ASTROPARTICLE PHYSICS 2019.

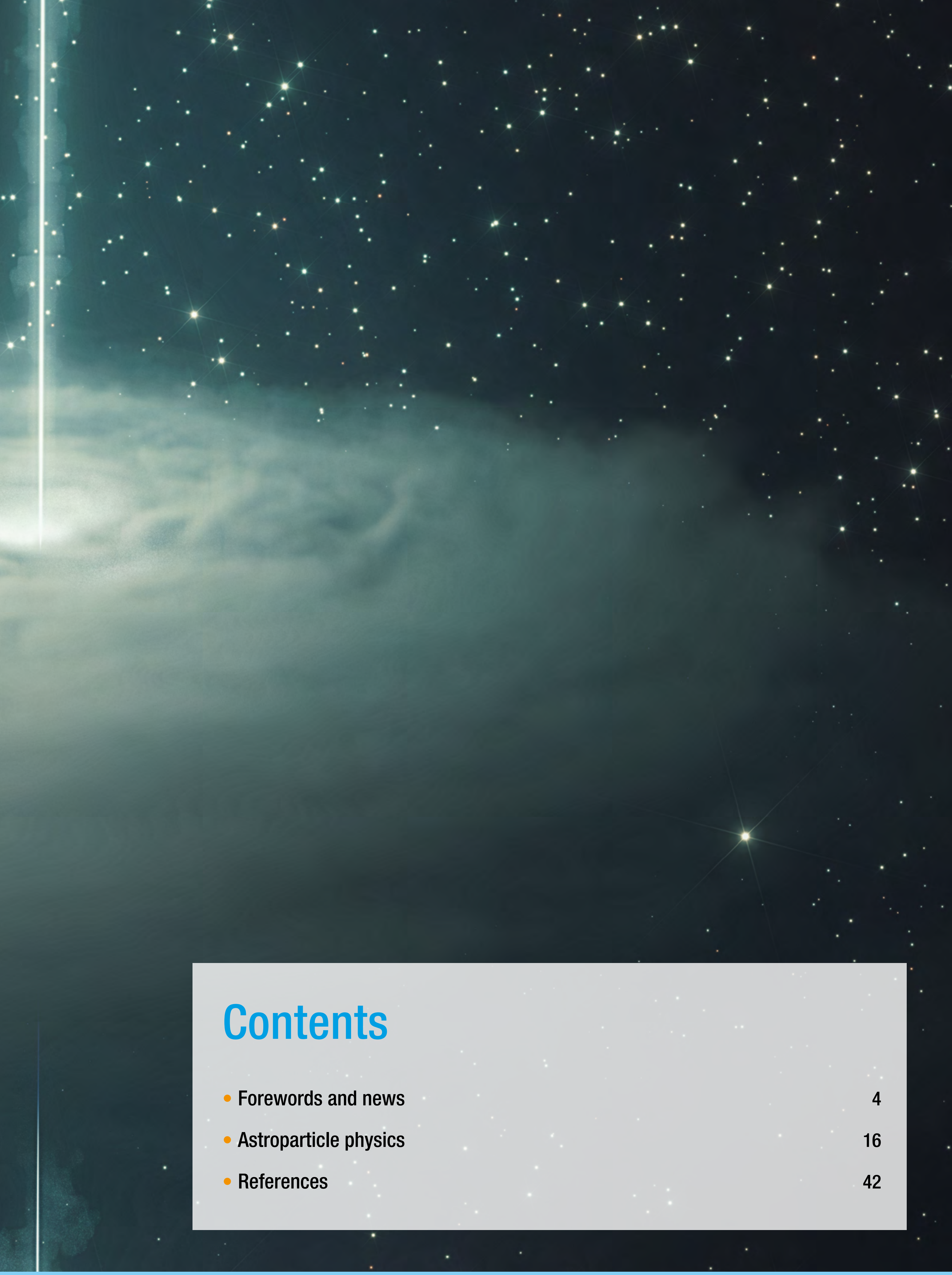
Highlights and Annual Report

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

Cover
Artist's impression of an active galaxy with jets

ASTROPARTICLE PHYSICS 2019.

Highlights and Annual Report



Contents

The year 2019 at DESY

Chairman’s foreword

Dear Colleagues and
Friends of DESY,

2019 was a year with marked advances. Most prominently, DESY turned 60! The event was celebrated with a festive reception in the Hamburg city hall in the presence of Hamburg’s Deputy Mayor and Senator for Science, Research and Equality Katharina Fegebank and the newly appointed State Secretary at the Federal Ministry of Education and Research (BMBF) Wolf-Dieter Lukas. Both complimented us on our work, giving us confidence that the City of Hamburg and the German federal government will continue their support for our core business: basic research.

With Wim Leemans and Christian Stegmann, we welcomed two new directors to DESY: Wim has taken over the accelerator division from Reinhard Brinkmann, and Christian is heading our new astroparticle physics division. With this restructuring, we are strengthening our activities in astroparticle physics and giving dynamic leadership to these two important areas of our science portfolio.

Recent highlights in astroparticle physics include the detection of gamma-ray bursts in the TeV energy range, the identification of the source of a PeV neutrino and the detection of gamma rays from a gravitational merger event. The upgrade of the IceCube neutrino observatory at the South Pole and the construction of the Cherenkov Telescope Array (CTA), the two major facilities of astroparticle physics, are progressing well. With the ULTRASAT satellite, a joint project with the Weizmann Institute of Science in Israel, DESY ventures into space. These are exciting times for astroparticle physics, in which DESY plays a prominent role.

Remarkable results were also achieved at our synchrotron radiation and free-electron laser (FEL) light sources. Ultrafast imaging of biological samples is steadily improving and becoming routine, with yet unimaginable implications. Our synchrotron radiation source PETRA III (soon to become PETRA IV), our FLASH FEL facility and the European XFEL X-ray laser have a huge potential for new techniques and future biomedical applications. A first position paper on the National Photon Science Strategy was developed jointly by the Helmholtz centres DESY, HZB in Berlin and HZDR in Dresden. The future looks bright for photon science.

Particle physics research too continued successfully in 2019. With the Large Hadron Collider (LHC) at CERN being upgraded, data analysis and the preparations for the construction of tracker end-caps for the ATLAS and CMS experiments were the focus of our work. The Belle II detector at the SuperKEKB collider in Japan started to take data, and first dipoles were installed at DESY for the ALPS II experiment. The DESY Foundation Council approved the construction of the Wolfgang Pauli Centre (WPC) for theoretical physics. As a common hub for broad theoretical physics research on the campus in Hamburg-Bahrenfeld, the WPC will be the leading institute for theoretical physics in Germany, greatly benefitting our research, training, public visibility and on-site experimental programme.

In the next 20 years, DESY, Universität Hamburg and the City of Hamburg plan to realise the “Science City Bahrenfeld”, a joint campus for science, education, training, innovation and knowledge transfer to industry and society. At the heart of this campus, DESY will be well positioned for its next 60 years!

Finally, I would like to thank the DESY staff and all our national and international partners, who are so important for the success of our vibrant research centre.

Yours

Helmut Dosch
Chairman of the DESY Board of Directors

Astroparticle physics at DESY

Director’s foreword

Dear friends of DESY,

2019 was the “year 1” of the Astroparticle Physics division, but not the first year of astroparticle physics at DESY. Activities in Zeuthen (then in the German Democratic Republic) started in the late 1980s with the participation of the Institute of High-Energy Physics (IfH) in a Russian experiment to detect astrophysical neutrinos in Lake Baikal. In 1991, the institute – and with it its astroparticle physics activity – became the Zeuthen branch of DESY. The Baikal neutrino telescope led to the DESY involvement in the AMANDA and IceCube neutrino observatories at the South Pole, the discovery of astrophysical neutrinos (breakthrough of the year 2013) and eventually the identification of the first source of a 290 TeV neutrino, along with many exciting results on neutrino properties, oscillation pattern and limits on potential source populations.

Today, DESY is the second strongest member of IceCube, and the research centre is firmly connected with the establishment of neutrino astronomy as a new window to the high-energy universe. Funding has been secured for a first upgrade of IceCube, which will eventually be followed by a significant extension to a multipurpose neutrino facility at the South Pole. Dubbed IceCube-Gen2, it promises another 30 years of exciting research on neutrinos from cosmic accelerators.

In 2006, in order to broaden its astroparticle physics scope, DESY chose to get involved in gamma-ray astronomy: Photons and neutrinos travel in straight lines and therefore lend themselves to astronomical observations. In the following years, DESY got involved in all major Cherenkov telescope projects and in the Large Area Telescope (LAT) on board the Fermi Gamma-Ray Space Telescope. These projects produced a wealth of important results that has only very few parallels. DESY is meanwhile a key member in the H.E.S.S. and VERITAS gamma-ray telescopes in Namibia and Arizona, respectively, and one of the largest collaborators in the next-generation Cherenkov Telescope Array (CTA), which is currently under construction and which will surpass all current instruments by orders of magnitude. The Science Data Management Centre of CTA will be hosted at DESY in Zeuthen.

In the past decade, gamma-ray astronomy yielded important results: Gamma-rays do trace cosmic particle accelerators, there are plenty of gamma-ray sources, many of which are variable and intermittent, and cosmic accelerators likely produce cosmic rays, gamma rays and neutrinos at the same time. Combined observations of all of these “cosmic messengers”, including the recently discovered gravitational waves, allow multimessenger and transient analyses revealing details of sources that one messenger alone cannot provide. In the past two years alone, the first source of a high-energy neutrino could be identified as an active galaxy in an outburst from optical to gamma-ray energies. Two merging neutron stars produced a gravitational wave event that was also observed in gamma rays as a gamma-ray burst, and, for the first time, two gamma-ray bursts were seen emitting gamma rays up to TeV energies, even hours after the explosion. Closely collaborating experimentalists and theorists are thrilled by the new perspectives and the promise of the field in the next decade.

There could have been no better time to establish an astroparticle physics division at DESY. We are just opening three new windows to the high-energy neutrino, gamma-ray and gravitational wave universe, revealing the power of their combination. In these exciting times, we see the first shiny gems of results, heralding a golden era in astroparticle physics with the next generation of instruments. And DESY is playing a leading part in it.

Christian Stegmann

Christian Stegmann
Director of Astroparticle Physics

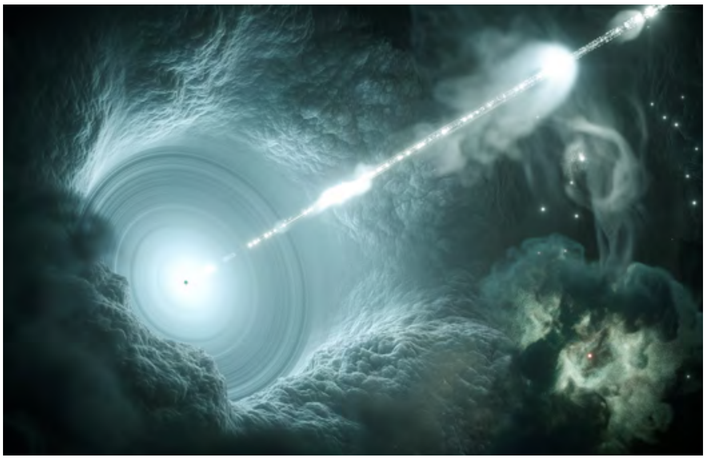
News and events

Highlights in 2019

January

Astroparticle physics becomes research division at DESY

DESY expands its activities for the exploration of the high-energy universe by setting up a new research division for astroparticle physics. The director in charge of astroparticle physics is Christian Stegmann, who is also the head of DESY's Zeuthen site. DESY now has four research divisions: accelerators, photon science, particle physics and astroparticle physics.



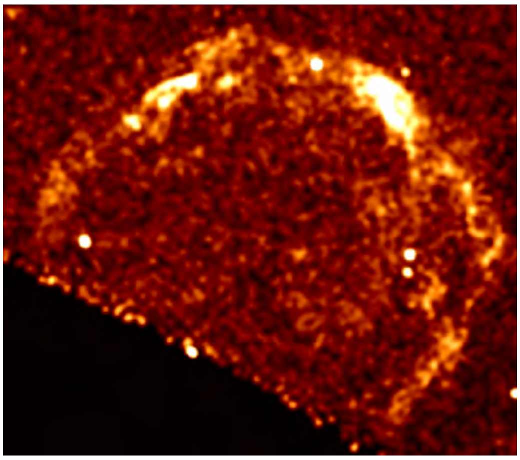
Cosmic particle accelerators like blazars (artist's impression) are typical objects for multimessenger astronomy.

Making KONTAKT with the public

A new national education and communication project called KONTAKT, funded by the German Federal Ministry of Education and Research (BMBF), was launched on 1 January 2019. Its primary goal is to introduce young people, but also the interested general public to the physics of the smallest particles. Scientists from 30 universities and research institutes in Germany are cooperating to promote the dialogue between science and society and to test new forms of participation. The project uses the structures of the national teaching network Netzwerk Teilchenwelt. DESY in Zeuthen is leading the subproject measuring cosmic particles with table-top detectors and coordinates the astroparticle projects.

Scientists explore gamma rays from “superbubble”

An international scientific team, including Stefan Ohm from DESY, used NASA's Chandra X-ray Observatory to reveal how very-high-energy (VHE) gamma rays are produced by the “superbubble” 30 Doradus C, an astronomical phenomenon on the southern sky and the only one of its kind visible in VHE gamma-rays. The energetic radiation is the product of the interaction of fast electrons with ambient light, as the team reported in the journal *Astronomy & Astrophysics*.



The “superbubble” 30 Doradus C, captured by the Chandra satellite

Prototype of new gamma-ray telescope inaugurated

A novel gamma-ray telescope could enhance the capabilities of the planned Cherenkov Telescope Array (CTA): The prototype of the Schwarzschild–Couder Telescope (pSCT) with a superior dual-mirror optics was inaugurated at the Fred Lawrence Whipple Observatory in Arizona, USA. DESY is a member of the international consortium that designed and built the pSCT, using synergies with the standard medium-sized telescopes for CTA that DESY has designed and will be building.

The Schwarzschild–Couder Telescope prototype (pSCT)

February

OpenAFS prize for Stephan Wiesand

The OpenAFS Foundation awarded a prize to Stephan Wiesand from the DESY computer centre in Zeuthen for his merits for the worldwide OpenAFS system, an open-source implementation of the Andrew distributed file system. For many years, Wiesand has been the release manager and support officer for the international OpenAFS user community.

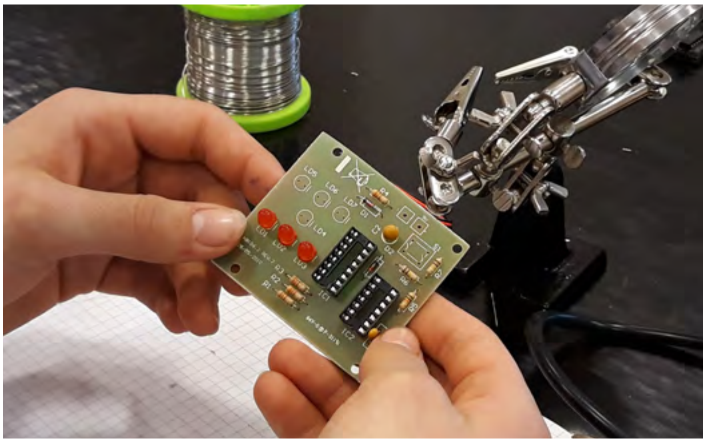
Prize winners of the Hans Riegel Foundation visit DESY

In February, a group of prize winners of the Hans Riegel Foundation visited DESY in Zeuthen. The pupils and students were awardees in mathematics, information science, natural science and technology (MINT) with keen interests in current research. This year, the visit was dedicated to astroparticle physics, with an introductory lecture and a visit to the prototype of the medium-sized telescope (MST) of CTA in Berlin-Adlershof and useful suggestions on how to get involved in school and student projects.

Prize winners of the Hans Riegel Foundation in front of the CTA MST prototype

March

beMINT projects



In the beMINT project, pupils got to know the profession of an electronics technician.

For the first time, pupils from secondary schools could get information and hands-on experience at DESY in the vocational profession of electronics technician. In 2018, a similar event had been organised for mechanics. With these beMINT projects, DESY will continue to provide orientation to adolescents looking for vocational training.

DESY's Zeuthen campus to receive a new appearance

In March, the winner of the architectural competition for the campus development, the new building for the CTA Science Data Management Centre and the canteen was announced. The first prize went to Heinle, Wischer und Partner, Freie Architekten GbR from Berlin, along with Ulrich Krüger Landschaftsarchitekten from Dresden. Planning towards the realisation of the winning design has commenced.

DESY staff examining the campus plans of the architectural competition.

New partnership with TH Wildau

DESY and the Technical University of Applied Sciences (TH) Wildau signed a cooperation agreement on innovation and spin-offs, aiming at a long-term strengthening of the innovation power and knowledge transfer of the two major science organisations in the Dahme-Spreewald district.

IceCube Masterclass

Participants in the IceCube Masterclass at DESY in Zeuthen

DESY in Zeuthen participated the 6th International Icecube Masterclass. A total of 19 research labs in Europe and the USA participated in the project and invited local pupils to work like researchers in astroparticle physics for a day and to meet scientists of the IceCube neutrino telescope. IceCube was introduced, data were analysed, and results were discussed with the participants from all over the world.

17th Future Day for girls and boys

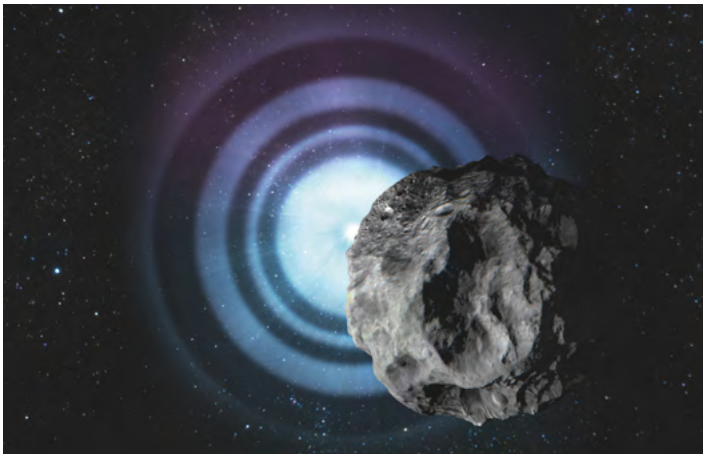
DESY in Zeuthen welcomed about 40 pupils to the Future Day, an annual information day on the range and specialisations of professions needed in a large research centre. The multitude of professions at DESY was presented, and pupils spent the rest of the day with a staff member of their choice to learn more about their education and daily work. Typically, every year some participants of the Future Day return for internships and apply for places for vocational training later on.

Participants in the Future Day at DESY in Zeuthen

April

Asteroids reveal the sizes of distant stars

A new technique greatly improved the power of angular size measurements of stars. Using the unique capabilities of Cherenkov telescopes, scientists measured the smallest apparent size of a distant star known to date. The measurements with the Very Energetic Radiation Imaging Telescope Array System (VERITAS) reveal diameters of a giant star 2674 light years away and of a sun-like star at a distance of 700 light years as small as about 100 microarcseconds. The new method uses the very short-lived diffraction pattern created when an asteroid in our solar system coincidentally covers a distant star. The development and the analysis were led by Tarek Hassan from DESY and Michael Daniel from the Smithsonian Astrophysical Observatory.



When an asteroid passes in front of a star, the resulting diffraction pattern (here greatly exaggerated) can reveal the star's angular size.

Why lightning often strikes twice

In contrast to popular belief, lightning often does strike twice, but the reason why a lightning channel is “reused” remained a mystery. An international research team including scientists from DESY used the LOFAR radio telescope to study the development of lightning flashes in unprecedented detail. Their work shows the occurrence of a break in the discharge channel, at a location where so-called needles are formed. The needles appear to store negative charges from the main channel, which subsequently re-enter the cloud and recharge it. Once the charge in the cloud becomes high enough again, the flow through the channel is restored, leading to a second discharge of lightning. The results were published in the journal *Nature*.

Lightning above LOFAR (montage)

May

Rafael Porto secures an ERC consolidator grant at DESY

Rafael Porto, newcomer to DESY’s Astroparticle Physics division, does not only bring an exciting research topics, but also one of the most prestigious grants of the European Union. He secured an ERC consolidating grant (two million euros over a five years) to continue his work in gravitational wave physics, using methods from particle physics. He developed this novel combination for high-precision gravitational wave physics.

Showing face for science

For the 2019 March for Science, DESY, the Leibniz Institute for Astrophysics Potsdam (AIP) and TH Wildau started the campaign “WISSEN SCHAFFT”. On this day, scientists showed their faces and spoke out for science in the German federal state of Brandenburg (https://wissen-schafft.org). The campaign stayed active throughout the year.

Start of the campaign “WISSEN SCHAFFT” for the March of Science on 4 May

Long Night of the Economy in the Dahme-Spreewald district

In May, DESY and 18 other firms and organisations in the Dahme-Spreewald district opened their doors for visitors to learn about their activities and potential. About 400 persons came to the DESY campus and were impressed by its activities. While DESY features regularly in various Long Nights of the Sciences, this was the first such event emphasising economic activities.

DESY scientists explain their research projects at the Long Night of the Economy.

