exploding star must be somewhat special,” says Jochen Greiner from the Max Planck Institute for Extraterrestrial Physics (MPE) and member of the Excellence Cluster Universe. To date, it was assumed that these GRBs come from very massive stars (about 50 times the mass of the sun) and that they signalled the formation of a black hole. “Our new observations suggest, however, that this is not the case for very long lasting GRBs.”

A week-long burst of optical and infrared radiation was supposed to result from the decay of the radioactive nickel isotope Ni-56, which was created in the supernova explosion. The combined observations from GROND and VLT have now shown clearly for the first time that this is not correct. Other theories could also be ruled out.

The only explanation that fitted the observations was that the burst was being powered by a magnetar — a tiny neutron star spinning hundreds of times per second and possessing a magnetic field much stronger than normal neutron stars, which are known as radio pulsars. Magnetars are thought to be the most strongly magnetised objects in the universe.

“For the first time we have an excellent evidence for a link between GRBs, very bright supernovae and magnetars,” says Jochen Greiner. “This finding brings us much closer to a better understanding of the causes of gamma ray bursts.”

Excellence Cluster Universe PhD Awards 2015

Distinctions for outstanding doctoral theses

The Excellence Cluster Universe awards the Universe PhD Prizes 2015 to Cora Uhlemann (LMU) and Peter Ludwig (TUM) for their outstanding dissertations. The thesis work of Peter Ludwig is the experimental discovery of supernova-produced Fe-60 in marine sediments, which must have been accumulated on the earth about two million years ago. Cora Uhlemann develops in her thesis theoretical models for the formation of dark matter structures in the nonlinear region. The award ceremony took place during the Science Week 2015 of the Excellence Cluster. The award is endowed with 2.000 Euro.

Credit: NRAO/AUI/NSF/GBT/VLA, Chandra X-ray O., NASA/CXC/Rutgers, C.Schmidt opt. telescope, NOAO/AURA/NSF/CTIO and Digitized Sky Survey.

A supernova remnant (here SN1006): In his work, Peter Ludwig proves the presence of supernova traces in marine sediments from the Pacific Ocean.

Credit: ESO/L. Calçada

Artist's impression of the expected dark matter distribution around our Milky Way: Cora Uhlemann explores new theoretical models for the structure formation of dark matter.

In his thesis ‘Search for Fe-60 of Supernova Origin in Earth's Micro Fossil Record’, Peter Ludwig proved the presence of the iron Fe-60 in marine sediments from the Pacific Ocean, an iron isotope that is only produced in supernovae. In his interdisciplinary work Peter Ludwig for the first time succeeded in determining a time-resolved signal of the Fe-60. Accordingly, the supernova remnant must have crossed our solar system about two million years ago for a period of about 750,000 years.

The supernova remnant Fe-60 was integrated into nanometer-sized magnetites (Fe_3O_4) by iron-loving bacteria that live in ocean sediments. These magnetotactic bacteria obtain the iron from atmospheric dust that enters the ocean. After the death of the cells, the magnetites remain on the ocean floor and, over geological time, gradually turn into ‘magneto fossils’. The test to determine the Fe-60 content was performed at the accelerator mass spectrometer located at the Maier-Leibnitz Laboratory in Garching. Furthermore, Peter Ludwig was able to increase the Fe-60 sensitivity of the spectrometer by a factor of ten.

Photo: Riedel/TUM

Cora Uhlemann and Peter Ludwig with their laudators Prof. H. Wolter (LMU) (l.) and Prof. W. Hillebrandt (MPA)

Prof. Wolfgang Hillebrandt (MPA) highlighted the quality of the work at the award ceremony on November 30, 2015: “For this outstanding interdisciplinary, extremely dilligent and engaged piece of work, Peter Ludwig deserves the Universe PhD Award in the category ‘experiment’.”

The theoretical work of Cora Uhlemann ‘Theoretical models for the formation of the Large-Scale Structure in the Universe’ explores theoretical models for the two different kinds of structure formation of dark matter: The development of individual tied structures of dark matter called halos that envelop the galactic discs, and the evolution of the large-scale structures of the cosmic dark matter web. Both aspects are not well understood in theory, and have to rely on results from numerical simulations. The issues investigated in the thesis lie at the interface between theoretical, numerical and observational cosmology.

Cora Uhlemann tackles the problems with new approaches. She presents a method based on the correspondence of classical and quantum mechanics that is able to generate a halo. Cora Uhlemann also develops a new model to calculate the correlation function in the redshift space. The calculations are compared with results derived by the standard perturbation theory. It is shown that the Gaussian flow model is sufficient for this approach. Finally, the results are compared with N-particle simulations.