Workshop for real-time multimessenger astronomy

In May, scientists from DESY, Humboldt University (HU) Berlin and AIP met in Zeuthen to discuss real-time alerting systems for multimessenger astronomy. Presentations included the AMPEL framework, developed at HU Berlin and DESY, as well as real-time systems of H.E.S.S. and plans for CTA. Possibilities were discussed on how to join forces for a multimessenger analysis centre that would also offer software for alert streams from other observatories.

Astroparticle Physics Review Committee established

In May, the constituting meeting of the Astroparticle Physics Review Committee (APC) took place at DESY in Zeuthen. The APC will advise the DESY Directorate in all matters concerning astroparticle physics and review the activities and plans of the newly established astroparticle physics division twice a year. Its founding members are Christian Weinheimer (University of Münster, chair), Antoine Kouchner (APC Paris, vice chair), Elena Amato (INAF / University of Florence), Gianfranco Bertone (University of Amsterdam), David Hanna (McGill University, Montreal) and Jörn Wilms (University of Erlangen-Nürnberg).

The APC at its first meeting in May 2019 in Zeuthen. Standing from left: Antoine Kouchner (APC Paris), Christian Stegmann (DESY), Elena Amato (INAF/ University of Florence), Jörn Wilms (University of Erlangen-Nürnberg), Gianfranco Bertone (University of Amsterdam), Christian Weinheimer (University of Münster) and David Hanna (McGill University).

June

Long Night of the Sciences in Berlin-Adlershof

DESY and HU Berlin jointly presented their projects in particle and astroparticle physics at the Long Night of the Sciences in Berlin-Adlershof. Eight selected talks, the exhibition “From the Micro- to the Macrocosmos” and the vacuum experiments from the DESY school lab “physik.begreifen” were on show for a large interested audience.

DESY scientists demonstrate their research at the Long Night of the Sciences.

Radio neutrino detector workshop

A workshop was held at DESY in Zeuthen on simulation and reconstruction strategies for radio neutrino detectors. About 25 participants from experiments aiming to detect neutrinos using radio emission from neutrino-induced particle showers (e.g. ARA, ARIANNA, GRAND, RNO, etc.) met to discuss and develop common tools and equipment.

Guest lecture by Saul Perlmutter

In June 2019, the physics Nobel laureate and eminent astrophysicist Saul Perlmutter came to DESY for an inspirational lecture titled “Science, Reality and Credibility – The Necessity of Critical Thinking”. Perlmutter spoke about teaching the critical thinking used so effectively in science to a wider, non-expert audience. More than 200 people crowded into the auditorium at DESY in Hamburg.

PhD students and postdocs with Nobel laureate Saul Perlmutter

July

DESY welcomes more than 100 summer students

In 2019, the DESY summer student programme brought together participants from more than 25 countries. The students gained practical experience in research at the DESY sites in Hamburg and Zeuthen. The DESY summer school is one of the largest of its kind in Europe.

Sixteen summer students studied DESY's Zeuthen site.

Anna Nelles receives IUPAP Young Scientist Award

The astroparticle physics commission of the International Union of Pure and Applied Physics (IUPAP) awarded one of two Young Scientist Awards to Anna Nelles for her work on the detection of neutrinos using radio emission from the particle showers that neutrinos can create in the atmosphere. The technology is being refined to also use it in ice for the detection of ultrahigh-energy neutrinos in a major upgrade of the IceCube experiment. The award was presented at the 2019 International Cosmic Ray Conference in Madison, USA.

International Cosmic Ray Conference (ICRC) in Madison

More than 20 DESY staff members participated in the ICRC with lectures and poster contributions.

The worldwide astroparticle physics community met in July for the International Cosmic Ray Conference (ICRC) in Madison, USA. About 900 physicists from 39 countries presented new results and developments. Twenty-two DESY staff members participated in the conference, presenting 16 talks and 22 posters. Stefan Ohm served as member of the International Scientific Programme Committee. The next conference of the series will be organised by DESY in summer 2021 in Berlin.

August

Minister-President of Brandenburg visits DESY

The Minister-President of Brandenburg, Dietmar Woidke, visited DESY in Zeuthen and was briefed on current science topics and the role of DESY as a prime location for science and education in the German federal state of Brandenburg.

Group photo with the Prime Minister of Brandenburg: Dietmar Woidke (third from the left, front row) visits DESY in Zeuthen.

Conference PAHEN 2019

The Perspectives in Astroparticle physics from High Energy Neutrinos (PAHEN) conference was organised by DESY at HU Berlin. About 80 scientists came to Berlin to discuss scientific results of recent neutrino measurements and their implications for other branches of astrophysics.

September

Making the invisible visible

Under the 2019 motto “Making the invisible visible”, DESY in Zeuthen participated in the science festival Highlights of Physics in Bonn, presenting gamma-ray astronomy on the large central square. Many scientists from all over Germany presented their work in astronomy, particle physics and quantum physics fitting the motto and answered the questions of the more than 60 000 visitors.

Students speaking to visitors at the exhibition Highlights of Physics 2019

Good-bye to the CTA prototype in Berlin-Adlershof

The prototype of the medium-sized, 12 m CTA telescope that was operated in Berlin-Adlershof for almost seven years had to make room for another use of the plot. The prototype served well to refine the telescope design and test how to mount and operate the structure and the mirrors, calibrate the pointing and assess and optimise the failure rate of the whole system. With the precious experience gained with the prototype, work is now ongoing towards the construction of the first production telescope at the northern CTA site on La Palma, Spain.

Past and present personnel involved in the MST prototype

15 years of DESY school lab in Zeuthen

Demonstration of an experiment

With its largest teacher training so far, DESY celebrated the 15th anniversary of its school lab “physik.begreifen”. A total of 170 teachers saw a first show of the new collection of experiments for the school course “Natural Sciences 5/6”, which were developed by DESY and a team of teachers in a common effort with the Brandenburg Ministry of Education, Youth and Sports (MBJS). Since May 2004, the DESY school lab has been offering activities for pupils and teachers on various topics. More than 40 000 pupils and hundreds of teachers have visited DESY and benefited from the teaching and learning materials and experimental setups.

IceCube Impact Award

Thomas Kintscher, a former PhD student at DESY, received the IceCube Impact Award for his important contributions to the IceCube real-time alerting system, which helped to achieve a number of groundbreaking science results.

Thomas Kintscher with an IceCube digital optical module

October

DESY strengthens cooperation with Armenia

A DESY delegation visited Armenia to intensify the long-standing scientific relations between DESY and Armenian research institutions. A declaration was signed between CANDLE and the DESY accelerator division and another one between the Alikhanian National Lab (formerly Yerevan Physics Institute) and the DESY particle and astroparticle physics divisions. A common element in both agreements is the training of young scientists. In a meeting with the President of the Republic of Armenia, both sides emphasised their will to continue and strengthen the good relations.

DESY Lifetime Achievement Award

Helga Schwendicke and Wolfgang Lange from DESY in Zeuthen were honoured with the DESY Lifetime Achievement Award. Both worked at the institute already in the 1980s, well before it became part of DESY, and were well-esteemed colleagues until their retirement.

Helga Schwendicke and Wolfgang Lange

DESY PhD Thesis Prize for Marcel Usner

DESY PhD Thesis Prize winners Marcel Usner and Max Rose at the award ceremony with VFFD Chairman Wilfried Buchmüller and DESY Director Helmut Dosch (from left)

The 2019 PhD Thesis Prize of the Association of the Friends and Supporters of DESY (VFFD) went (in part) to Marcel Usner from the DESY astroparticle physics division. For the first detection of cosmic tau neutrinos with the IceCube detector, Marcel Usner improved the event reconstruction significantly, so that tau neutrinos with energies as low as 100 TeV could be unambiguously identified.

DESY Science Slam

Th DESY astroparticle physics division was victorious in the 2019 DESY Science Slam. Robert Stein and Summer Blot (both from IceCube) came in first and second in the overall ranking. Eight candidates fought for the honour, two from each DESY research division. In the end, Robert and Summer convinced the whole audience and carried the trophy home to Zeuthen.

Robert Stein and Summer Blot won the first DESY Science Slam.

Workshop on science of gravitational wave detectors

A topical two-day workshop was held at the Berlin-Brandenburg Academy of Sciences and Humanities to discuss the science case of third-generation gravitational wave detectors. Sixty experts met to review the science potential of experiments such as the Einstein Telescope or the Cosmic Explorer as well as the potentially very fruitful links of gravitational wave physics to cosmology, various branches of astrophysics, fundamental physics and physics under extreme conditions. The workshop also served to sound out the community interest and a possible contribution of the Helmholtz Association, the Max Planck Society and the German universities to the Einstein Telescope, which could be built in the border region between the Netherlands, Belgium and Germany.

New UV satellite to view exploding stars and black holes

A new space telescope will open up an unprecedented view of the universe in ultraviolet light: The Israel-led ULTRASAT satellite will provide fundamental new insights into high-energy phenomena such as supernova explosions, colliding neutron stars and active black holes, all of which can also generate gravitational waves and act as cosmic particle accelerators. On 28 October, Helmholtz President Otmar D. Wiestler and DESY Director Helmut Dosch signed a corresponding cooperation agreement with the Weizmann Institute of Science in Rehovot, Israel. DESY will build the 100-megapixel UV camera as the German contribution to the ULTRASAT space telescope.

Israeli–German partnership (from left to right): Otmar D. Wiestler (President of the Helmholtz Association), Eli Waxman (Principal Investigator of ULTRASAT at the Weizmann Institute of Science), Avi Blasberger (Director General of the Israeli Space Agency (ISA), Daniel Zajfman (President of the Weizmann Institute of Science), Helmut Dosch (Chairman of the DESY Board of Directors), Christian Stegmann (DESY Director of Astroparticle Physics).

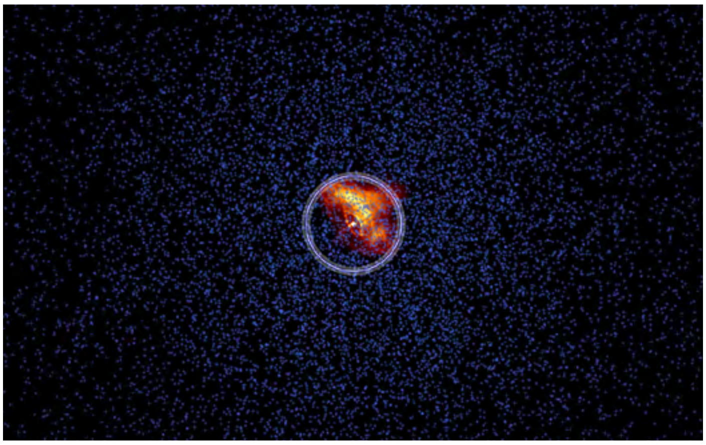
Kick-off for Graduate School for Multimessenger Astronomy

The Israeli-German International Helmholtz-Weizmann Graduate School for Multimessenger Astronomy was opened with a festive ceremony in Israel. The programme, in which the Weizmann Institute of Science in Rehovot, HU Berlin and the University of Potsdam joined forces with DESY, is funded by the Helmholtz Association with 1.8 million euros. The school initially started with 17 doctoral students, eight of whom were at DESY and nine at the Weizmann Institute at the time.

Opening of the International Helmholtz-Weizmann Graduate School for Multimessenger Astronomy. Front row, from left: Christian Stegmann (DESY Director of Astroparticle Physics, second), Helmut Dosch (Chairman of the DESY Board of Directors), Daniel Zajfman (President of the Weizmann Institute of Science), Marek Kowalski (speaker of the school, DESY), Otmar D. Wiestler (President of the Helmholtz Association), Eli Waxman (speaker of the school, Weizmann), and the principal investigators and graduate students

Size of Crab Nebula measured with gamma rays

The Crab Nebula is the remnant of a supernova in our galaxy that was observed almost 1000 years ago. Although it is one of the most-studied celestial objects, its extension in very-high-energy gamma rays remained unknown. Since the first detection of such gamma rays from the nebula with ground-based gamma-ray telescopes in 1989, it could not be distinguished from a point source, owing to the comparably poor angular resolution of the telescopes. Using a novel simulation environment that takes into account the observation conditions at an unprecedented level of detail, the international team operating the H.E.S.S. telescopes in Namibia eventually succeeded in measuring the extension of the Crab Nebula in the high-energy range. The nebula exhibits a very-high-energy gamma-ray extension that is larger than that in X-rays but smaller than the one in the ultraviolet regime.



Crab nebula (yellow-orange), as seen in X-rays with Chandra (Data from M.C. Weisskopf und J.J. Kolodziejczak).

November

International Cosmic Day 2019

The 8th International Cosmic Day took place on 6 November. The series is organised by DESY in Zeuthen with support of research institutions from all over the world, with the common aim of sparking interest in scientific subjects among young people. Participants from 72 institutes in 18 countries on six continents learned about cosmic rays, their origins and how to measure them. The results were discussed via video conference, just like real scientists do.

Gamma-ray bursts with record energy

The ground-based gamma-ray telescopes H.E.S.S. and MAGIC detected gamma-ray bursts for the very first time. These strongest explosions in the universe produce even more energetic radiation than previously known: The two international teams registered the highest-energy gamma rays ever measured from gamma-ray bursts, reaching about 100 billion times as much energy as visible light. The H.E.S.S. and MAGIC collaborations presented their observations in three publications in the journal *Nature*. DESY plays a major role in both observatories, which are operated under the leadership of the Max Planck Society.

Trainee honoured by IHK Cottbus

On 20 November, Caroline Brademann was honoured by the Cottbus Chamber of Industry and Commerce (IHK) as the best trainee of the year in industrial mechanics (“Feingerätebau”) in the district of Cottbus. Through outstanding performance, she was able to shorten her training and convincingly passed her final examination after only three years. She is the first trainee of the “dual education system” at DESY in a cooperation with TH Wildau.

December

GNN-Dissertation Prize 2019

Marcel Usner from DESY and HU Berlin was awarded the GNN Dissertation Prize of the Global Neutrino Network, an organisation representing all neutrino astronomy researchers worldwide. Usner received the prize for his PhD thesis “Search for Astrophysical Tau-Neutrinos in Six Years of High-Energy Starting Events in the IceCube Detector”.
He shared the prize with Silvia Celli from GSSI L’Aquila, INFN and Sapienza University of Rome, Italy.

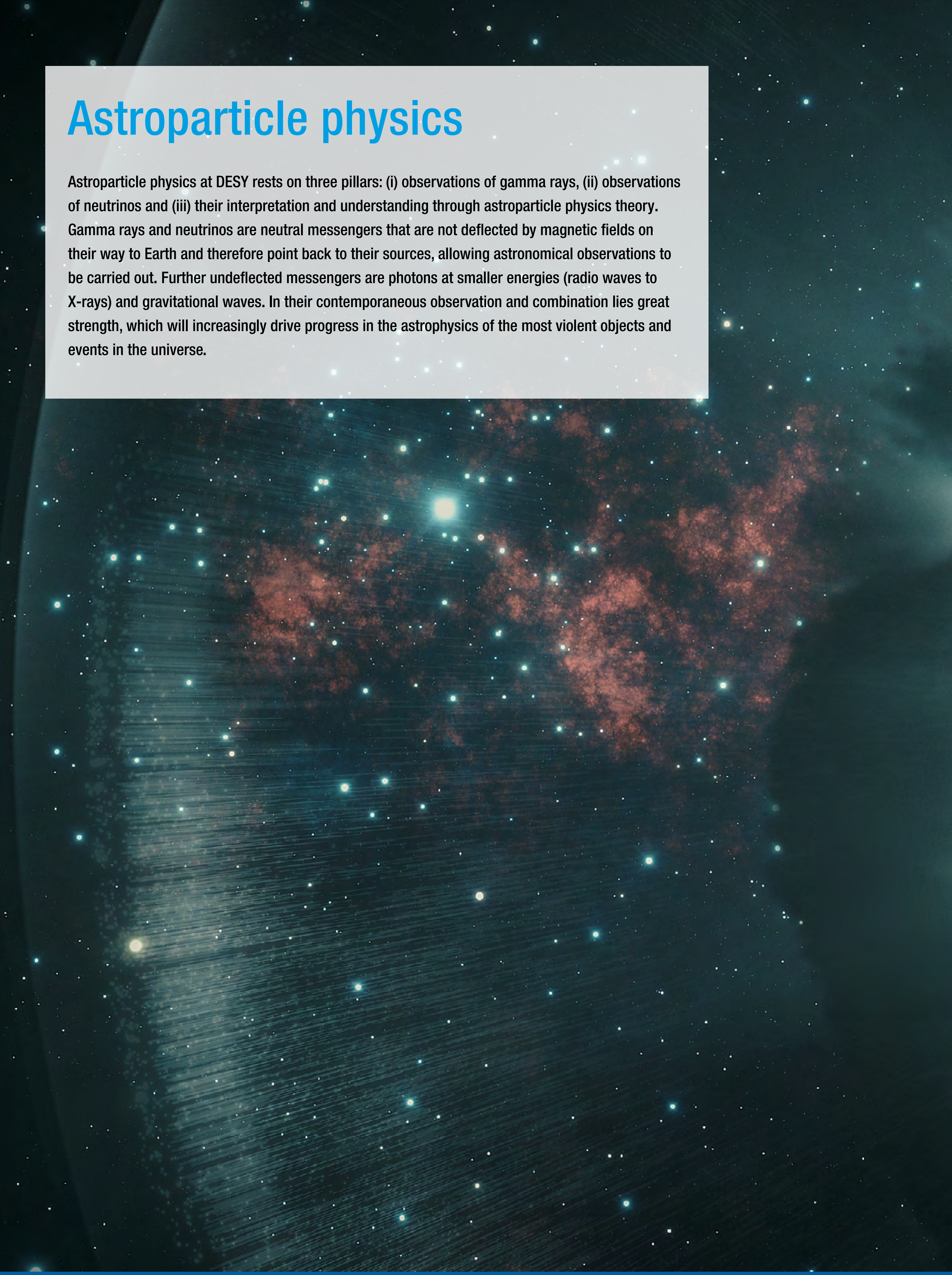
60 years of DESY

Germany’s largest accelerator centre turned 60 on 18 December 2019. Its history has been a story of success, for global research and for Germany as a science hub. Fundamental research was first carried out at DESY in Hamburg-Bahrenfeld – which was joined in 1991 by the second DESY site in Zeuthen.

The DESY staff in Zeuthen celebrates DESY’s 60th anniversary.

Astroparticle physics

Astroparticle physics at DESY rests on three pillars: (i) observations of gamma rays, (ii) observations of neutrinos and (iii) their interpretation and understanding through astroparticle physics theory. Gamma rays and neutrinos are neutral messengers that are not deflected by magnetic fields on their way to Earth and therefore point back to their sources, allowing astronomical observations to be carried out. Further undeflected messengers are photons at smaller energies (radio waves to X-rays) and gravitational waves. In their contemporaneous observation and combination lies great strength, which will increasingly drive progress in the astrophysics of the most violent objects and events in the universe.



Experiments, theory, projects and infrastructure

Gamma-ray bursts with record energies

First detection of cosmic monster explosions with ground-based gamma-ray telescopes

The strongest explosions in the universe produce even more energetic radiation than previously known: Using Cherenkov telescopes, two international teams involving DESY scientists have registered the highest-energy gamma rays ever measured from gamma-ray bursts, reaching about 100 billion times as much energy as visible light.

Gamma-ray bursts

Gamma-ray bursts (GRBs) are sudden, short bursts of gamma radiation happening about once a day somewhere in the visible universe. According to current knowledge, they originate from colliding neutron stars or from supernova explosions of giant stars collapsing into a black hole (Fig. 1). Gamma-ray bursts are the most powerful explosions known in the universe and typically release more energy in just a few seconds than our sun during its entire lifetime – they can shine through almost the entire visible universe. The cosmic phenomenon was discovered by chance at the end of the 1960s by satellites used to monitor compliance with the nuclear test ban on Earth.

Since then, astronomers have been studying gamma-ray bursts with satellites, as the Earth's atmosphere very effectively absorbs gamma rays. Astronomers have developed specialised telescopes for the highest energy end of the spectrum. They can observe a faint blue glow called Cherenkov light that cosmic gamma rays induce in the atmosphere (Fig. 2), but these instruments are only sensitive to the very rare gamma rays with very high energies. Unfortunately, the brightness of gamma-ray bursts falls steeply with increasing energy. In the past, Cherenkov telescopes have identified many sources of cosmic gamma rays at very high energies, but no gamma-ray bursts. The detectors on satellites, on the other hand, are much too small to be sensitive to the low brightness of gamma-ray bursts at very high energies. So, it was effectively unknow whether the monster explosions emit gamma rays also in the very-high-energy regime.

Gamma-ray astronomy with Cherenkov telescopes

In independent publications in the journal *Nature* [1, 2, 3] in 2019, the scientists of the High-Energy Stereoscopic System (H.E.S.S.) in Namibia and the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes on La Palma presented their first detections of gamma-ray bursts with ground-based gamma-ray telescopes. DESY plays a major role in both observatories, which are operated under the leadership of the Max Planck Society. DESY scientists were crucially involved in the recording of the bursts, the analysis of the gamma signals and spectra and the interpretation of the results.

Scientists had tried for many years to catch a gamma-ray burst with Cherenkov telescopes. Then suddenly, between summer 2018 and January 2019, the two international teams of H.E.S.S. and MAGIC detected gamma rays from two such events for the first time from the ground. On 20 July 2018, faint afterglow emission of GRB 180720B in the gamma-ray regime was observed with the 28 m telescope of H.E.S.S.. On 14 January 2019, bright early emission from GRB 190114C was detected by the MAGIC telescopes and immediately announced to the astronomical community.

Both observations were triggered by gamma-ray satellites of NASA that monitor the sky for gamma-ray bursts and send automatic alerts to other gamma-ray observatories upon detection. MAGIC was able to point to the region of origin so quickly that observation could be started only 57 s after the initial detection of the explosion. In the first 20 min of observation, about thousand photons from GRB 190114C were detected.

MAGIC registered gamma rays with energies between 200 and 1000 billion electronvolts (0.2 to 1 TeV). These are by far the highest-energy photons ever discovered from a gamma-ray burst.

The rapid discovery allowed the teams to quickly alert the entire observational community. As a result, more than 20 different telescopes had a deeper look at the target. This allowed the scientists to pinpoint the details of the physical

Figure 1

Gamma-ray bursts can be triggered by the explosion of a dying, supermassive star collapsing into a black hole. From the vicinity of the black hole, powerful jets shoot in opposite directions into space, accelerating electrically charged particles, which in turn interact with magnetic fields and radiation to produce gamma rays.

Figure 2

Cherenkov telescopes detect the bluish Cherenkov light generated by faster-than-light particles that are produced by cosmic gamma rays in the Earth's atmosphere.

mechanism responsible for the highest-energy emission, as described in the second paper, led by the MAGIC collaboration. Follow-up observations placed GRB 190114C at a distance of more than four billion light years. This means that its light travelled more than four billion years to us, or about a third of the current age of the universe.

GRB 180720B, which is even further away at a distance of six billion light years, could still be detected in gamma rays at energies between 100 and 440 billion electronvolts (100 to 440 GeV) long after the initial blast. Surprisingly, the H.E.S.S. telescope observed a surplus of 119 gamma quanta from the direction of the burst more than 10 h after the explosion event was first seen by satellites.

This detection came quite unexpected, as gamma-ray bursts fade fast, leaving behind an afterglow that can be seen for hours to days across many wavelengths from radio to X-rays, but had never been detected in very-high-energy gamma rays before. The success was also due to an improved follow-up strategy in which observations were also made at later times after the actual star collapse.

The detection of gamma-ray bursts at very high energies provides important new insights into the gigantic explosions. Having established that gamma-ray bursts produce photons of energies hundreds of billion times higher than visible light, it is clear now that they are able to efficiently accelerate particles within the explosion ejecta. Moreover, the energy released in very-high-energy gamma rays is comparable to the amount radiated at all lower energies taken together. That is remarkable!

To explain how the observed very-high-energy gamma rays are generated is challenging. Both groups assume a two-stage process: First, fast electrically charged particles from the explosion cloud are deflected in the strong magnetic fields and emit synchrotron radiation, which is of the same nature as the radiation that can be produced in synchrotrons or other particle accelerators on Earth, for example at DESY. However, only under fairly extreme conditions would the synchrotron photons from the explosion be able to reach the very high energies observed. Instead, the teams consider a second step, where the synchrotron photons collide with the fast particles that generated them, which boosts them to the very high gamma-ray energies recorded. The latter step is called inverse Compton scattering.

For the first time, the two instruments have measured gamma radiation from gamma-ray bursts from the ground. These two groundbreaking observations have established that gamma-ray bursts can be detected with terrestrial gamma-ray telescopes, which have the potential to significantly advance our understanding of these violent phenomena. The scientists estimate that up to ten such events per year can be observed with the planned Cherenkov Telescope Array (CTA), the next-generation gamma-ray observatory. CTA will consist of more than 100 individual telescopes of three types that will be built at two locations in the northern and southern hemispheres.

Contact:

Andrew Taylor, andrew.taylor@desy.de
Konstancja Satalecka, konstancja.satalecka@desy.de

References:

[1] H.E.S.S. Collaboration, "A very-high-energy component deep in the γ-ray burst afterglow", Nature 575, 464–467 (2019), DOI: 10.1038/s41586-019-1743-9

[2] MAGIC Collaboration, "Teraelectronvolt emission from the γ-ray burst GRB 190114C", Nature 575, 455–458 (2019), DOI: 10.1038/s41586-019-1750-x

[3] MAGIC Collaboration, "Observation of inverse Compton emission from a long γ-ray burst", Nature 575, 459–463 (2019), DOI: 10.1038/s41586-019-1754-6

Extreme-energy accelerators in extragalactic outer space

Understanding extreme sources of high-energy gamma radiation

The most powerful persistent accelerators in the universe are active galaxies with a supermassive black hole in their centre. They often form jets through which a small fraction of accreting matter can be emitted with a speed approaching the speed of light. Blazars are such active galaxies where one of the jets is directed towards Earth. Their luminosity and energy emission are thus boosted to higher values. Blazars dominate the extragalactic gamma-ray sky. Still, most of the highest-energy particle accelerators probably elude detection.

Millions to billions of light years from our galaxy, blazars are relentlessly accelerating particles to extreme energies. What do we know about these extreme sources of radiation?

Blazars are among the most fascinating objects in the universe. They are powered by black holes of enormous mass, billions of times that of the sun, located in the centre of distant galaxies. In blazars, part of the material in the vicinity of the black hole is swallowed, while another part is channelled through the action of the magnetic field and escapes the tremendous attraction. To astronomers, the escaping plasma appears as a thin stream clearly identifiable when seen edge-on (in this case, we speak of radio galaxies).

Blazars form a continuous sequence from low- to high-energy-peaked objects, with an overall correlation of the two peak frequencies. A small fraction (≤1%) of blazars presents a particularly intense emission at the highest energies, peaking in X-rays and TeV gamma rays: They are called extreme blazars (Fig. 1).

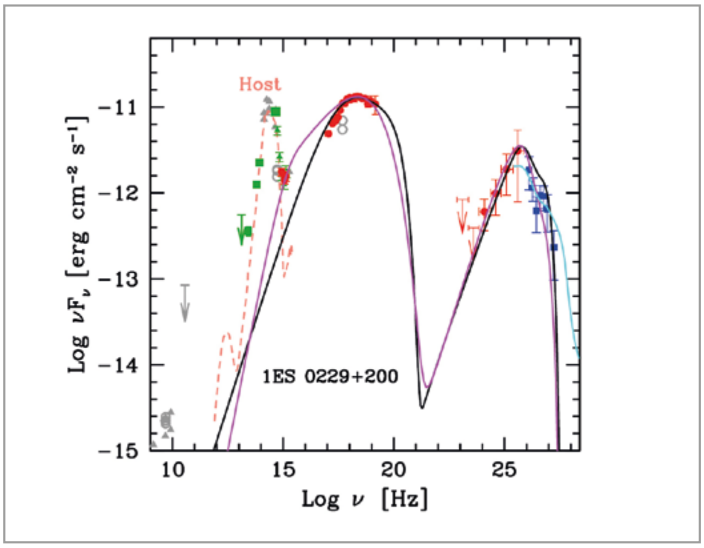


Figure 1

The spectral energy distribution of the blazar 1ES 0229+200 shows the unusually high frequency of the emission peaks that is characteristic of extreme blazars. The solid lines indicate attempts to model the observed data points.

Extreme blazars, whose energy emission can peak beyond 10 TeV, are ideal targets to study particle acceleration and radiative processes and may provide links from gamma rays to cosmic rays and astrophysical neutrinos. The growing number of extreme blazars observed at TeV energies has been critical for the emergence of gamma-ray cosmology, including measurements of the extragalactic background light, tight bounds on the intergalactic magnetic field and constraints on exotic physics at energies inaccessible with human-made accelerators. Tremendous progress has been achieved over the past decade, which bodes well for the future, particularly with the next-generation Cherenkov Telescope Array (CTA) gamma-ray observatory.

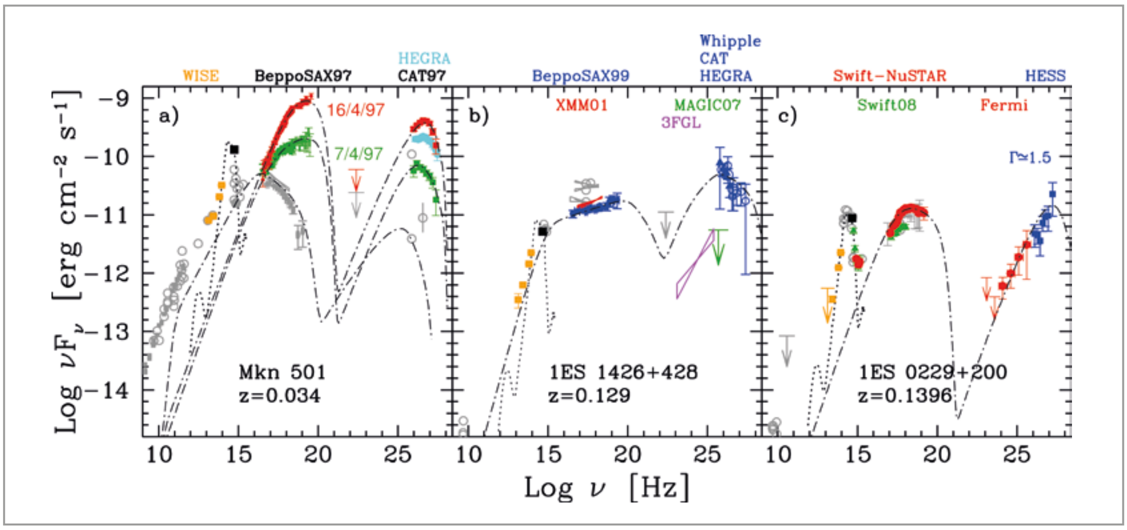


Figure 2

Prototypical spectral energy distributions illustrating the three types of extreme blazar behaviour. (a, b) Two extreme-synchrotron blazars, showing their energy flux during short-lived large flares (a) and long-lasting quiescent states (b). (c) Extreme-TeV blazar.

Early models predicted spectral gamma-ray peaks below 1 TeV because of the assumed limited maximum energy of the electrons. The discovery of extreme blazars with gamma-ray peaks up to 10 TeV therefore came as a surprise. A decade ago, only three out of ten extreme blazars with TeV emission were detected in the GeV range, already constraining some of their intrinsic properties. A new window on extreme blazars was opened by the growth of gamma-ray astronomy. Observational progress promoted not only the development of elaborate acceleration and radiative schemes, but also the investigation of ties with cosmic magnetism, ultrahigh-energy cosmic rays and physics beyond the Standard Model of particle physics.

A team of researchers from France (Paris Observatory, IN2P3), Germany (ESO, DESY, University of Munich) and Italy (ASI, INAF), including DESY scientists Andrew Taylor and Elisa Pueschel, has been investigating the nature of these enigmatic sources. In their publication in the journal *Nature Astronomy*, they presented the first census of extreme blazars observed in the gamma-ray band (the most energetic electromagnetic radiation). Twenty-four blazars with redshift out to $Z = 0.287$ (about four million light years) were studied, resulting in firm redshift measurements and published TeV spectra. All these blazars have meanwhile been detected at GeV energies by the Fermi Large Area Telescope (Fermi-LAT).

The blazars' main observational properties were analysed, yielding a rather complex picture in which some objects seem to fall within the prevailing model while some, the highest-energy blazars, may not. How particles such as protons and electrons are accelerated in these objects to generate such energetic gamma rays remains an unresolved question and a challenge for theoretical acceleration and emission models.

There are three distinct extreme behaviours (Fig. 2):

a) Blazars that become extreme during large flares, when both peaks shift to higher energies (e.g. Mkn 501). These objects revert back to their standard state.
b) Blazars that show a steady, hard synchrotron spectrum up to 10–100 keV (e.g. 1ES 1426+428), which is not accompanied by a persistently hard TeV spectrum.
c) Blazars that show a persistently hard gamma-ray spectrum with a peak above several TeV, which remains mostly unchanged across flux variations (e.g. 1ES 0229+200). Their synchrotron spectrum tends to peak in the X-ray band.

We know, however, that many of the questions raised by the article in *Nature Astronomy* will be within the reach of next-generation telescopes, such as CTA, with its two sites currently under construction on the Canary Island of La Palma and at Paranal in Chile. The work highlights that these objects are ideal laboratories for cutting-edge studies in cosmology, fundamental physics and plasma physics.

Contact:

Elisa Pueschel, elisa.pueschel@desy.de
Andrew Taylor, andrew.taylor@desy.de

Reference:

[1] https://www.nature.com/articles/s41550-019-0988-4

Gravitational collider physics

Probing ultralight bosons with binary black holes

While colliders have so far uncovered many of the building blocks of nature, probing new physics in this way relies on novel particles having appreciable interactions with the particles involved in the collision. Hence, traditional collider experiments are blind to (dark) sectors that couple very weakly to ordinary matter, even if the associated particles are much lighter than the ones in the Standard Model of particle physics. However, ultralight dark matter particles may still be copiously produced in astrophysical environments, e.g. around spinning black holes. The gravitational waves emitted by black hole binaries may then carry the fingerprints of the masses and spins of such hypothetical new particles, making these systems effectively "gravitational colliders" to search for physics beyond the Standard Model. Gravitational waves have thus not only initiated the era of multimessenger astronomy, they also provide an opportunity to explore new frontiers in particle physics through "gravitational wave precision data".

New frontier

While traditionally "new physics" searches have been associated with high energies and heavy particles, ultralight bosons have emerged as well-motivated extensions of the Standard Model to shed light on many puzzles in cosmology and particle physics. In particular, weakly interacting sub-eV particles (WISPs), predicted in many scenarios, are compelling candidates for the dark matter in the universe. Yet, detecting these particles by traditional experimental means is extremely challenging [1]. Moreover, if these hypothetical particles turn out to interact only gravitationally, new strategies will be needed to explore this exciting frontier in particle physics.

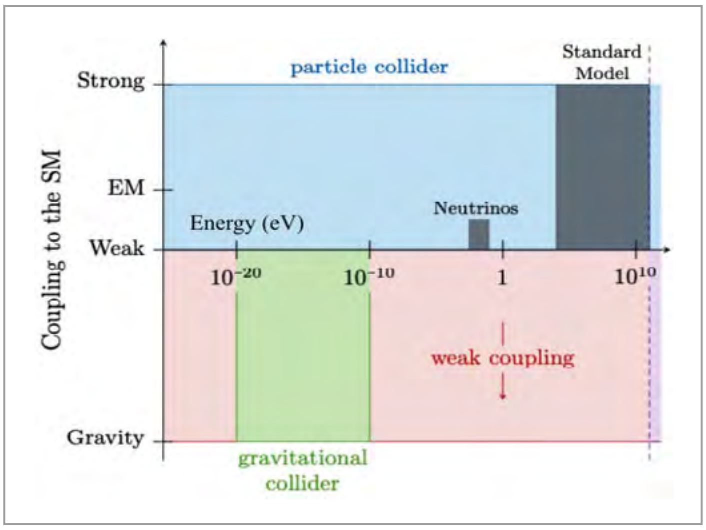


Figure 1

Particle colliders are blind to new particles that are either too heavy or too weakly coupled to be produced in sufficient numbers. On the other hand, bosons with masses in the range [10^{-20}, 10^{-10}] eV can be produced around black holes, leaving distinct imprints in the gravitational waves emitted by binary systems.

Loud universe

The direct detection of gravitational waves by the LIGO/Virgo collaboration marked the beginning of gravitational wave astronomy and the birth of "precision gravity" [2, 3]. Binary systems will soon become the leading probe to test gravitational dynamics and the physics of compact objects, such as black holes and neutron stars, under unique conditions. It is indisputable that gravitational wave science will play a transformative role in astrophysics. But at the same time, gravitational waves will also be sensitive to physics beyond the Standard Model, through the imprint of putative ultralight particles in the emission from binary black holes, unfolding a new era for explorations of the universe.

Gravitational atom

Light bosons can condensate around rapidly rotating black holes through "superradiant" instabilities [4]. The new particles that may be produced in this fashion span a vast range of scales, from 10^{-20} to 10^{-10} eV, corresponding to black holes of a few to billions of solar masses.

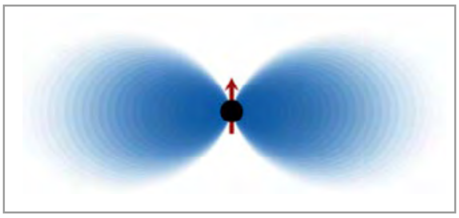


Figure 2

Rapidly rotating black holes may be endowed with an atmosphere produced by the condensation of ultralight particles.

Black holes carrying such a cloud are often called "gravitational atoms", due to the resemblance with the structure in hydrogen. For instance, like the electron around the proton, the gravitational atom can be in different discrete "energy levels", each with particular properties that depend on the mass and spin of the new particle.

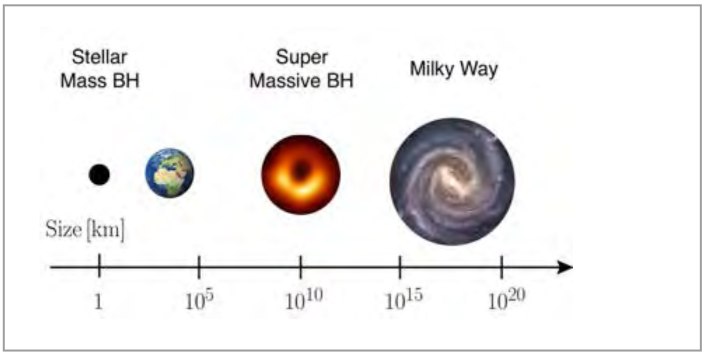


Figure 3

Typical sizes for astrophysical black holes that may be observed with Earth- and space-based gravitational wave experiments

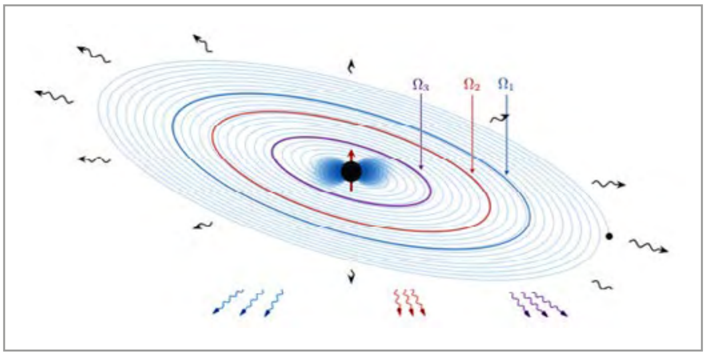


Figure 4

The gravitational atom experiences resonant transitions between different levels of the boson cloud at different orbital frequencies. These transitions leave a distinctive imprint in the gravitational waves emitted by the binary system.

In isolation, inferring the presence of a boson cloud is challenging, relying on the detection of a very feeble monochromatic gravitational wave signal [5]. However, in binaries, the much louder gravitational wave signatures from the two-body systems acquire distinctive features that may carry the fingerprints of ultralight particles in nature.

Gravitational collider

In atomic physics, transitions between different energy levels can be induced by applying an external field with just the right frequency. The electron then “jumps” from one state into another. Similarly, gravitational atoms in binary systems can experience “resonant transitions”, induced by the presence of a companion, when the orbital frequency matches the energy gap between different states [6, 7].

The existence of these resonant transitions is thus a smoking-gun signature of boson clouds in binary systems, whose properties (mass and spin of the associated ultralight particles) can be inferred from a precise reconstruction of the gravitational wave signal. Similarly to what is standard practice in traditional colliders, the position of the resonances determines the boson’s mass, and the reconstruction of the final state distinguishes particles with different spin. The latter is achieved through the study of so-called tidal (finite-size) effects on the waveforms. The discovery potential of gravitational wave observations thus necessitates the development of high-precision gravitational waveforms, which also incorporate the characteristic features of boson clouds in black hole binaries [7, 8].

Precision gravity

In order to construct faithful templates, the two-body problem in gravity must be solved to a high level of accuracy. In particular for the inspiral regime, extracting tidal effects requires analytic control of the dynamics to fifth post-Newtonian (5PN) order (and beyond) [2].

Moreover, this 5PN threshold is a unique diagnostic for new physics. While neutron stars deform depending on their equation of state, black holes in isolation do not at this order [2]. Using an analogy with particle physics, this means that there is no “Standard Model background” for new physics searches with binary black holes. A non-zero tidal effect appearing at 5PN, and more mass than what is allowed for neutron stars, would unambiguously point to new phenomena, either in the form of hitherto unknown compact bodies, black holes with “hair” [4], or clouds of ultralight bosons [6, 7]. Gravitational wave observations will thus constrain the content of the universe in an unprecedented fashion through gravitational wave precision data [8]. As a consequence, both present and next-generation detectors will explore new frontiers in particle physics, while offering for the first time an “ear” to the dark universe.