“For this original and extensive work comprising many new ideas, approaches and solutions to interesting questions in the field of cosmology, Cora Uhlemann receives this year's Universe PhD Award in the category ‘theory’”, the laudator Prof. Hermann Wolter (LMU) said.

1st Atmospheric Neutrino Workshop in Garching

Takaaki Kajita at the Excellence Cluster

The Nobel laureate Takaaki Kajita was a guest at the 1st Atmospheric Neutrino Workshop at the Excellence Cluster Universe. The professor of the University of Tokyo and director of the Japanese Institute for Cosmic Ray Research came as a member of the organizing committee and one of the speakers. The workshop held in early February was organized by Prof. Elisa Resconi of the Technical University of Munich (TUM). Around 35 international researchers got together in Garching to attempt solving the problem of the neutrino mass hierarchy by using atmospheric neutrinos.

Photo: Riedel/TUM

A meeting in Garching: Prof. Stefan Schönert (TUM), Prof. Elisa Resoni (TUM), Prof. Takaaki Kajita (University of Tokyo), Prof. Martin Beneke (TUM) (f.l.).

The Standard Model of particle physics describes the fundamental building blocks of the universe and its interactions and has been widely tested and confirmed. However, there are a number of open questions to which the model has no answer. This includes the question of the neutrino masses.

The scientists know from experiments that a neutrino of a given type can, after travelling a certain distance, transform into a neutrino of another type (the Standard Model knows three types of neutrinos: the electron, muon and tauon neutrinos). As these transformations occur within certain periods, physicists refer to the phenomenon as neutrino oscillations. As a consequence of the oscillations, neutrinos must have masses – unlike the Standard Model predicts. It is experimentally attested that these masses must be vanishingly small, but it has not yet been possible to exactly measure their quantities.

The mystery of the neutrino masses

Now, the physicists want to solve the hierarchy of these three mass states, thus, the question of which mass state is the largest and which one is the smallest. "This longstanding problem can be clarified by exploring atmospheric neutrinos in a relatively short time," says Prof. Elisa Resconi from the Excellence Cluster Universe at the Technical University of Munich (TUM). 'Atmospheric' refers to the neutrino's place of origin, produced by collisions of cosmic particles, mainly protons, with the molecules of the earth's atmosphere.

To bring together the international scientists working on these experiments, Elisa Resconi organized the 1st Atmospheric Neutrino Workshop in Garching. From February 7 to 9, 2016 around 35 researchers and numerous students met at the Munich Institute for Astro- and Particle Physics (MIAPP). At this international visiting research centre of the Excellence Cluster Universe, they discussed the physical issues and challenges related to these experiments.

Elisa Resconi was especially pleased by one particular participant: "We had invited Takaaki Kajita some time before his Nobel Prize and feel very honoured that he came in spite of his many new invitations and obligations." In autumn 2015, the Japanese particle physicist was awarded the Nobel Prize in Physics for the discovery of neutrino oscillations with the Super-Kamiokande detector made in 2003. During his visit in Garching he introduced the concept of the future detector Hyper-Kamiokande, which is planned to be about 20 times larger than the predecessor experiment Super-Kamiokande.

"The detector size is a crucial factor for next generation neutrino experiments," Elisa Resconi explains. "To obtain significant results an event rate of at least 100,000 neutrino signals per year is needed, which is roughly a doubling compared to what is achieved today." Elisa Resconi and her research group at TUM are a member of the IceCube collaboration, with a size of one cubic kilometre the world's largest neutrino telescope that was designed to observe high-energy cosmic neutrinos.

With the project PINGU (Precision IceCube Next Generation Upgrade) the IceCube collaboration has proposed a detector upgrade to make IceCube sensitive for atmospheric neutrinos. In this way, the collaboration could contribute to solving the problem of the neutrino mass hierarchy within a few years.

The workshop in Garching was also joined by scientists of the future experiment DUNE (Deep Underground Neutrino Experiment) at the Sanford Lab in South Dakota, USA, and the planned Mediterranean neutrino telescope Orca (Oscillation Research with Cosmics in the Abyss).

Elisa Resconi considers the workshop a great success: "The very pleasant and relaxed atmosphere at our international visiting research centre MIAPP has ensured that everybody felt comfortable and immediately got into discussion." Next year, the researchers will meet again, very likely in Japan.

Scientific & Public Events

Preview

Within the next couple of months, the Excellence Cluster Universe will organize numerous scientific and public events. The lectures, conferences and workshops highlighted in orange are primarily addressing experts. All other events are aimed at the interested public.