Contact:

Rafael A. Porto, rafael.porto@desy.de

References:

[1] https://alps.desy.de/
[2] R. A. Porto, arXiv:1703.06440[physics.pop-ph]
[3] R. A. Porto, Fortsch. Phys. 64 no. 10, 723–729 (2016)
[4] Y. Zel’ Dovich, JETP Letters 14, 180 (1971)
[5] R. Brito et al., Phys. Rev. D96 no. 6, 064050 (2017)
[6] D. Baumann, H. S. Chia, R. A. Porto, Phys. Rev. D 99, 044001 (2019) (Editor’s suggestion)
[7] D. Baumann, H. S. Chia, R. A. Porto, J. Stout, arXiv:1912.04932[gr-qc]
[8] R. A. Porto, Phys. Reports. 633, 1–104 (2016)

IceCube to receive significant upgrade

Neutrino detector at the South Pole will be expanded into a neutrino laboratory

The international neutrino observatory IceCube at the South Pole will be considerably expanded in the coming years. In addition to the existing 5160 sensors, a further 700 optical modules will be installed in the polar ice cap of Antarctica. The National Science Foundation (NSF) in the USA and the Helmholtz centres DESY and Karlsruhe Institute of Technology (KIT) have committed substantial funding and given the go-ahead to an expansion that will turn the observatory into a broader neutrino facility. In 2019, the US-led IceCube collaboration, of which Germany is the second most important member, published convincing indications of a first source of high-energy neutrinos from the cosmos.

IceCube

Neutrinos are among the most mysterious elementary particles. They hardly interact and can easily traverse entire planets, stars and galaxies – which is why they are often referred to as “ghost particles”. The neutrino observatory IceCube scours the deep Antarctic ice for the shy elementary particles. Below the surface, its extremely light-sensitive digital optical modules (DOMs) watch out for the bluish flashes that high-energy neutrinos from outer space can trigger in their very rare collisions in the ice. On 86 long cables, 5160 DOMs have been lowered up to 2.5 km deep into the transparent ice. From the precise measurement of the Cherenkov light triggered by a neutrino collision, the direction of origin and the energy of the incident particle can be reconstructed. Since neutrinos interact so extremely rarely, IceCube monitors a complete cubic kilometre of underground ice.

The IceCube neutrino observatory is located at the Amundsen–Scott South Pole Station. The observatory is managed and operated by the Wisconsin IceCube Particle Astrophysics Center (WIPAC) at the University of Wisconsin-Madison, USA. The science programme is run by more than 300 researchers from 52 institutes in 12 countries. After the USA, Germany is the second largest partner in the international project, with DESY the leading German institute. In addition to DESY, KIT and nine German universities are also involved in the project.

During the past decade, Ice Cube has established that astrophysical neutrinos do exist, measured their energy spectra, neutrino type ratio and oscillation parameters as well as arrival directions and put limits on the various source types regarding the production of the observed neutrinos. In 2019, observations with IceCube and a large number of other observatories spread across the globe led to the first localisation of a cosmic source of high-energy neutrinos. The particles detected by IceCube came from an active galaxy about four billion light years away, called TXS 0506+056, at the centre of which a gigantic black hole acts as a natural particle accelerator [1].

Despite these advances, many questions about the origin and properties of 100 GeV to PeV neutrinos still puzzle scientists. A way forward is to build a number of extensions to the existing IceCube detector to enhance its performance and sensitivity.

Figure 1

The IceCube neutrino observatory is located at the Amundsen–Scott South Pole Station

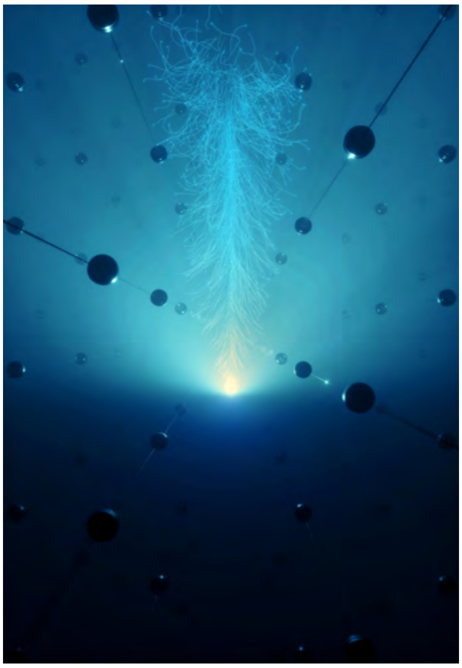


Figure 2
Deep down in the eternal ice of Antarctica, IceCube watches out for a faint bluish glow that indicates a rare collision of a cosmic neutrino within the ice.

Figure 3
The multipixel digital optical module (mDOM) measures 36 cm across horizontally.

The IceCube upgrade

The grand plan leading to a greatly enhanced neutrino facility called IceCube-Gen2 is still in the far future, but a first step was successfully taken in 2019, when US, German and other funding agencies agreed to finance an extension of the current installation by 700 newly designed optical sensors and by various calibration facilities. The NSF approved 23 million US dollars for the expansion. The Helmholtz centres DESY and KIT support the construction of 430 new optical modules with a total of 5.7 million euros (6.4 million US dollars). A number of other countries are making smaller contributions to the extension.

The IceCube upgrade will improve both neutrino astronomy and our knowledge of neutrino properties. IceCube has been collecting data for ten years already, and the upgrade will considerably enhance this data.

DESY will provide many of the new optical modules. For the IceCube upgrade, which is due to take place in the Antarctic summer of 2022/23, seven additional cables with the newly developed sensors are to be melted more than 1.5 km deep into the ice in the centre of the detector. Two types of optical modules will be used, which will also be tested for the ten times larger future extension IceCube-Gen2. One type of these new optical sensors, the multipixel digital optical module (mDOM), was developed in Germany by the participating universities and Helmholtz centres. Compared to the previous modules, the mDOMs, of which about 400 will be installed, have a significantly larger and segmented detection area and thus a significantly higher sensitivity.

The expansion will not only increase the sensitivity of the observatory, it will also lower the energy threshold above which neutrinos can be detected. This will allow the properties of the particles to be measured with unprecedented accuracy: IceCube will also become a neutrino laboratory.

Neutrinos are the least understood particles in the Standard Model of particle physics. They have properties that the Standard Model cannot explain. Neutrinos come in three flavours: electron, muon and tau neutrino. Surprisingly, the particles can switch back and forth between these flavours – a phenomenon called neutrino oscillation.

One of the goals of the IceCube upgrade is to determine the parameters of neutrino oscillations with much higher precision than currently possible. A further goal is to measure the optical properties of the ice more precisely, which will allow a better reconstruction of the properties of observed neutrinos in all energy ranges. This will not only sharpen the view of the neutrino observatory into space in the future, but also enhance the reconstruction of neutrino events that have already been recorded. In this way, the upgrade will improve the IceCube results of every analysis performed so far.

With the IceCube upgrade and the later expansion to IceCube-Gen2, this unique neutrino observatory will expand our view into space at a crucial point and thus decisively contribute to solving the puzzles about the physics of the highest-energy processes in our universe.

Contact:

Timo Karg, timo.karg@desy.de

Reference:

[1] M.G. Aartsen et al. (IceCube Collaboration), “Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert”, Science, Vol. 361, Issue 6398, pp. 147–151 (2018)

Simulating radio detectors for ultrahigh-energy neutrinos

First step towards a discovery instrument

With the recent detection of a first source of high-energy neutrinos, activities have started at DESY towards future upgrades of the IceCube neutrino detector at the South Pole. Radio detection from neutrino-induced showers in ice is a promising and cost-effective way to reach energies beyond PeV (10^{15} eV), because of the long attenuation length of radio waves in polar ice. It allows very sparsely instrumented detectors with few strings at large distances, thereby covering large detector areas. Designing and building a detector of this scale first requires extensive simulations.

Radio detection of neutrinos

The concept of radio detection of neutrinos was already suggested in the 1960s. Secondary particles in neutrino-induced showers in ice produce broadband radio emission that can be detected with antennas quite far away. However, the technology (fast and broadband digital electronics) was almost unimaginable at the time. Still, the theory was developed over the years, and radio detection of air showers made incredible progress, eventually making the detection of neutrinos in large volumes of ice feasible.

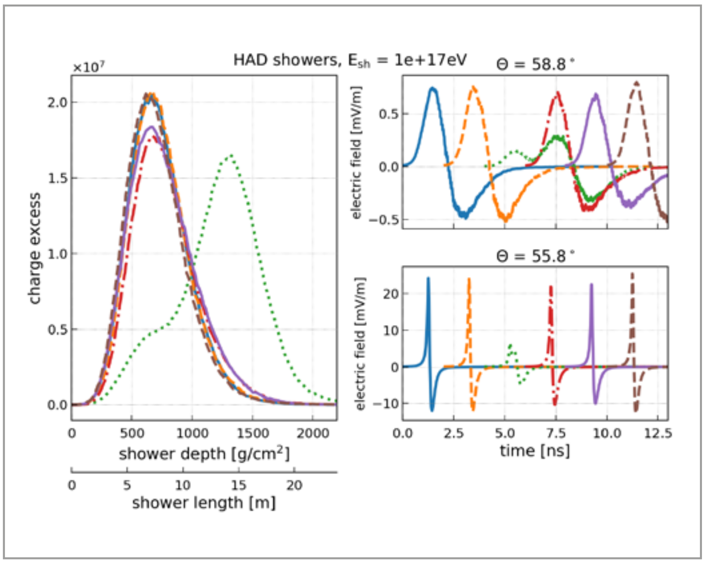


Figure 1

Radio emission following an electromagnetic shower from a neutrino interaction. The left panel shows the development of six simulated showers as a function of shower depth/length. The two right panels show electric field signals as measured by radio detectors at different angles with respect to the shower axis. The signature is thus a non-repeating nanosecond-scale pulse. Image from [1].

Radio emission is generated from the shower of charged particles following a neutrino interaction. The shower sweeps up electrons from the surrounding medium and becomes negatively charged. The charge separation between shower front and medium creates radio emission, which can propagate in media transparent to radio signals, such as ice or air. Instruments are more sensitive if the medium has a long attenuation length (e.g. kilometres in ice).

Preparing to build an experiment

After a number of prototype arrays in Antarctica (most prominently ARA [3] and ARIANNA [4]), a first pathfinder for IceCube-Gen2 will be deployed on Greenland, beginning in 2020, the Radio Neutrino Observatory on Greenland (RNO-G). However, to optimise the science output and detector design, state-of-the-art simulations had to be developed first.

Designing a neutrino detector requires a couple of ingredients: the understanding of the signal, its propagation and detection and a good assumption of the neutrino flux to be measured. On the latter part, a fruitful collaboration between the theory and experimental groups at DESY has developed (see article by Arjen van Vliet p. 28), which guides experimentalists through the various models and predictions.

Radio emission is generated from the shower of charged particles following a neutrino interaction. The shower sweeps up electrons from the surrounding medium and becomes negatively charged. The charge separation between shower front and medium creates radio waves, which can propagate in transparent media, such as ice or

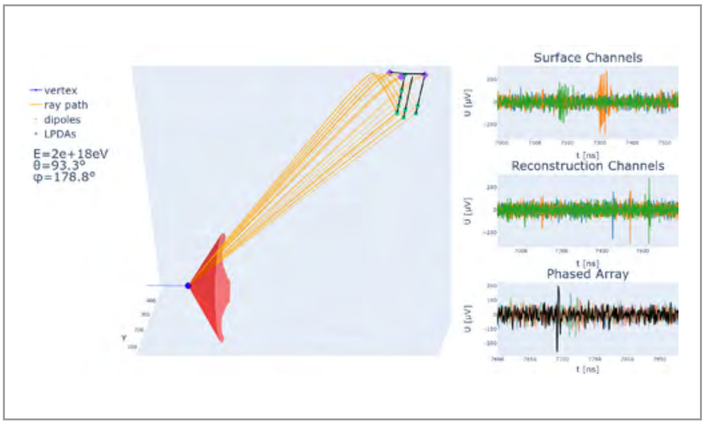


Figure 2

Simulated neutrino event in an RNO-G detector. The left side shows the incoming neutrino (blue) and the signal cone (red). The yellow lines trace the signal propagation to the antennas. Since the ice is getting less dense near the surface, the signal trajectories are bent and antennas can see the direct and refracted signals. The right side shows the recorded signals in different antennas. The phased array combines multiple antennas to increase the signal strength for more efficient triggering.

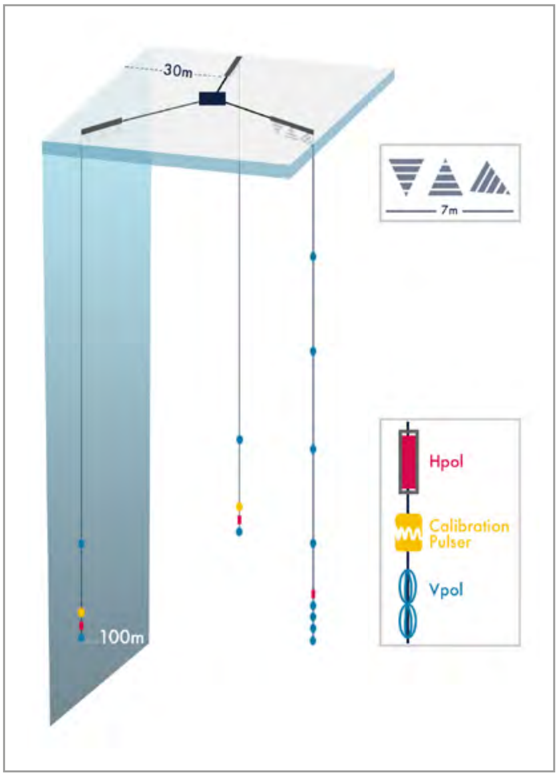


Figure 3

RNO-G station design. The design combines three deep strings of antennas (down to 100 m) with nine antennas at the surface. The stations will be equipped with internal calibration devices. The main trigger is a phased array on one string. The holes will be drilled mechanically, making drilling fast and cost-effective.

air. Instruments are more sensitive if the medium has a long attenuation length (e.g. kilometres in ice).

What needs to be simulated

For the first time, this simulation framework allowed the comparison of all signal parameterisations, all locations on Earth, all different ice models and all antenna and detector types in a fast way, so that actual benchmarking was feasible. A new approach to signal ray-tracing (in real polar ice) sped up the calculations significantly, while still allowing for more complex propagation modules to be used when high accuracy was needed.

The simulations were already used to design RNO-G and deliver sensitivity estimates to theorists, suggesting that the detection of ultrahigh-energy neutrinos may really get feasible quite soon.

The station design in Fig. 3 was optimised for both effective volume (i.e. the chance to detect a neutrino) and reconstruction of the signal. Should a neutrino be detected, alerts for multimessenger observations will be sent out, so a reasonable angular reconstruction is essential.

What will happen on Greenland?

A total of 35 stations as shown in Fig. 3 are planned to be installed in Greenland during the coming three years. The installation will be close to Summit Station in the very centre of Greenland. The stations combine different antenna types with low-power electronics. The stations will run autonomously on solar power. In addition, the inclusion of wind turbines will be explored in the coming years. All electronics have to be cold-resistant and electronically quiet to avoid mistaking any stray signals of the detectors for a neutrino.

A collaboration of European and US partners is driving the project, with DESY delivering the largest share of the software and key hardware components.

Contact:

Anna Nelles, anna.nelles@desy.de

References:

[1] C. Glaser et al., Eur. Phys. J. C80 no. 2, 77 (2020)
[2] C. Glaser et al., Eur. Phys. J. C79 no. 6, 464 (2019)
[3] P. Allison et al., Nucl. Instrum. Meth. A930 112–125 (2019)
[4] A. Anker et al., Adv. Space Res. 64, 2595–2609 (2019)

Predictions for cosmogenic neutrino fluxes

Modelling the potential for upcoming experiments to detect ultrahigh-energy neutrinos

Cosmogenic neutrinos are neutrinos created in interactions of ultrahigh-energy cosmic rays (UHECRs) with extragalactic background light. The observation of cosmogenic neutrinos would open up a new chapter of multimessenger astrophysics and provide new insights into the unknown sources of UHECRs. Many experimental set-ups have been designed specifically for this purpose. But will they actually be able to detect cosmogenic neutrinos? And if so, what can they say about the sources of UHECRs? The astroparticle theory group at DESY has shown the strong potential of these experiments for measuring cosmogenic neutrinos and constraining UHECR source models, based on the latest UHECR measurements and models.

Cosmogenic neutrinos

When UHECRs (with energies above 10^9 GeV) travel through the universe, they interact with the cosmic microwave background and other extragalactic background light. In these interactions, all kinds of secondary particles can be created, including neutrinos. Neutrinos generated in this way are called cosmogenic neutrinos (in contrast to neutrinos from cosmic particle accelerators, such as active galactic nuclei or supernovae). These neutrinos are expected to be diffuse (i.e. have the same flux from all directions) and typically have energies in the range 10^5–10^{11} GeV. The IceCube neutrino observatory at the South Pole has detected an astrophysical neutrino flux with energies up to around 4×10^6 GeV, but it is unlikely that these neutrinos are cosmogenic.

Currently, IceCube provides the best upper limits for the diffuse neutrino flux for energies above 4×10^6 GeV [1]. The planned extension of IceCube, IceCube-Gen2 [2], and other future experiments aim at sensitivities more than ten times better than current experiments, mainly by using radio measurements in large volumes. The astroparticle theory group at DESY investigated the potential of these experiments for detecting cosmogenic neutrinos [3–5]. Predictions for the cosmogenic neutrino flux were derived from simulations of UHECR propagation through space and comparison with measurements of the Pierre Auger collaboration [6, 7].

The sensitivity scales roughly linearly with the number of stations, so target size is crucial. The discovery potential as function of target size was derived with the neutrino group at DESY (see the article by Anna Nelles on p. 26).

UHECR propagation simulations

The UHECR spectrum, composition and the cosmogenic neutrino flux at Earth depend on the propagation of UHECRs through the universe. Propagation simulations include various energy-loss mechanisms of UHECRs with extragalactic background light. Simulation results depend, among others, on the spectrum and the elemental composition of the UHECRs at their sources and on the source distribution with redshift z.

Fit to UHECR spectrum and composition

The UHECR spectrum and composition at Earth, affected by propagation, was fitted to the measurements by Auger [3]. A rather low maximum energy ($E_{max}/Z \sim 1$–3×10^9 GV) and a rather heavy composition (mostly nitrogen) reproduced the measurements best.

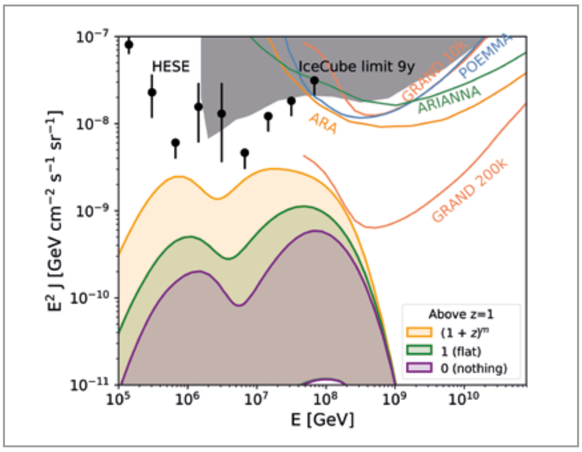


Figure 1

Allowed 3σ range for expected all-flavour cosmogenic neutrino fluxes from a fit to the UHECR spectrum and composition measured by Auger. The ranges are given for three different source evolution models for $z > 1$. Figure from [3].

Figure 1 shows the allowed 3σ range for the expected cosmogenic neutrino flux of such a fit. While only UHECRs from relatively nearby sources ($z < 1$) can make it to Earth,

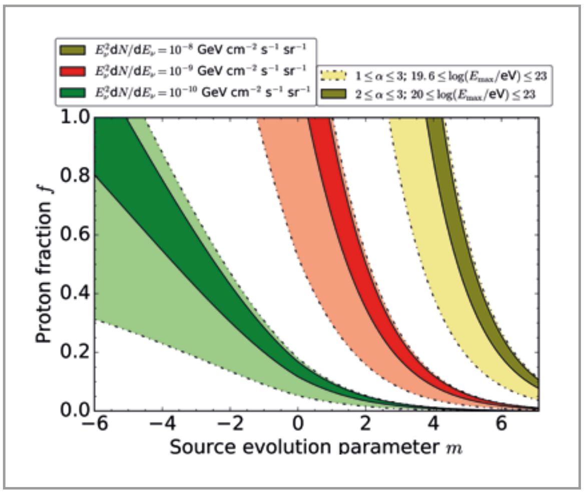


Figure 2

Combinations of the proton fraction in UHECRs at $10^{10.6}$ GeV and distribution of sources with redshift that give three specific single-flavour cosmogenic neutrino fluxes at a neutrino energy of 10^9 GeV. Figure from [4].

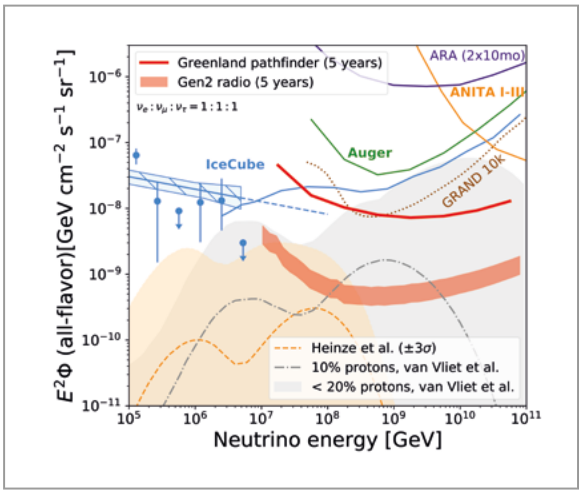


Figure 3

Allowed ranges of cosmogenic neutrino fluxes for various source distributions, with and without a proton fraction. Sensitivity estimates for the pathfinder in Greenland (RNO-G) and the radio array of IceCube-Gen2 are indicated as well (see [2] and the article by Anna Nelleson on p. 26).

neutrinos will also reach us from cosmological distances. Therefore, the expected cosmogenic neutrino flux is especially sensitive to the distribution of UHECR sources for $z > 1$, while the fit results do not depend on the source distribution at large distances. To illustrate this, three different ranges are shown in Fig. 1, representing three different source distributions for $z > 1$. Due to the heavy composition and low $E_{\max}$, the expected cosmogenic neutrino flux is so low that it will likely not be detectable with IceCube-Gen2.