04. - 29.04.2016	MIAPP I: Cosmic Reionization	MIAPP, Boltzmannstr. 2, Garching
08.04.2016, 11:00	Special Universe Talk: Dr. Leslie Sage (Nature Publ. Group): "How to write a Nature Paper"	MPE, new seminar room, Gießenbachstraße, Garching
12.04.2016, 19:00	Café & Kosmos: Dr. Marco Drewes (TUM): „Wie heiß war der Urknall?"	Muffatcafé, Zellstr. 4, München
19.04.2016, 16:15	1. Hans-Peter Dürr Colloquium Prof. Rolf-Dieter Heuer (CERN/DPG): "Science and Society – Connecting Worlds"	MPP, auditorium, Föhringer Ring 6, München
02. - 27.05.2016	MIAPP II: Higher Spin Theory and Duality	MIAPP, Boltzmannstr. 2, Garching
17.05.2016, 19:00	Café & Kosmos: Dr. Wolfgang Kerzendorf (ESO): "Was uns historische Supernova-Überreste verraten" for further events see: www.cafe-und-kosmos.de	Muffatcafé, Zellstr. 4, München
23. - 25.05.2016	MIAPP II Topical Workshop: Aspects of Higher Spin Theory Registration on: www.munich-iapp.de (bis 23.04.2016)	MPA, room E.0.11, Karl-Schwarzschild-Str. 1, Garching
30.05. - 01.06.2016	Interdisciplinary Cluster Workshop on Detectors and Instrumentation www.universe-cluster.de/detectors2016	to be announced
30.05. - 24.06.2016	MIAPP III: Why is there more Matter than Antimatter in the Universe?	MIAPP, Boltzmannstr. 2, Garching
06. - 08.06.2016	MIAPP III Topical Workshop: Baryogenesis – Status of Experiment and Theory Registration on: www.munich-iapp.de (bis 06.05.2016)	MPA, room E.0.11, Karl-Schwarzschild-Str. 1, Garching
06. - 08.07.2016 9:00 - 17:00	Presentation Workshop for Excellence Cluster Universe students and scientists For registration: andreas.mueller@universe-cluster.de	LMU, room C007, Pettenkoferstr. 12, München
19. - 21.07.2016 13:00 - 15:00	Dr. Celine Peroux (CNRS Marseille): Lecture Series on Cosmic Flows	MIAPP-Seminarraum, Boltzmannstr. 2, Garching
25.07. - 19.08.2016	MIAPP IV: The Chemical Evolution of Galaxies	MIAPP, Boltzmannstr. 2, Garching
22.08. - 16.09.2016	MIAPP V: The Physics of Supernovae	MIAPP, Boltzmannstr. 2, Garching
12. - 16.09.2016	MIAPP V Topical Workshop: Supernovae: The Outliers Registration on: www.munich-iapp.de (until 12.08.2016)	MPA, room E.0.11, Karl-Schwarzschild-Str. 1, Garching
24.10. - 18.11.2016	MIAPP VI: Flavour Physics with High-Luminosity Experiments	MIAPP, Boltzmannstr. 2, Garching
07. - 09.11.2016	Interdisciplinary Cluster Workshop on Data Analysis www.universe-cluster.de/dataanalysis2016	to be announced

Personalia | New entries & farewells, awards and honours

Photos: Andreas Heddergott, Astrid Eckert, privat

Stefan Schönert

professor of experimental astroparticle physics at TUM and principal investigator of the Excellence Cluster Universe, recently became a Max Planck Fellow at the Max Planck Institute for Physics (MPP). He will conduct research in the field of dark matter and neutrino physics. The fellowship programme of the Max Planck Society strives to deepen the cooperation between its institutions and outstanding academics.

Claudia Hagedorn

since November 2013 a research fellow at the Excellence Cluster Universe, was appointed assistant professor at the Centre for Cosmology and Particle Physics Phenomenology at the University of Southern Denmark in Odense, Denmark, starting January 1, 2016. The theoretical particle physicist works in the fields of modelling, flavour symmetries, neutrino physics, lepton flavour violation and leptogenesis.

Andreas Weiler

was appointed associate professor for theoretical particle physics at colliders at the TUM on October 1, 2015. After completing his PhD at TUM in 2005, he was postdoc at Cornell University, Ithaca, USA, until 2009, he then became a CERN fellow and since 2011 he is a staff member at DESY and since 2013 also at CERN. His interests lie in theoretical high-energy physics, especially on the implications of the LHC results.

Bastian Märkisch

was appointed tenure track assistant professor for elementary particle physics at low energies at the TUM on April 1, 2015. After receiving his PhD in 2006 at the University of Heidelberg and followed by various research visits, he headed a DFG research group at the University of Heidelberg starting in 2010. His main focus is on weak interaction measurements in the decay of free neutrons.

IMPRESSUM

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