Additional proton component

In this scenario, no protons are present at the highest energies. UHE protons would produce much more neutrinos during their propagation through the universe than heavier nuclei of the same energy. Therefore, a subdominant proton component in UHECRs would completely change the expected cosmogenic neutrino flux [4]. Results are shown in Fig. 2.

Two parameters turned out to be crucial: the source distribution, determined by the parameter m, in $(1+z)^m$, where larger values of m mean more far-away sources (see [4] for details), and the fraction of protons (f) at the highest energies. Figure 2 shows combinations of these parameters leading to three specific levels of cosmogenic neutrino fluxes at $E_\nu = 10^9$ GeV. The three flux levels indicate roughly the current flux limit and the range of proposed sensitivities for IceCube-Gen2.

From Fig. 2, it can be concluded that the combination of many far-away sources and a large proton fraction is already ruled out by current limits. IceCube-Gen2 will probe this parameter space further, going down to the star formation rate (SFR) source distribution, where most UHECR source candidates reside.

Potential for upcoming experiments

Figure 2 indicates that, for realistic source distributions and proton fractions, IceCube-Gen2 and other experiments with similar sensitivities will have a fair chance to detect cosmogenic neutrinos. They will likely even be able to determine viable combinations of proton fraction and source distribution, hinting indirectly at the types of sources of UHECRs.

In Fig. 3, the expected cosmogenic neutrino fluxes for both the combined-fit results and the scenario with an additional proton component are summarised and compared with sensitivity estimates for RNO-G, a pathfinder radio array, and the radio array of IceCube-Gen2 [2]. The 3σ range around the best fit is shown. With 20% added protons and many far-away sources, the maximum of the range is reached. A 10% proton fraction for the SFR source distribution is indicated as well (see [5] for more details).

Thus, the UHECR fit of [3] showed that a rather low cosmogenic neutrino flux must be expected, which will be hard to detect, even for IceCube-Gen2. However, it is plausible that an additional proton component is present [4] which would produce neutrinos that IceCube-Gen2 could detect to constrain the UHECR sources.

Contact:

Arjen van Vliet, arjen.van.vliet@desy.de

References:

[1] IceCube Collaboration, Phys. Rev. D 98, 062003 (2018)
[2] IceCube Collaboration, arXiv:1911.02561
[3] J. Heinze et al., ApJ 873, 88 (2019)
[4] A. van Vliet, R. Alves Batista and J. R. Hörandel, Phys. Rev. D 100, 021302 (2019)
[5] A. van Vliet, R. Alves Batista and J. R. Hörandel, PoS, ICRC2019, 1025 (2020)
[6] F. Fenu for the Pierre Auger Collaboration, PoS, ICRC2017, 486 (2018)
[7] J. Bellido for the Pierre Auger Collaboration, PoS, ICRC2017, 506 (2018)

Magnetic field orientation and anisotropic diffusion in pulsar wind nebulae

Multiwavelength observation of Geminga’s TeV halo suggests anisotropic diffusion of particles

The detection of diffuse very-high-energy gamma-ray emission within 100 light years of the Geminga pulsar and the non-detection of diffuse X-ray emission from the same region seem to contradict each other, because both types of emissions should arise from the same population of relativistic electrons and positrons emitted from the pulsar. A team from DESY and the University of Potsdam suggests that such a puzzling result can be explained by anisotropic diffusion of the injected particles in a local magnetic field that is aligned roughly with the line of sight.

Recent observations of the High-Altitude Water Cherenkov Gamma-Ray Observatory (HAWC) in Mexico have revealed a TeV gamma-ray halo around the Geminga pulsar, with a spatial extension of about 30 pc [1] (Fig. 1). The TeV emission is believed to arise from cosmic-ray electrons and positrons accelerated in the pulsar wind nebula, via inverse Compton scattering off cosmic microwave background photons, and injected in the interstellar medium (ISM) near the pulsar wind nebula, where they produce gamma radiation. The detection of such a diffuse TeV emission has been interpreted as the presence of a slow-diffusion zone around the pulsar [1, 2, 3] in the framework of 1D isotropic diffusion, which entails both a diffusion coefficient two orders of magnitude smaller than typical (ISM) values and a magnetic field an order of magnitude smaller than normal ISM fields.

Seemingly, the charged particles move slower in the plane confined by the magnetic field and the line of sight. This would explain the observation of a smaller TeV halo (the orbicular area around a galaxy) compared to the expectation based on one average interstellar diffusion coefficient.

This is a natural consequence given that the coherence length of the interstellar magnetic field is on the order of a few ten parsecs (as shown by earlier observations). The orientation of the local magnetic field being close to the line of sight also naturally explains the low X-ray intensity, since the synchrotron radiation intensity is proportional to the projection of the local magnetic field into the plane of the sky (i.e. perpendicular to the line of sight). Thus, a new way emerges to probe the local interstellar turbulence, through the flux level and the morphology of the TeV halos and their lower-energy counterparts of other pulsars.

On the other hand, the magnetic field in ISM generally has a mean direction within one coherence length, which is typically around 50–100 pc [4–5] and is comparable to the size of the TeV halo. 1D particle diffusion actually cannot hold in this scenario, since particles diffuse faster along the mean magnetic field than they diffuse perpendicular to the mean magnetic field in the case of sub-Alfvenic turbulence. Due to the anisotropy of turbulence in this case, the perpendicular diffusion coefficient is given by $D_\perp = D_\parallel M_A^4$ with M_A being the Alfvenic Mach number [6]. Also, the synchrotron radiation intensity becomes anisotropic. Electrons that move along the magnetic field will radiate much less efficiently than those that move perpendicular to the magnetic field.

Theorists at DESY and the University of Potsdam thus demonstrated that both X-ray and TeV observations can be explained with typical conditions for ISM, such as the magnetic field, the diffusion coefficient and the field perturbation level, by considering anisotropic particle diffusion, which is a natural outcome in the presence of sub-Alfvenic turbulence (Fig. 2). Thus, the viewing angle significantly affects the signals observed at Earth [7].

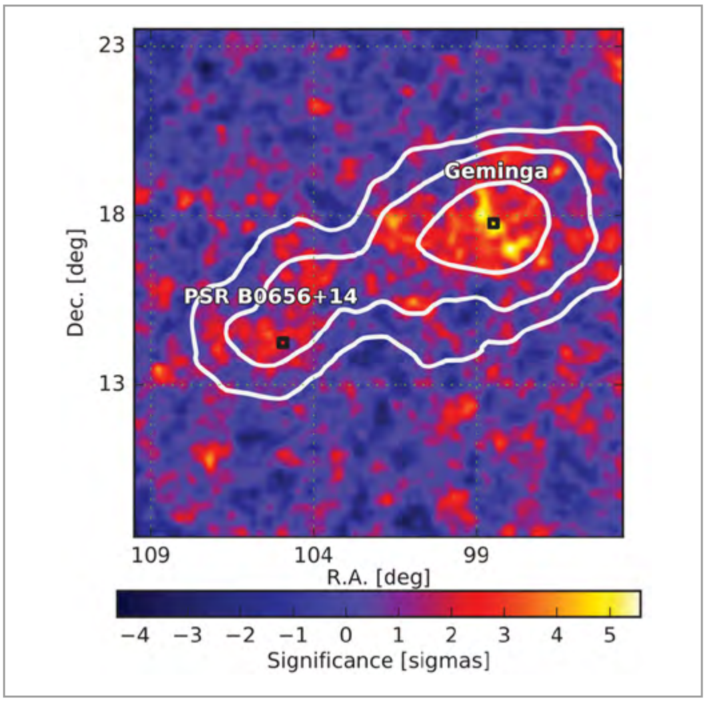


Figure 1

Spatial morphology of Geminga and its surroundings as measured by HAWC (between 1 and 50 TeV). The balance between diffusion rate and cooling effects determines the energy-dependent size of the halo around Geminga. TeV particles diffuse the farthest [1].

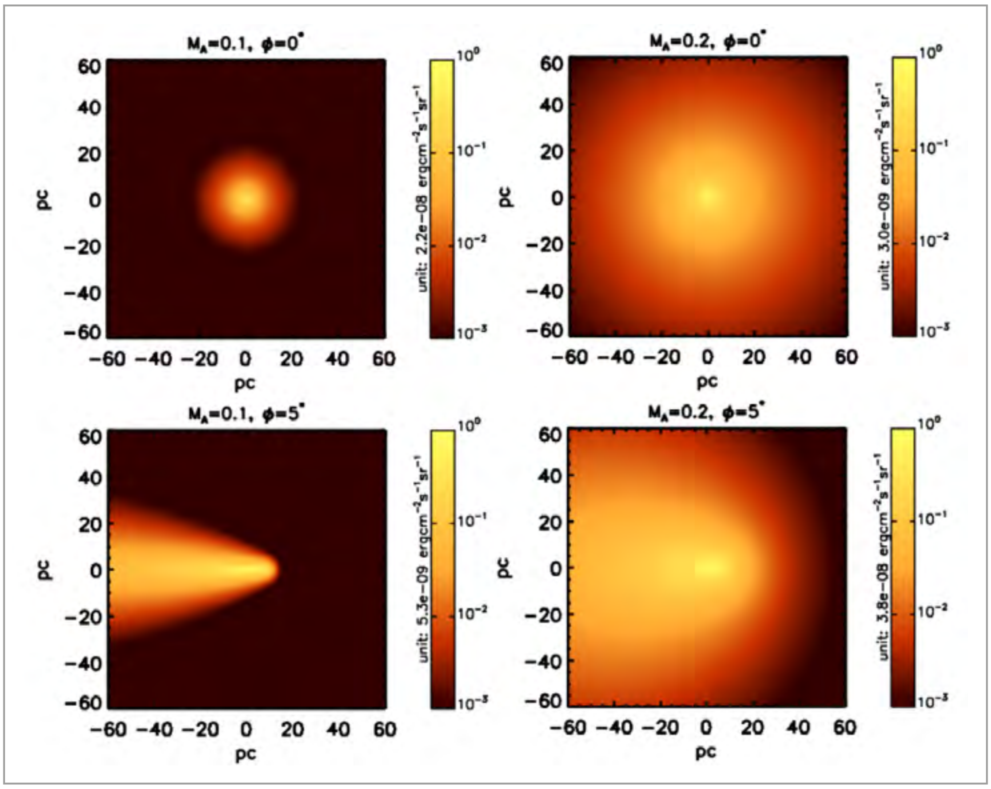


Figure 2

In the presence of a local mean magnetic field, the apparent diffuse X-ray emission is dependent on the viewing angle and the level of turbulence [7].

Contact:

Ruoyu Liu, ruoyu.liu@desy.de
Huirong Yan, huirong.yan@desy.de

References:

[1] HAWC Collaboration, Science 358, 911 (2017)
[2] S. Profumo et al., Phys. Rev. D 97, 123008 (2018)
[3] S.-Q. Xi et al., Astrophys. J. 878, 104 (2019)
[4] A. Chepurnov and A. Lazarian, Astrophys. J. 710, 853 (2010)
[5] M. C. Beck et al., JCAP 2016, 056 (2016)
[6] H. Yan and A. Lazarian, Astrophys. J. 673, 942 (2008)
[7] R. Liu, H. Yan and H. Zhang, Phys. Rev. Lett. 123, 221103 (2019)

Very-high-energy air shower observations in Berlin

Towards the first medium-sized telescope on the CTA northern observatory site

The Cherenkov Telescope Array (CTA) will be the first ground-based gamma-ray observatory open to the worldwide astronomical and particle physics communities. More than 1400 scientist and engineers from 31 countries are engaged in the scientific and technical development of CTA, in which DESY is a key player. Besides hosting the Science Data Management Centre, DESY is involved in the development of the small-sized telescope camera electronics, operation control software and science performance simulations. The largest contribution of DESY to CTA is the medium-sized telescope (MST) project, which reached several important milestones in 2019.

Inauguration of the Schwarzschild-Couder Telescope

In January 2019, the prototype Schwarzschild-Couder Telescope (pSCT), located in Arizona (USA), was unveiled in an inauguration ceremony at the Fred Lawrence Whipple Observatory (FLWO), which is operated by Harvard University and the Smithsonian Institution (Fig. 1). This dual-mirror MST candidate promises a better performance than the single-mirror designs traditionally used in gamma-ray telescopes. The SCT optics provides better optical quality over a larger field of view in the sky and is well suited to the use of compact, highly efficient photosensors in the telescope camera.

Figure 1

Inauguration of the pSCT in Arizona, USA

The pSCT uses a positioner and drive system developed at DESY for the one-mirror MST Davis-Cotton design. Based on experience with the first MST prototype in Berlin-Adlershof and input from the US teams, an improved positioner was produced in Germany and assembled by DESY engineers in Arizona in 2016. This second MST prototype built at an observatory site and operated by external partners is a good opportunity for the MST team to further improve the functionality, availability and performance of the telescope and its individual components. The lessons learned from the project helped to optimise the upcoming serial production, preassembly and deployment of the telescopes.

Integration of the NectarCAM Cherenkov camera

In May 2019, the NectarCAM prototype camera was successfully installed on the MST prototype in Berlin-Adlershof (Fig. 2). The partially equipped camera with 427 photomultiplier tubes (about 23% of the full focal plane) underwent a joint testing and observing campaign. The camera consists of photomultiplier tubes whose trigger electronics were developed and built at the electronics workshop at DESY.

Already during the second night of data taking, the NectarCAM saw its first air showers in Cherenkov light, generated by very-high-energy cosmic particles in the atmosphere. The challenge was to attenuate the night-sky background light and eliminate the impact of nearby street and building lights. The observing campaign with daily night shift observations lasted over one month. Single photoelectron and flat-fielding calibrations were performed, and more than 100 000 showers were recorded.

With the tests of the FlashCam in 2017 and the NectarCAM in 2019, both Cherenkov camera designs proposed for the MSTs could be integrated and their performance verified at the prototype telescope structure in Berlin. Integration of the

Figure 2

MST prototype structure in Berlin-Adlershof equipped with the Cherenkov camera NectarCAM (May 2019)

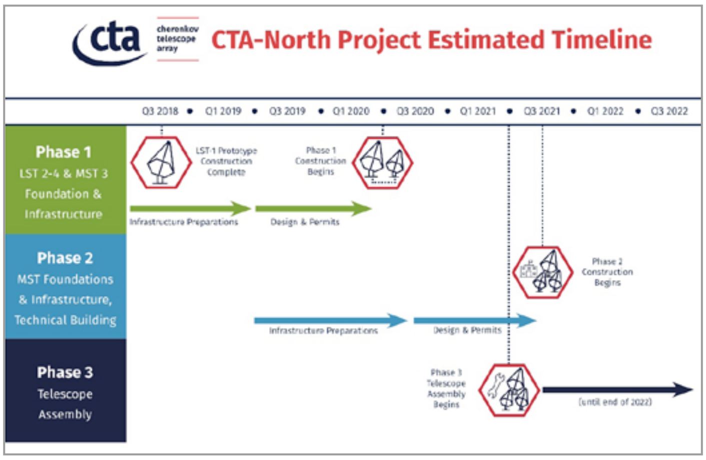


Figure 3

The current project timeline for the CTAN site

cameras with the telescope structure and field tests are important to ensure a proper definition of the mechanical, electrical and functional interfaces and procedures.

Preparation for MST deployment on CTA North

To make best use of the available funding, deployment of the CTA northern observatory (CTAN) on the Canary Island of La Palma has to be finalised before 2023. The CTAN threshold array consists of four large-sized telescopes (LSTs) and five MSTs, with the first LST prototype currently being commissioned. In August 2019, work on the design of the infrastructure for the remaining telescopes and the environmental monitoring equipment was initiated. A joint venture of local architects and engineering companies started to design the telescope foundations, underground services for the electrical and data network, access roads and fences. The design specifications for the MSTs were defined by the DESY team, which follows and monitors the progress of the design. Figure 3 shows a few major CTAN milestones. The infrastructure design will be finished in mid-2020, and the deployment of the first MST is planned for early 2021.

Getting ready for the MST serial production

As the preconstruction phase ended in December 2019, tests and verification measurements at the MST prototype telescope structure in Berlin were intensified in 2019. A revision of the camera support structure performance and further improvements of the latest design were initiated with our partner institute in Brazil (University of Sao Paulo, San Carlos). Two mirror designs initially developed in Poland and France could be merged. A batch of mirrors produced according to this merged design showed very good optical performance. It is planned to propose this design and the independent Italian mirror designs as solutions for the two CTA sites in Spain and Chile, respectively.
Single mirror testing on the prototype telescope and comparison of the measurements with ray-tracing simulations were carried out to verify that the performance is within the requirements. New methods to improve the telescope pointing and tracking accuracy by correcting the mechanical errors using a bending model were developed at Humboldt University Berlin and successfully tested. A novel scheme to monitor the telescope structure and drive system assemblies was developed. The system was successfully verified by measuring structure eigenfrequencies, rotation frequencies and modes of motors, gears and bearings.

The MST team started to prepare the tendering, production and assembly documentation for the next telescopes and to prepare the documentation for the critical design review, planned for mid-2020. This includes preparation of the technical documentation repository, for which the widely used Electronic Document Management System (EDMS) will be used.

At the end of 2019, the MST officially entered the “next level” towards project completion. At the celebration, many internal and external project members bid farewell to the telescope prototype structure in Berlin-Adlershof, which served us so well for the design and optimisation of the MSTs in the past years. Due to the end of the site rental agreement between Helmholtz-Zentrum Berlin (HZB) and DESY, the prototype structure was disassembled in early 2020. All team members are now looking forward to the start of telescope production.

Contact:
Maria Krause, maria.krause@desy.de
Markus Garczarczyk, markus.garczarczyk@desy.de

Precision gravity

From the LHC to LISA and ET

The nascent field of multimessenger astronomy will be an interdisciplinary subject enriching many branches of physics. Gravitational waves play an important role here. Yet the associated computational challenges are enormous. Faithful theoretical templates of gravitational-wave signals are a compulsory ingredient for successful data analysis and reliable physical interpretation. Current templates for binary sources are sufficient for detection and crude parameter estimation, but are still too coarse for precision physics with the next-generation gravitational wave observatories, such as the Laser Interferometer Space Antenna (LISA) and the Einstein Telescope (ET). To maximise their discovery potential, more accurate waveforms are needed. The research programme of Rafael Porto from DESY – recently recognised with an ERC Consolidator Grant – uses tools from particle physics to tackle the two-body problem in general relativity [1] and allows in-depth study of the nature of compact objects (neutron stars and black holes [2]) and of physics beyond the Standard Model of particle physics [3, 4] through precise gravitational waveforms.

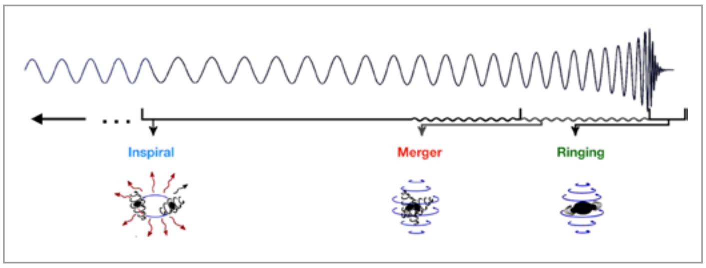


Figure 1

The three regimes in the dynamics of binary systems

The detection of gravitational waves by the LIGO/Virgo collaboration has initiated an unprecedented era for physics investigations. As a consequence, the two-body problem in gravity has turned into a very active area of research, relying on both numerical and analytic methods. Simulations cover mostly the late stages and the merger regime of a binary's dynamics, where gravity becomes strong. However, numerical codes are incapable of simulating the entirety of the observed orbits within the detectors' frequency band (order of thousands with future experiments). The orbits during the inspiral regime are instead described using perturbation theory, e.g. the post-Newtonian (PN) and mass ratio expansions. Perturbative methods may also be used to study the ring-down phase, in which the final black hole forms.

Rafael Porto, new to the astroparticle physics division at DESY in Hamburg, has pioneered the implementation of a new formalism, the effective field theory (EFT) approach [1], which was used for the construction of the present template banks, currently reaching the fourth PN order [5]. The novel EFT framework uses tools from particle physics to go beyond standard computational techniques in general relativity. By implementing successful ideas from collider physics in gravity, Porto's group reduced the problem of motion and gravitational wave emission to the computation of a series of Feynman diagrams and associated integrals. The EFT approach benefits from diagrammatic systematisations, dimensional regularisation, renormalisation and the method of regions, which separates the relevant scales one at a time.

The goal of precision gravity is to reach the level of analytic control at which e.g. tidal deformations show up during inspiral. Tidal effects will reveal the nature of compact objects [2] and constrain the existence of weakly coupled ultralight particles surrounding black holes [3, 4]. Reaching this accuracy is challenging, but tools from particle physics used in gravitational wave physics [6] make it feasible. Moreover, there is a remarkable connection between scattering processes and observables for bound orbits, which can transform the current waveform models [7]. In combination with EFT, all of these findings will have a big impact on the production of accurate gravitational waveforms, also revealing the underlying structure of general relativity [7].

ERC Consolidator Grant

"Precision Gravity: From LHC to LISA"

Contact:

Rafael Porto, rafael.porto@desy.de

References:

[1] R. A. Porto, Phys. Rept. 633 1–104 (2016)
[2] R. A. Porto, Fortsch. Phys. 64 no. 10, 723–729 (2016)
[3] D. Baumann, H. S. Chia, R. A. Porto, Phys. Rev. D 99, 044001 (2019) (Editor's suggestion)
[4] D. Baumann, H. S. Chia, R. A. Porto, J. Stout, arXiv: 1912.04932[gr-qc]
[5] S. Foffa, R. A. Porto, R. Sturani, I. Rothstein, Phys. Rev. D100 no. 2, 024048 (2019)
[6] Z. Bern et al., Phys. Rev. Lett. 122 no. 20, 201603 (2019)
[7] G. Kalin and R. A. Porto, JHEP 2001, 072 (2020), and JHEP 2002, 120 (2020)

Radio detection of neutrinos

New technology in the cosmic messenger portfolio

DESY uses various means to detect high-energy particle showers, which includes photons of all wavelengths, from optical and ultraviolet to X-rays and gamma rays. The detection of radio waves is just an extension to lower-energy photons. A new group established within the W2/W3 professorship programme at the University of Erlangen-Nürnberg and DESY under the leadership of Anna Nelles will use radio emission to measure neutrino-induced showers of the highest energies.

The neutrino astronomy group at DESY has been targeting highest-energy neutrinos for over a decade. With involvements in early detectors at the South Pole and in Siberia, a new field has taken shape. Eventually, in 2015, the IceCube neutrino observatory was able to confirm an astrophysical flux of neutrinos and thus properly start neutrino astronomy.

So far, the detected flux leaves many questions unanswered. All expected source classes, such as blazars, seem to contribute only sub-dominantly, and the measured energies are too low for the signals expected from ultrahigh-energy (10^{16} – 10^{19} eV) cosmic-ray interactions with the cosmic microwave background.

An extension of IceCube, called IceCube-Gen2, is in strategic planning to improve the existing results. But with an extension of the optical detector array alone, the energy reach will not go far beyond current energies. For ultrahigh energies, the radio detection of neutrinos is more promising. Radio photons are less scattered and attenuated than optical ones and can therefore travel farther in the ice. Consequently, radio detectors can be much sparser and therefore larger. Radio detection has an intrinsically higher energy threshold, which makes it not a replacement, but an ideal complement of optical detection towards higher energies.

The first pathfinder for radio detection within IceCube-Gen2 – the Radio Neutrino Observatory on Greenland (RNO-G) – has been designed and will soon be installed in the Greenland ice shield. The deployment will take place in the Arctic summer seasons 2020–2022. By the end of the pathfinder operation, RNO-G may have seen ultrahigh-energy neutrinos already, but in any case, it will have laid a solid foundation for radio detection at IceCube-Gen2, which will cover an area of 200 km^2.

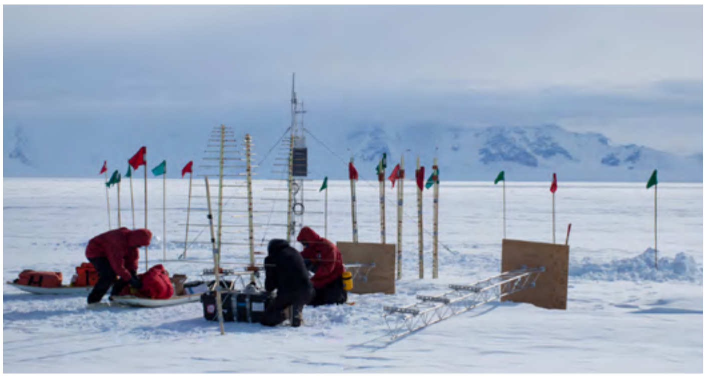


Figure 1

Installation of a prototype setup for radio detection of neutrinos in Antarctica. The radio antennas are still visible before being buried in the ice. A dedicated prototype of IceCube-Gen2 will be installed beginning in 2020 on Greenland.

Anna Nelles and her group are part in all aspects of this effort [1, 2] leading up to the operation of the full radio detection array in IceCube-Gen2. The planning and installation of IceCube-Gen2 will be a major effort for the whole neutrino astronomy group at DESY and will shape neutrino astronomy for years to come.

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Helmholtz W2/W3 Initiative

DESY / Univ. Erlangen-Nürnberg

Contact:

Anna Nelles, anna.nelles@desy.de

References:

[1] NuRadioMC: D. García-Fernández et al., PoS (ICRC2019) 896

[2] NuRadioReco: C. Glaser et al., PoS (ICRC2019) 900

Upgrade of the H.E.S.S. on-site computing

On-site computing boosts science performance

The H.E.S.S. collaboration has successfully operated an array of four (later five) telescopes in the Namibian Khomas highland for almost two decades. The reliable operation of the on-site computing cluster, used for science data acquisition and the real-time analysis of science data, has been of prime importance for the instrument, and continuous efforts have been needed to operate the experiment stably. In June 2019, the initial cluster was replaced with modern machines and updated software stacks to ensure successful operations over the coming years.
The boosted performance of the computing cluster now paves the way for enhanced science results: More detailed data can now be recorded, and more sensitive physics analyses can be performed on-site quickly, allowing for faster decisions on follow-up observations of transient phenomena.

The H.E.S.S. on-site cluster

The High Energy Stereoscopic System (H.E.S.S. [1]) is an array of five imaging atmospheric Cherenkov telescopes located in Namibia. H.E.S.S. has played a substantial role in the young research field of very-high-energy gamma-ray astronomy, which has seen a revolution over the last decades [2]. At the core of these successful operations lies continuous support and maintenance of hardware and software systems. A fundamental part of the H.E.S.S. on-site IT infrastructure is the computing cluster. Its main purpose is the execution of the data acquisition (DAQ [3]) software, which receives and processes scientific data at kHz rates from the telescopes and provides the shift crew with a central control interface for the operation of the telescope array during the observing night. In addition, it provides the H.E.S.S. collaboration with the necessary means for external access to the raw data and derived results.

As of 2019, the computing hardware had been running stably for about a decade. With such a long operation time, the cluster had passed its lifetime and it was getting harder to find parts replacements (e.g. for broken hard disks) on the market, leading to an increased risk of failing hardware. Thus, the H.E.S.S. group at DESY decided to leverage its knowledge of the on-site system and the support from the IT department at DESY in Zeuthen to replace the cluster machines with newer hardware.

Preparation

To enable rapid on-site replacement of the computing cluster with the least possible interference with ongoing data taking, an extensive preparatory phase for the upgrade was launched in August 2018. The very first step was an in-depth analysis of the requirements (e.g. computing resources and data storage, etc.). Many unknown factors needed to be accounted for, such as an increased data rate after an anticipated future upgrade of a Cherenkov camera, potential changes of data taking modes, improved, yet more computing-intense on-site physics analysis algorithms, etc.

A small-scale test cluster (dubbed TestDAQ) was set up at DESY in Zeuthen to study all key components of the new cluster, including hardware (new computing nodes, data storage servers, network equipment), software (operating system, libraries) and improved methods for distributed computing to improve data taking and minimise maintenance efforts. To simulate and test data taking and processing, archival raw data produced by the Cherenkov cameras running in Namibia were used. Once the feasibility of the cluster replacement was verified using the TestDAQ system, the on-site cluster was installed in June 2019.

Installation campaign in Namibia

The six-person upgrade crew arrived in the Namibian savannah shortly before the full moon period around 17 June. Cherenkov telescopes cannot take data during bright moonlight, and this period was chosen so that the upgrade would interfere least with science data taking. The schedule was tight, as an important, internationally coordinated observation campaign (the Deeper Wider Faster (DWF) programme [4]) with a large number of other astronomical observatories around the globe was scheduled to start on 23 June.

The initial installation and setup of the computing hardware and network equipment (Fig. 1) took less than a day. During the next two days, the installation of the custom-made DAQ

Figure 1

Front view of the new H.E.S.S. DAQ computing rack

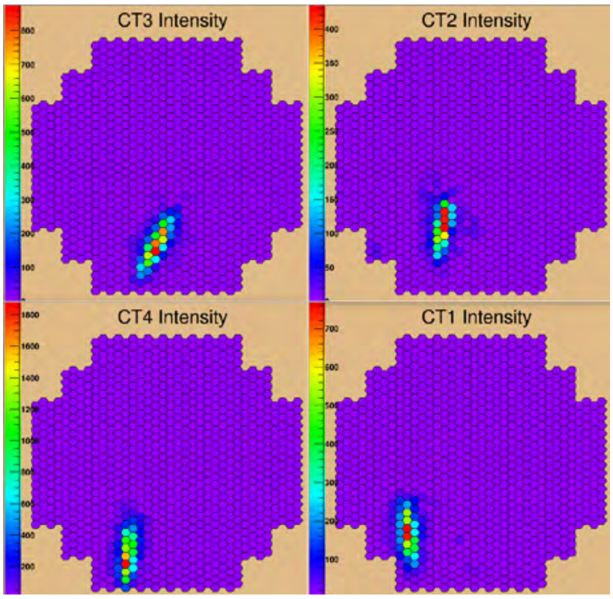


Figure 2

Images of extensive air showers induced either by charged cosmic rays or very-high-energy gamma rays. These images were recorded with the H.E.S.S. telescopes CT1–4.

software and supporting services like databases or virtual machines progressed well. Several small problems needed to be identified and fixed, such as small incompatibilities between database versions. The biggest challenge, however, was the integration of various field devices into the updated DAQ system.

For most subsystems, this integration worked remarkably well and smoothly. For example, the four Cherenkov cameras of the smaller telescopes CT1–4 could be used without problems. However, the drive systems of all the telescopes caused severe headache. For no obvious reason, the communication with the embedded hardware of these systems did not work well. After several days of debugging and with the DWF campaign approaching, the problem was identified and fixed at the last minute – four out of five telescopes became usable! The issue was caused by an upgrade of the C++ compiler, which brought up a software bug that had existed unnoticed in the code for 15 years.

But what about the large, fifth telescope? By accident, and completely unrelated to the upgrade campaign, the GPS clock required for telescope movements had broken and needed replacement. This could be fixed quickly, so that the array was back just in time for the DWF campaign. In total, the array missed less than 10 h of observations due to the upgrade. The first shower images recorded with the Cherenkov cameras of CT1–4 after the upgrade are shown in Fig. 2.

Performance boost

The upgraded on-site hardware and software have brought a performance boost to the experiment. The number of computing cores has doubled, and the data-taking network now provides a bandwidth of up to 20 Gbit/s, (from 1 Gbit/s before the upgrade). The upgrade allows more details of the shower images to be recorded, such as the time development of the images, which in turn enables the use of more elaborate analysis algorithms. Furthermore, during the upgrade, another mode of observation was tested and introduced. Before the upgrade, observations were conducted only during astronomical darkness, i.e. with the moon and sun sufficiently far below the horizon. Now, the telescopes can also observe under moonlight conditions. This significantly increases the available observation time and in particular the ability of the telescopes to react to science alerts from new, exciting transient events issued by other ground- and space-based astronomical facilities.

Thanks to the increased computing power and better algorithms, more accurate analyses can be produced instantly on site. This enables better decisions to follow up on transient phenomena and observations from the previous night – a significant improvement in the new era of multiwavelength, multimessenger and time-domain astronomy.

Contact:

Thomas Murach, thomas.murach@desy.de
Stefan Ohm, stefan.ohm@desy.de

References:

[1] H.E.S.S. Collaboration, https://www.mpi-hd.mpg.de/hfm/HESS/
[2] B. Degrange, G. Fontaine, https://arxiv.org/abs/1604.05488
[3] A. Balzer et al., https://doi.org/10.1016/j.astropartphys.2013.11.007
[4] I. Andreoni, J. Cooke, DWF Campaign, https://arxiv.org/abs/1802.01100

Computing and software development for astroparticle physics

New challenges for data processing in gamma-ray astronomy

The data processing (DV) group at DESY in Zeuthen has been supporting astroparticle physics projects for many years. Currently, its computing centre features about 2500 CPU cores, 3.7 PB of storage and about 100 dedicated GPUs. These resources are mainly used for Monte Carlo simulations and data analysis for experiments in neutrino and gamma-ray astronomy. For many years, DESY has been the IceCube Tier-1 centre for Europe. The DV group has great expertise in hardware and software technology as well as in the design, construction and operation of cutting-edge computing installations. Recently, new challenges for the group have arisen in the context the Cherenkov Telescope Array (CTA) project. The CTA consortium decided to locate its Science Data Management Centre at DESY in Zeuthen, and DESY has started to make sizeable commitments to the CTA computing and software efforts.

Computing system support for CTA

As part of the DESY involvement in the Cherenkov Telescope Array Observatory (CTAO, the legal entity of CTA), members of the DV group have significantly contributed to the design and definition of the CTA on-site information and communication technology (ICT) needs for the two CTA sites (CTA North on La Palma, Spain, and CTA South at Paranal, Chile). In 2019, the activities concentrated on the northern site by defining basic network configurations and establishing a virtual LAN (VLAN) infrastructure based on the on-site ICT centre design documents. DESY worked closely with the company Fujitsu, which is the provider of the LST1 prototype computing centre, and the University of Tokyo in Japan, which is operating it. The design and definition of the on-site ICT were presented by DESY and successfully passed the CTA North review in December 2019.

Software development for CTA

The Array Control and Data Acquisition (ACADA) system will provide the functionality required to monitor and control all telescopes and auxiliary instruments of CTA, to perform observations and calibration procedure, to handle, filter and store data from all the telescope and auxiliary instruments and to produce status and quality reports. ACADA is a central element at each of the CTA sites and interfaces with many other CTA systems. Additionally, ACADA has direct interfaces with collaborating external scientific facilities and laser traffic control systems at each of the sites.

The ACADA system is composed of several closely interrelated subsystems (Resource Manager & Central Control, Human Machine Interface, Array Data Handler, Science Alert Generation Pipeline, Short-Term Scheduler, Transients Handler, Monitoring and Logging Systems, Array Alarm System, Array Configuration System and Reporting System). In addition to subsystems, ACADA contains Management & Systems Engineering, Assembly, Integration and Verification (AIV) and Development Infrastructure work elements. The system is modelled following the guidelines proposed by the Software Platform Embedded Systems (SPES) approach for modelling the architecture of online systems. The model uses a combination of the system modelling language SysML and Unified Modeling Language (UML).

As a key contributor to ACADA, DESY is responsible for the delivery of the Resource Manager & Central Control (RM&CC) and Human Machine Interface (HMI) subsystems.

The Resource Manager & Central Control (RM&CC) subsystem is a core element of ACADA. It was prototyped following the Model-Driven Architecture (MDA) approach of ACADA and is responsible for the execution of the scheduling blocks provided by the Short-Term Scheduler by sending corresponding commands to the telescopes and other controllable array elements, while supervising the ongoing operations, coordinating the allocation of telescopes to subarrays and overseeing the Array Data Handler. RM&CC supervises all other systems of ACADA and any external system under its supervision, such as the Telescope Control Systems. In 2019, the DV group put considerable effort into making the RM&CC system capable of executing basic observation modes and running multiple operations on various subarrays simultaneously. The context of the RM&CC from the ACADA Architecture Design Document is illustrated in Fig. 1.

The Human Machine Interface (HMI) subsystem is also under the responsibility of DESY. The development of the HMI for CTA poses interesting new challenges compared to previous experiments. This is primarily due to the large number and

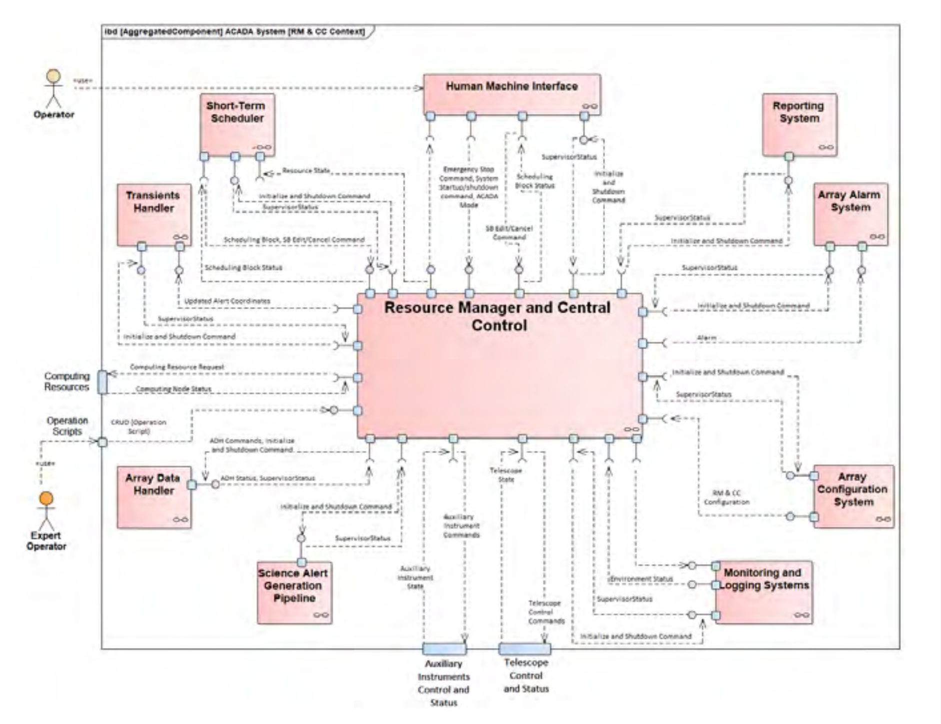


Figure 1

Context view of the RM&CC subsystem with the main stakeholders and external blocks depicted together with the information flow. The stick figures represent the human actors interacting with the system.

variety of CTA hardware elements that need to be controlled. The operations plan for CTA is to nominally conduct automated observations. However, the HMI is also intended to enable fine-grain control of the instruments. Correspondingly, the interface will incorporate different monitoring and control capabilities. These will span different scales of complexity, from high-level array operations to telescope-centric hardware monitoring. Over the course of 2019, the DESY ACADA team made significant advances in implementing such capabilities. Activities centred on the manipulation of so-called scheduling and observation blocks, which are units of operation associated for example with a particular source being observed for several tens of minutes (Fig. 2).

Figure 2

Display for monitoring and modifying “observing blocks” for CTA operations, where a single block corresponds for example to a few ten minutes of observations of a particular source. The top panel shows the observing plan for a full night, highlighting the different observing components of block S9 and their operational properties (e.g. duration, sky-pointing coordinates, etc.). The bottom panel allows the modification of the properties of predefined blocks and the creation of new ones by providing an interface to an automatically generated optimisation algorithm for nightly observations.

Contact:

Peter Wegner, peter.wegner@desy.de
Rico Lindemann, rico.lindemann@desy.de

Campus development at DESY in Zeuthen

DESY campus in Zeuthen is getting a face lift

The DESY location in Zeuthen has been growing over the past decade, largely due to the increased research activities in astroparticle physics. Thanks to its leading role in neutrino and gamma-ray astronomy, DESY is an increasingly sought-after partner for key projects in the wider field and a recognised hub for new projects and developments, both nationally and internationally. As a consequence, the Cherenkov Telescope Array (CTA) collaboration decided to locate its Science Data Management Centre, the heart of the CTA data handling and scientific analysis, on the DESY campus in Zeuthen. Requests to DESY for local outreach and education are also growing steadily. All these developments will increase the number of employees working on the site by about 40% to around 400. The substantial increase in workspace will be met by activating reserves in existing buildings, but also by constructing new buildings and reshaping the campus.

DESY in Zeuthen is growing

DESY is an important laboratory for international astroparticle physics and has one of the world's largest research groups in gamma-ray astronomy. For this reason, the international CTA consortium decided in 2016 to locate its Science Data Management Centre (SDMC) – and the office of its scientific director – on the DESY campus in Zeuthen. The decision represents an enormous upgrade of the DESY site and will have a decisive impact on the campus, the city of Zeuthen and the German federal state of Brandenburg for decades to come.

DESY in Zeuthen is one of the largest scientific institutions in Brandenburg and offers excellent prospects for young persons through its teaching and training programme in technology and research. As an attractive workplace, DESY and the SDMC secure and provide a highly qualified and skilled workforce, which is highly sought-after in industry. The additional SDMC personnel and numerous guest scientists and visitors to DESY and the SDMC will bring the number of persons working on the site to about 400.

The current architectural structures of the campus are not sufficient for its current and future use and the growing role and importance of the site. DESY's aim is to reorganise the whole campus, extend existing premises and realise suitable new constructions. Much of the site will become accessible to the general public.

Figure 1

The winning design for the new CTA and canteen building

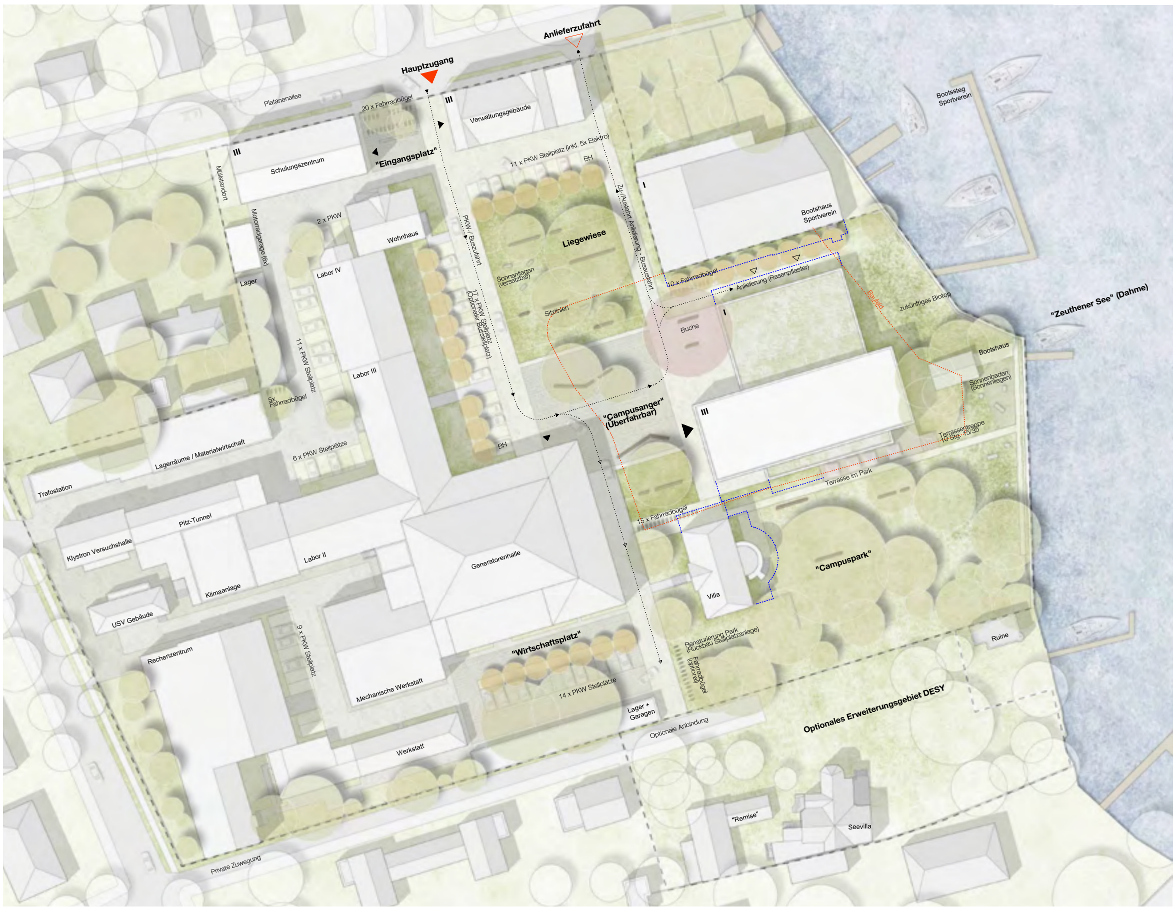


Figure 2

The DESY campus in Zeuthen after the rework

A new master plan for the campus design redefines the various outdoor spaces, develops the untapped potential of the location on Lake Zeuthen and merges the existing heterogenic buildings into a representative and functional ensemble (Fig. 2). The new buildings will both meet the functional requirements and adequately represent the new significance of the location to the outside world.

CTA, gamma-ray astronomy, education and outreach

The CTA SDMC with its 35 employees and numerous scientific visitors will need approx. 1200 m^2 of office and lab space. About 500 m^2 will additionally be required for a new canteen to meet the needs of the growing workforce on the campus. Both these demands will be covered by one new building on the campus, near the lake (Fig. 1).

Existing buildings will be refurbished and extended, and some office space will be created by moving into so-far underused areas.

In addition to the expansion for gamma-ray astronomy needed with CTA, DESY in Zeuthen will also expand and develop its training and outreach programmes for pupils, teachers and the wider public in the state of Brandenburg. Already today, there is a lack of meeting and lecture rooms for daily communication and outreach purposes. In a second phase, a training and conference centre with a floor space of more than 900 m^2 will therefore be created in a separate new building.

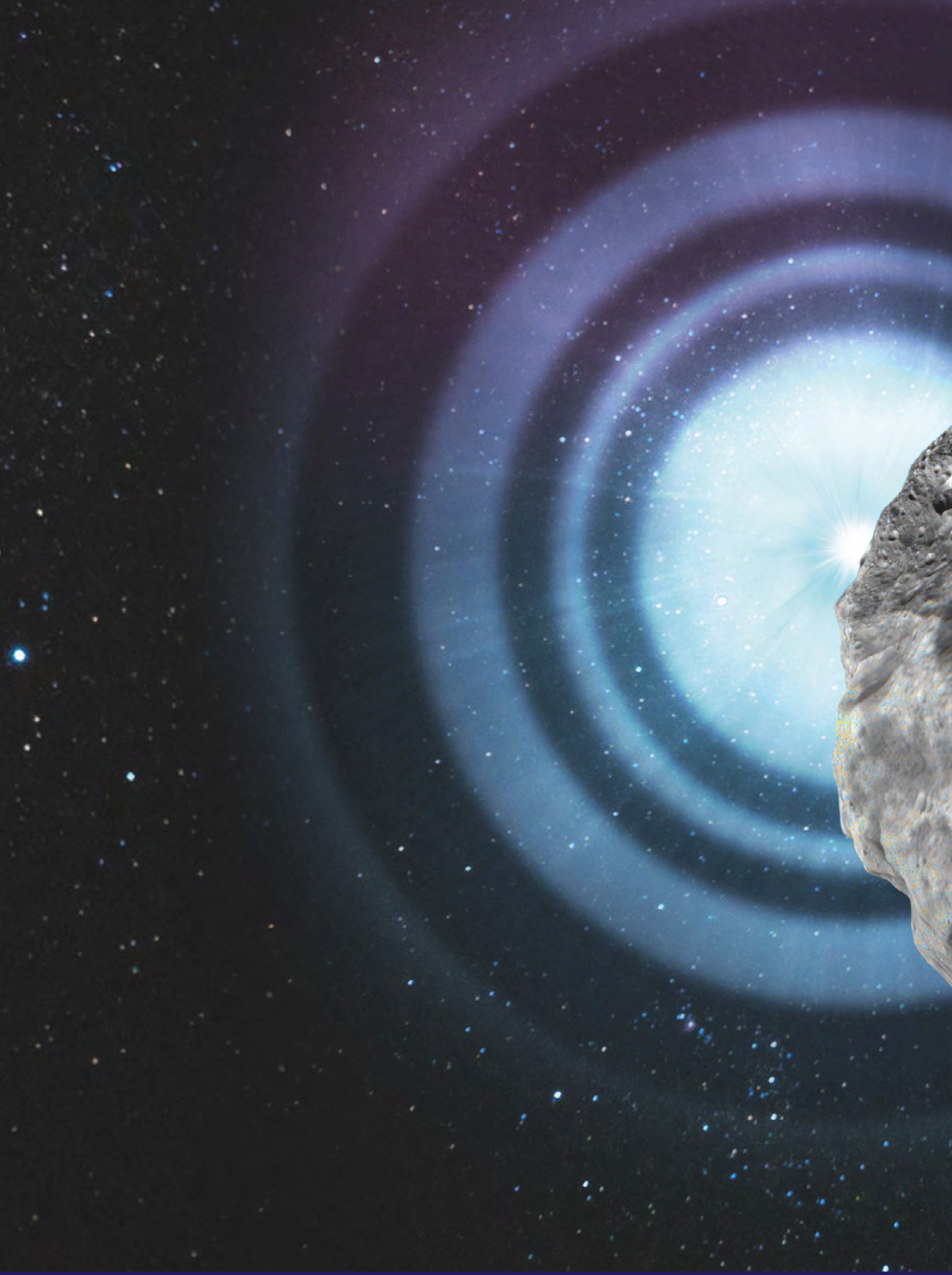
Realisation

For the first time at DESY, an architectural competition was launched to develop a coherent campus plan combining the existing buildings from various periods with new constructions into a representative and harmonious entity. An expert panel assessed 20 submissions and narrowed them down to a shortlist of eight to be invited for more detailed submissions. In March 2019, the winning proposal was selected. The prize of the competition was awarded to Heinle Wischer und Partner Freie Architekten GbR, Berlin, and Ulrich Krüger Landschaftsarchitekten, Dresden, for an outstanding and convincing plan. The team is now a very capable partner, which will help DESY to realise the plans in the near future.

The implementation of the plans will be carried out in several steps. The building permit for the SDMC and the canteen is now requested, and the construction work is to begin in 2021. Funding for this phase is secured. The costs are estimated at about 6.1 million euros. Construction of the training and conference building and the realisation of the outdoor spaces are planned for the years 2023 and beyond (still subject to funding).

Contact:

Verena Ruhm, verena.ruhm@desy.de



References

Committees

DESY Foundation Council

Representatives of the Federal Republic of Germany

MinDirig Dr. **V. Dietz** (Chair)
(Federal Ministry of Education and Research)

MinDirig'in **O. Keppler** (until 30 September)
RD'in Dr. **A. Fischer** (from 1 October)
(Federal Ministry of Education and Research)

A. Hohlt (until 30 September)
T. Stolzenberg (from 1 October)
(Federal Foreign Office)

Representatives of the Free and Hanseatic City of Hamburg

SD Dr. **R. Greve** (Deputy Chair)
(Ministry of Education and Research, Hamburg)

N. Abend
(Ministry of Education and Research, Hamburg)

Representatives of the Federal State of Brandenburg

H. Roth
(Ministry of Finance, Brandenburg)

MR **C. Feller**
(Ministry of Science, Research and Culture, Brandenburg)

Representatives from science and industry

Prof. Dr. **A. Brückner**
(Leibniz-Institut für Katalyse e.V.)

Prof. Dr. **D. Lenzen**
(President of Universität Hamburg)

Dr. **M. Kraas**
(Olympus Surgical Technologies)

Dr. **G. Mecke**
(AIRBUS)

Guests

Dr. **R. Abela**
(Chair of the DESY Scientific Council)

Prof. Dr. **R. Röhlsberger**
(Chair of the DESY Scientific Committee)

Prof. Dr. **O. Wiestler**
(President of the Hermann von Helmholtz Association)

A.-C. Jauch
(DESY Equal Opportunity Officer)

C. Joithe
(Chair of DESY Works Council)

DESY Board of Directors

Prof. Dr. **H. Dosch**
(Chairman of the DESY Board of Directors)

C. Harringa
(Administrative Division)

Dr. **W. Leemans**
(Accelerator Division)

Prof. Dr. **E. Weckert**
(Photon Science Division)

Prof. Dr. **J. Mnich**
(Particle Physics Division)

Prof. Dr. **Ch. Stegmann**
(Astroparticle Physics Division)

Dr. **A. Willner**
(Associate Director for Innovation)

DESY Scientific Council

Dr. **R. Abela**
PSI (CH)

Prof. Dr. **O. Botner**
Uppsala University (SE)

Prof. Dr. **J. Daillant**
SOLEIL Synchrotron (France)

Prof. Dr. **K. Hämäläinen**
University of Helsinki (FIN)

Prof. Dr. **G. Hoffstaetter**
Cornell University (USA)

Prof. Dr. **Y.-K. Kim**
University of Chicago (USA)

Prof. Dr. **T. Lohse**
Humboldt University Berlin (DE)

Prof. Dr. **L. Merminga**
Fermilab (USA)

Dr. **B. Murphy**
Christian-Albrechts-University Kiel (DE)

Prof. Dr. **S. Ritz**
University of California (USA)

Prof. Dr. **L. Rivkin**
PSI (CH)

Prof. Dr. **B. Roldán Cuenya**
Fritz Haber Institute (DE)

Prof. Dr. **N. Wermes**
University of Bonn (DE)

and the chairpersons of

DESY APC:
Dr. **Ch. Weinheimer**, University of Münster (DE)

DESY MAC:
Dr. **O. Bruening,** CERN (CH)

DESY PRC:
Prof. Dr. **P. Burrows,** University of Oxford (UK)

DESY PSC:
Dr. **Ch. David,** PSI (CH)

DESY Scientific Committee:
Prof. Dr. **R. Röhlsberger,** DESY

European XFEL:
Prof. Dr. **R. Feidenhans'l,** European XFEL (DE)

and the representative of the BMBF:
Dr. **A. Volz**, BMBF (DE)

DESY Scientific Committee

Elected members from

FH Hamburg:
K. Büßer (DESY/FLC)
M. Diehl (DESY/T)
V. Gülzow (DESY/IT)
I.M. Gregor (DESY/ATLAS)
S. Heim (DESY/ATLAS)
H. Jansen (DESY/CMS)
I. Melzer-Pellmann (DESY/CMS)
A. Mußgiller (DESY/CMS)
C. Niebuhr (DESY/Belle)
A. Ringwald (DESY/ALPS)
T. Schörner-Sadenius (DESY/CMS)
P. van der Reest (DESY/IT)

FS Division:
S. Bari (DESY/FS-SCS)
A. Burkhardt (DESY/FS-PE)
R. Döhrmann (DESY/FS-PE)
H. Graafsma (DESY/FS-DS)
T. Laarmann (DESY/FS-PS)
N. Müller (DESY/FSR)
E. Plönjes-Palm (DESY/FS-FL)
R. Röhlsberger (DESY/FS-PS)
H. Schulte-Schrepping (DESY/FS-BT)
O. Seeck (DESY/FS-PE)
M. Tischer (DESY/FS-US)
R. Treusch (DESY/FS-FL)

M Division:
N. Baboi (DESY/MDI)
M. Bieler (DESY/MBB)
U. Dorda (DESY/MPY)
H.-J. Eckold (DESY/MKK)
K. Honkavaara (DESY/MPY)
R. Kammering (DESY/MCS)
G. Kube (DESY/MDI)
L. Lilje (DESY/MVS)
S. Schreiber (DESY/MFL)
M. Schmitz (DESY/MIN)
N. Walker (DESY/MPY)

V Division:
S. Haid (DESY/VQ)
I. Mahns (DESY/ITT)
C. Porthun (DESY/D4)

Zeuthen Campus:
M. Ackermann (DESY/Z_ICE)
I. Bloch (DESY/Z_DLAB)
J. Knapp (DESY/Z_GA)
S. Ohm (DESY/Z_HESS)
W. Winter (DESY/AP-THAT)

Delegates from partner institutes and committees:
J. Dietrich (HU Berlin)
S. Fiedler (EMBL)
J. Haller (U Hamburg)
S. Köster (KfS)
D. Lott (HZG)
S. Molodtsov (European XFEL)
N.N. (KAT)
N.N. (KET)
N.N. (KfB)
N.N. (U Hamburg)

Leading Scientists:
R. Aßmann (DESY/MPY)
T. Behnke (DESY/FLC)
D. Berge (DESY/AP-GA)
K. Borras (DESY/CMS)
R. Brinkmann (DESY/M)
F. Calegari (DESY/FS-CFEL)
H. Chapman (DESY/FS-CFEL)
B. Foster (DESY/FLA)
E. Gallo (DESY/CMS)
C. Grojean (DESY/T)
G. Grübel (DESY/FS-CSX)
B. Heinemann (DESY/ATLAS)
Ç. İşsever (DESY/ATLAS)
F. Kärtner (DESY/FS-CFEL)
M. Kasemann (DESY/CMS)
M. Kowalski (DESY/AP-ICE)
K. Mönig (DESY/ATLAS)
K. Peters (DESY/ATLAS)
M. Pohl (DESY/AP-THAT)
N. Rohringer (DESY/FS-TUX)
K. Rossnagel (DESY/FS-SXQM)
R. Santra (DESY/FS-CFEL)
M. Schnell-Küpper (DESY/FS-SMP)
V. Schomerus (DESY/T)
C. Schroer (DESY/FS-PETRA)
C. Schwanenberger (DESY/CMS)
G. Servant (DESY/T)
A. Stierle (DESY/FS-NL)
K. Tackmann (DESY/ATLAS)
S. Techert (DESY/FS-SCS)
G. Weiglein (DESY/T)
H. Weise (DESY/MPY)
H. Yan (DESY/AP-THAT)

Physics Research Committee (PRC)

Prof. Dr. **P. Burrows** (U Oxford, UK, Chair)
Prof. Dr. **A. Boehnlein** (JLab, USA)
Prof. Dr. **L. Covi** (U Göttingen, DE)
Prof. Dr. **L. Feld** (RWTH Aachen, DE)
Prof. Dr. **J. Fuster Verdú** (IFIC Valencia, SP)
Prof. Dr. **N. Glover** (IPPP Durham, UK)
Prof. Dr. **U. Husemann** (KIT, DE)
Prof. Dr. **Y. Semertzidis** (KAIST Seoul, KR)
Prof. Dr. **R. Wallny** (ETH Zürich, CH)

Astroparticle Physics Committee (APC)

Prof. Dr. **E. Amato** (INAF Florence, IT)
Prof. Dr. **G. Bertone** (U Amsterdam, NL)
(until 30 September)
Prof. Dr. **M. Branchesi** (Gran Sasso Science Institute, IT)
(from 1 October)
Prof. Dr. **D. Hanna** (McGill University Montreal, CA)
Prof. Dr. **A. Kouchner** (APC Paris, FR, Vice-Chair)
Prof. Dr. **C. Weinheimer** (U Münster, DE, Chair)
Prof. Dr. **J. Wilms** (U Erlangen-Nürnberg, DE)

Ex-officio members in PRC and APC:

Prof. Dr. **H. Dosch** (DESY)
Dr. **W. Leemans** (DESY)
Prof. Dr. **J. Mnich** (DESY)
Prof. Dr. **C. Stegmann** (DESY)
Prof. Dr. **E. Weckert** (DESY)

German Committee for Astroparticle Physics (KAT)

K. Danzmann (U Hannover)
R. Diehl (TU München)
R. Engel (KIT, ex-officio)
S. Funk (U Erlangen-Nürnberg)
A. Haungs (KIT, Vice-Chair)
U. Katz (U Erlangen-Nürnberg, Chair)
M. Lindner (MPP München)
T. Schwetz-Mangold (KIT)
A. Stahl (RWTH Aachen)
C. Stegmann (DESY, ex-officio)
K. Valerius (KIT)

Memberships

APPEC (deputy chair)
Christian Stegmann

ARENA International Advisory Board
Anna Nelles

Armenia-Brandenburg (ARBRA) 2019 Summer School (co-chair)
Johannes Knapp

ASEC Advisory Board, AANL, Armenia (chair)
Johannes Knapp

Astroteilchenphysik im Netzwerk Teilchenwelt (chair)
Ulrike Behrens

Blois Workshop Particle Physics, Cosmology, Astroparticle Physics, Scientific Programme Committee (member)
David Berge

BMBF Advisory Committee for ground-based Astro and Astroparticle Physics (chair)
Christian Stegmann

Board of Trustees of *Physik in unserer Zeit*
Christian Stegmann

CTA Blazar Population Working Group (chair)
Tarek Hassan

CTA Consortium Board (member)
Gernot Maier

CTA MST-North Executive Board (chair)
Markus Garczarczyk

CTA MST-North Principle Investigator
Markus Garczarczyk

CTA Science Working Group (chair)
Emma De Oña Wilhelmi

CTA Speakers and Publication office
Elisa Pueschel

CTAO Council
Christian Stegmann

CTAO Project Committee
Markus Garczarczyk

Dark Matter at the LHC Scientific Advisory Committee
David Berge

Deutsches Komitee für Astroteilchenphysik (KAT)
Martin Pohl

EAS 2020, Leiden, Science Advisory Committee
Anna Nelles

Editorial board of Journal *Astroparticle Physics* (chair)
Johannes Knapp

Editorial board of Journal *Nuclear Physics B* (member)
Walter Winter

EPS 2019 Scientific Organisation Committee
Huirong Yan

Gamma 2020 Science Organisation Committee
Emma De Oña Wilhelmi

Helmholtz Multimessenger Graduate School (speakers for DESY)
David Berge, Marek Kowalski

Helmholtz Topic “Matter and Radiation from the Universe” (chair)
Christian Stegmann

H.E.S.S. Collaboration Board
David Berge

H.E.S.S. Executive Committee (member)
Stefan Ohm, Andrew Taylor, Heike Prokoph

H.E.S.S. Observation Committee (member)
Andrew Taylor

IceCube Analysis Coordination (chair)
Anna Franckowiak

IceCube Collaboration International Oversight and Finance Group (IOFG)
Christian Stegmann

IceCube Executive Board
Markus Ackermann, Marek Kowalski

IceCube Publication Committee (chair)
Markus Ackermann

IceCube-Gen2 working group (chair)
Marek Kowalski

ICRC 2019 Science Organisation Committee (member)
Stefan Ohm

ICRC2021 Local Organising Committee
Johannes Knapp (chair), David Berge (deputy chair)

ICTP School on High-Energy Astrophysics 2019 Scientific Advisory Committee (member)
Johannes Knapp

IUPAP Neutrino Panel
Marek Kowalski, Walter Winter

Jugend forscht Berlin (juror)
Adelheid Sommer

Karl Heinz Beckurts Foundation (chair)
Christian Stegmann

Komitee Astroteilchenphysik (KAT) (ex-officio member)
Christian Stegmann

L2 IceCube-Upgrade Sensors (chair)
Timo Karg

LabEx UnivEarthS Scientific Committee
Anna Franckowiak

Lux-Zeplin Oversight Committee, STFC, UK (member)
Johannes Knapp

MAGIC Technical Board
Markus Garczarczyk

Netzwerk der Schülerlabore in der Helmholtz-Gemeinschaft (chair)
Adelheid Sommer

Potsdam Research Network PEARLS, Stifterversammlung (member)
Ulrike Behrens

Potsdam Research Network PEARLS, Wissenschaftliches Kollegium (member)
Martin Pohl

ProWissen Potsdam e.V., Arbeitskreis (co-chair)
Ulrike Behrens

ProWissen Potsdam e.V., Kuratorium (member)
Ulrike Behrens

Rat Deutscher Sternwarten
Martin Pohl

Steering Group Global Cosmic in the International Particle Physics Outreach Group (IPPOG) (chair)
Carolin Schwerdt

TAIGA Collaboration Board (member)
Dmitriy Kostunin

TEPA 2019 Scientific Advisory Committee (member)
Johannes Knapp

Texas Symposium 2020 Science Organisation Committee (member)
Emma De Oña Wilhelmi

Tunka Astrophysical Observatory (TAIGA)
German-Russian Astroparticle Data Life Cycle Initiative
Dmitriy Kostunin

Universität Potsdam Selection Committee (member)
Maria Haupt, Maria Krause

VERITAS Science Working Group (deputy chair)
Elisa Pueschel

VERITAS Speaker’s Bureau (chair)
Martin Pohl

VERITAS Time Allocation Committee
Martin Pohl

ZTF Collaboration Board
Marek Kowalski

ZTF Publication Board
Marek Kowalski

ZTF Science Survey Committee
Marek Kowalski

Publications

Published

M. G. Aartsen et al.
Constraints on minute-scale transient astrophysical neutrino sources.
Physical review letters, 122(5):051102, and PUBDB-2020-00327, arXiv:1807.11492.
doi: 10.1103/PhysRevLett.122.051102.

M. G. Aartsen et al.
Cosmic ray spectrum and composition from PeV to EeV using 3 years of data from IceTop and IceCube.
Physical review / D, 100(8):082002, and PUBDB-2019-03880.
doi: 10.1103/PhysRevD.100.082002.

M. G. Aartsen et al.
Detection of the temporal variation of the Sun's cosmic ray shadow with the IceCube detector.
The astrophysical journal / 1, 872(2):133, and PUBDB-2020-00120, arXiv:1811.02015.
doi: 10.3847/1538-4357/aaffd1.

M. G. Aartsen et al.
Efficient propagation of systematic uncertainties from calibration to analysis with the SnowStorm method in IceCube.
Journal of cosmology and astroparticle physics, 2019(10):048, and PUBDB-2019-03882, arXiv:1909.01530.
doi: 10.1088/1475-7516/2019/10/048.

M. G. Aartsen et al.
Measurements using the inelasticity distribution of multi-TeV neutrino interactions in IceCube.
Physical review / D, 99(3):032004, and PUBDB-2020-00121, arXiv:1808.07629.
doi: 10.1103/PhysRevD.99.032004.

M. G. Aartsen et al.
Search for Sources of Astrophysical Neutrinos Using Seven Years of IceCube Cascade Events.
The astrophysical journal / 1, 886(1):13, and PUBDB-2019-04289.
doi: 10.3847/1538-4357/ab4ae2.

H. Abdalla et al.
A very-high-energy component deep in the γ-ray burst afterglow.
Nature / Physical science, 575(7783):464, and PUBDB-2019-04677.
doi: 10.1038/s41586-019-1743-9.

H. Abdalla et al.
The 2014 TeV γ-Ray Flare of Mrk 501 Seen with H.E.S.S.: Temporal and Spectral Constraints on Lorentz Invariance Violation.
The astrophysical journal / 1, 870(2):93, and PUBDB-2019-00749.
doi: 10.3847/1538-4357/aaf1c4.

V. A. Acciari et al.
A Fast Very High Energy γ-ray Flare from BL Lacertae during a Period of Multiwavelength activity in June 2015.
Astronomy and astrophysics, 623:A175, and PUBDB-2020-00484, arXiv:1901.01733.
doi: 10.1051/0004-6361/201834010.

V. A. Acciari et al.
Deep observations of the globular cluster M15 with the MAGIC telescopes.
Monthly notices of the Royal Astronomical Society, 484(2):2876, and PUBDB-2019-02174.
doi: 10.1093/mnras/stz179.

V. A. Acciari et al.
Measurement of the extragalactic background light using MAGIC and Fermi-LAT gamma-ray observations of blazars up to $z = 1$.
Monthly notices of the Royal Astronomical Society, 486(3):4233, and PUBDB-2019-03716.
doi: 10.1093/mnras/stz943.

V. A. Acciari et al.
Testing emission models on the extreme blazar 2WHSP J073326.7+515354 detected at very high energies with the MAGIC telescopes.
Monthly notices of the Royal Astronomical Society, 490(2):2284, and PUBDB-2019-04815.
doi: 10.1093/mnras/stz2725.

A. Acharyya et al.
Monte Carlo studies for the optimisation of the Cherenkov Telescope Array layout.
Astroparticle physics, 111:35, and PUBDB-2019-02176.
doi: 10.1016/j.astropartphys.2019.04.001.

F. Aharonian, R. Yang and E. de Oña Wilhelmi.
Massive stars as major factories of Galactic cosmic rays.
Nature astronomy, 3(6):561, and PUBDB-2019-02857.
doi: 10.1038/s41550-019-0724-0.

M. Ajello et al.
A Decade of Gamma-Ray Bursts Observed by Fermi -LAT: The Second GRB Catalog.
The astrophysical journal / 1, 878(1):52, and PUBDB-2019-02726.
doi: 10.3847/1538-4357/ab1d4e.

M. Ajello et al.
A Search for Cosmic-Ray Proton Anisotropy with the Fermi Large Area Telescope.
The astrophysical journal / 1, 883(1):33, and PUBDB-2020-00204.
doi: 10.3847/1538-4357/ab3a2e.

M. Ajello et al.
Bright Gamma-Ray Flares Observed in GRB 131108A.
The astrophysical journal / 2, 886(2):L33, and PUBDB-2020-00035, arXiv:1911.04642.
doi: 10.3847/2041-8213/ab564f.

R. Alves Batista et al.
Open Questions in Cosmic-Ray Research at Ultrahigh Energies.
Frontiers in astronomy and space sciences, 6:23, and PUBDB-2019-02725.
doi: 10.3389/fspas.2019.00023.

A. Anker et al.
Neutrino vertex reconstruction with in-ice radio detectors using surface reflections and implications for the neutrino energy resolution.
Journal of cosmology and astroparticle physics, 2019(11):030, and PUBDB-2019-04674.
doi: 10.1088/1475-7516/2019/11/030.

A. Anker et al.
Targeting ultra-high energy neutrinos with the ARIANNA experiment.
Advances in space research, 64(12):2595, and PUBDB-2019-04661, arXiv:1903.01609.
doi: 10.1016/j.asr.2019.06.016.

A. Archer et al.
A Search for Pulsed Very High-energy Gamma-Rays from 13 Young Pulsars in Archival VERITAS Data.
The astrophysical journal / 1, 876(2):95, and PUBDB-2019-02713.
doi: 10.3847/1538-4357/ab14f4.

I. Astapov et al.
Scintillation detectors for the TAIGA experiment.
Nuclear instruments & methods in physics research / A, A936:254, and PUBDB-2020-00241.
doi: 10.1016/j.nima.2018.10.081.

W. Benbow et al.
Direct measurement of stellar angular diameters by the VERITAS Cherenkov telescopes.
Nature astronomy, 3(6):511, and PUBDB-2019-02719.
doi: 10.1038/s41550-019-0741-z.

E. Bernardini et al.
Teraelectronvolt emission from the γ-ray burst GRB 190114C.
Nature / Physical science, 575(7783):455, and PUBDB-2019-04673.
doi: 10.1038/s41586-019-1750-x.

A. Bohdan et al.
Erratum: “Electron Pre-acceleration at Nonrelativistic High-Mach-number Perpendicular Shocks” (2017, ApJ, 847, 71).
The astrophysical journal / 1, 880(1):66, and PUBDB-2019-03012.
doi: 10.3847/1538-4357/ab2f89.

A. Bohdan et al.
Kinetic simulations of nonrelativistic perpendicular shocks of young supernova remnants. I. Electron shock-surfing acceleration.
The astrophysical journal / 1, 878(1):5, and PUBDB-2019-02507.
doi: 10.3847/1538-4357/ab1b6d.

A. Bohdan et al.
Kinetic Simulations of Nonrelativistic Perpendicular Shocks of Young Supernova Remnants. II. Influence of Shock-surfing Acceleration on Downstream Electron Spectra.
The astrophysical journal / 1, 885(1):10, and PUBDB-2019-03801, DESY-2019-134.
doi: 10.3847/1538-4357/ab43cf.

D. Boncioli, D. Biehl and W. Winter.
On the common origin of cosmic rays across the ankle and diffuse neutrinos at the highest energies from low-luminosity.
The astrophysical journal / Supplement series, 872(1):7, and PUBDB-2019-01184, arXiv:1808.07481.
doi: 10.3847/1538-4357/aafda7.

R. Brose et al.
Nonthermal emission from the reverse shock of the youngest Galactic supernova remnant G1.9+0.3.
Astronomy and astrophysics, 627:A166, and PUBDB-2020-00212, arXiv:1906.02725.
doi: 10.1051/0004-6361/201834430.

N. M. Budnev et al.
TAIGA: A Complex of Hybrid Systems of Cooperating Detectors for Gamma Astronomy and Cosmic Ray Physics in the Tunka Valley.
Bulletin of the Russian Academy of Sciences / Physics, 83(8):951, and PUBDB-2020-00508.
doi: 10.3103/S1062873819080100.

N. M. Budnev et al.
The primary cosmic-ray energy spectrum measured with the Tunka-133 array.
Astroparticle physics, 117:102406, and PUBDB-2019-05327.
doi: 10.1016/j.astropartphys.2019.102406.

M. W. Coughlin et al.
GROWTH on S190425z: Searching Thousands of Square Degrees to Identify an Optical or Infrared Counterpart to a Binary Neutron Star Merger with the Zwicky Transient Facility and Palomar Gattini-IR.
The astrophysical journal / 2, 885(1):L19, and PUBDB-2019-04288.
doi: 10.3847/2041-8213/ab4ad8.

P. J. Deka et al.
Erratum: “Revisit of Nonlinear Landau Damping for Electrostatic Instability Driven by Blazar-induced Pair Beams” (2019, ApJ, 873, 10).
The astrophysical journal / 1, 883(2):206, and PUBDB-2020-00234.
doi: 10.3847/1538-4357/ab4593.

DES Collaboration.
A DECam Search for Explosive Optical Transients Associated with IceCube Neutrinos.
The astrophysical journal / 1, 883(2):125, and PUBDB-2020-00219, arXiv:1907.07193; FERMILAB-PUB-19-342-AE; DES-2018-0408.
doi: 10.3847/1538-4357/ab3a45.

A. Desai et al.
A GeV–TeV Measurement of the Extragalactic Background Light.
The astrophysical journal / 2, 874(1):L7, and PUBDB-2019-02172.
doi: 10.3847/2041-8213/ab0c10.

A. Domínguez et al.
A new measurement of the Hubble constant and matter content of the Universe using extragalactic background light γ-ray attenuation.
The astrophysical journal / 1, 885(2):137, and PUBDB-2020-00208, arXiv:1903.12097.
doi: 10.3847/1538-4357/ab4a0e.

A. Fedynitch et al.
Hadronic interaction model sibyll 2.3c and inclusive lepton fluxes.
Physical review / D, 100(10):103018, and PUBDB-2020-00249, arXiv:1806.04140; DESY-18-110.
doi: 10.1103/PhysRevD.100.103018.

Fermi-LAT Collaboration and ASAS-SN Collaboration and IceCube Collaboration.
Investigation of Two Fermi -LAT Gamma-Ray Blazars Coincident with High-energy Neutrinos Detected by IceCube.
The astrophysical journal / 1, 880(2):103, and PUBDB-2019-03715, arXiv:1901.10806.
doi: 10.3847/1538-4357/ab2ada.

S. Foffa et al.
Conservative dynamics of binary systems to fourth Post-Newtonian order in the EFT approach II: Renormalized Lagrangian.
Physical review / D, 100:024047, and PUBDB-2019-02862, arXiv:1903.05113.
doi: 10.1103/PhysRevD.100.024047.

S. Gao et al.
Modelling the coincident observation of a high-energy neutrino and a bright blazar flare.
Nature astronomy, 3(1):88, and PUBDB-2019-04168, arXiv:1807.04275.
doi: 10.1038/s41550-018-0610-1.

C. Glaser et al.
NuRadioReco: a reconstruction framework for radio neutrino detectors.
The European physical journal / C, 79(6):464, and PUBDB-2019-03849.
doi: 10.1140/epjc/s10052-019-6971-5.

M. J. Graham et al.
The Zwicky Transient Facility: Science Objectives.
Publications of the Astronomical Society of the Pacific, 131(1001):078001, and PUBDB-2019-02721.
doi: 10.1088/1538-3873/ab006c.

H. E. S. S. Collaboration.
Constraints on the emission region of 3C 279 during strong flares in 2014 and 2015 through VHE γ -ray observations with H.E.S.S.
Astronomy and astrophysics, 627:A159, and PUBDB-2019-03104, arXiv:1906.04996.
doi: 10.1051/0004-6361/201935704.

H. E. S. S. Collaboration.
H.E.S.S. and Suzaku observations of the Vela X pulsar wind nebula.
Astronomy and astrophysics, 627:A100, and PUBDB-2019-03435.
doi: 10.1051/0004-6361/201935458.

H. E. S. S. Collaboration.
H.E.S.S. detection of very-high-energy gamma-ray emission from the quasar PKS 0736+017.
Astronomy and astrophysics, 633(162):11, and PUBDB-2020-00086, arXiv:1911.04761.
doi: 10.1051/0004-6361/201935906.

H. E. S. S. Collaboration.
H.E.S.S. observations of the flaring gravitationally lensed galaxy PKS 1830–211.
Monthly notices of the Royal Astronomical Society, 486(3):3886, and PUBDB-2019-03434.
doi: 10.1093/mnras/stz1031.

H. E. S. S. Collaboration.
Resolving the Crab pulsar wind nebula at teraelectronvolt energies.
Nature astronomy, 4:167, and PUBDB-2020-00088, arXiv:1909.09494.
doi: 10.1038/s41550-019-0910-0.

H. E. S. S. Collaboration.
Upper limits on very-high-energy gamma-ray emission from core-collapse supernovae observed with H.E.S.S.
Astronomy and astrophysics, 626:A57, and PUBDB-2019-02861, arXiv:1904.10526.
doi: 10.1051/0004-6361/201935242.

HAWC Collaboration and IceCube Collaboration.
All-Sky Measurement of the Anisotropy of Cosmic Rays at 10 TeV and Mapping of the Local Interstellar Magnetic Field.
The astrophysical journal / 1, 871(1):96, and PUBDB-2020-00512, arXiv:1812.05682.
doi: 10.3847/1538-4357/aaf5cc.

J. Heinze et al.
A New View on Auger Data and Cosmogenic Neutrinos in Light of Different Nuclear Disintegration and Air-shower Models.
The astrophysical journal / Supplement series, 873(1):88, and PUBDB-2019-01466, DESY 19-016; arXiv 1901.03338.
doi: 10.3847/1538-4357/ab05ce.

M. Hütten, C. Combet and D. Maurin.
CLUMPY v3: γ-ray and ν signals from dark matter at all scales.
Computer physics communications, 235:336, and PUBDB-2018-05621.
doi: 10.1016/j.cpc.2018.10.001.

IceCube Collaboration.
Erratum to: Search for annihilating dark matter in the Sun with 3 years of IceCube data.
The European physical journal / C, 79(3):214, and PUBDB-2020-00504, arXiv:1612.05949.
doi: 10.1140/epjc/s10052-019-6702-y.

IceCube Collaboration.
Erratum to: Search for non-relativistic magnetic monopoles with IceCube.
The European physical journal / C, 79(2):124, and PUBDB-2020-00503, arXiv:1402.3460.
doi: 10.1140/epjc/s10052-019-6582-1.

IceCube Collaboration.
Search for steady point-like sources in the astrophysical muon neutrino flux with 8 years of IceCube data.
The European physical journal / C, 79(3):234, and PUBDB-2020-00118, arXiv:1811.07979.
doi: 10.1140/epjc/s10052-019-6680-0.

Icecube Collaboration.
Measurement of atmospheric tau neutrino appearance with IceCube DeepCore.
Physical review / D, 99(3):032007, and PUBDB-2019-01536.
doi: 10.1103/PhysRevD.99.032007.

M. Iwamoto et al.
Precursor Wave Amplification by Ion–Electron Coupling through Wakefield in Relativistic Shocks.
The astrophysical journal / 2, 883(2):L35, and PUBDB-2019-04206.
doi: 10.3847/2041-8213/ab4265.

M. Jiménez-López et al.
Optimized framegrabber for the Cherenkov telescope array.
Journal of astronomical telescopes, instruments, and systems, 5(1):1, and PUBDB-2020-00500.
doi: 10.1117/1.JATIS.5.1.014001.

E. Kankare et al.
Search for transient optical counterparts to high-energy IceCube neutrinos with Pan-STARRS1.
Astronomy and astrophysics, 626:A117, and PUBDB-2019-02863, arXiv:1901.11080.
doi: 10.1051/0004-6361/201935171.

J. Knödlseder et al.
Analysis of the H.E.S.S. public data release with ctools.
Astronomy and astrophysics, 632:A102, and PUBDB-2020-00038, arXiv:1910.09456.
doi: 10.1051/0004-6361/201936010.

D. Kostunin et al.
Tunka Advanced Instrument for cosmic rays and Gamma Astronomy.
Journal of physics / Conference series, 1263:012006, and PUBDB-2020-00243, arXiv:1903.07460.
doi: 10.1088/1742-6596/1263/1/012006.

R. Kumar et al.
Time variability of TeV cosmic ray sky map.
Monthly notices of the Royal Astronomical Society, 483(1):896, and PUBDB-2019-04208.
doi: 10.1093/mnras/sty3141.

A. Lazarian and H. Yan.
Erratum: “Superdiffusion of Cosmic Rays: Implications for Cosmic Ray Acceleration” (2014, ApJ, 784, 38).
The astrophysical journal / 1, 885(2):170, and PUBDB-2020-00237.
doi: 10.3847/1538-4357/ab50ba.

R. Liu, H. Yan and H. Zhang.
Understanding the Multiwavelength Observation of Geminga’s Tev Halo: The Role of Anisotropic Diffusion of Particles.
Physical review letters, 123(22):221103, and PUBDB-2020-00036, arXiv:1904.11536.
doi: 10.1103/PhysRevLett.123.221103.

R.-Y. Liu et al.
Gamma-Ray Production in the Extended Halo of the Galaxy and Possible Implications for the Origin of Galactic Cosmic Rays.
The astrophysical journal / 1, 871(1):40, and PUBDB-2019-00257, arXiv:1805.03406.
doi: 10.3847/1538-4357/aaf567.

R.-Y. Liu et al.
Hadronuclear interpretation of a high-energy neutrino event coincident with a blazar flare.
Physical review / D, 99(6):063008, and PUBDB-2019-00268, arXiv:1807.05113.
doi: 10.1103/PhysRevD.99.063008.

R. Liu et al.
Constraining the Magnetic Field in the TeV Halo of Geminga with X-Ray Observations.
The astrophysical journal / 1, 875(2):149, and PUBDB-2019-02318, arXiv:1904.11438.
doi: 10.3847/1538-4357/ab125c.

MAGIC Collaboration.
Constraints on Gamma-Ray and Neutrino Emission from NGC 1068 with the MAGIC Telescopes.
The astrophysical journal / 1, 883(2):1, and PUBDB-2019-03719, arXiv:1906.10954.
doi: 10.3847/1538-4357/ab3a51.

MAGIC Collaboration.
Discovery of TeV γ-ray emission from the neighbourhood of the supernova remnant G24.7+0.6 by MAGIC.
Monthly notices of the Royal Astronomical Society, 483(4):4578, and PUBDB-2019-00561.
doi: 10.1093/mnras/sty3387.

E. Mestre et al.
Prospects for the characterization of the VHE emission from the Crab Nebula and Pulsar with the Cherenkov Telescope Array.
Monthly notices of the Royal Astronomical Society, 492(1):708, and PUBDB-2020-00101, arXiv:1912.01921.
doi: 10.1093/mnras/stz3421.

R. Mirzoyan et al.
Absolute reflectance of a concave mirror used for astro-particle physics experiments.
Astroparticle physics, 105:1, and PUBDB-2019-00563.
doi: 10.1016/j.astropartphys.2018.09.001.

R. D. Monkhoev et al.
The Search for Diffuse Gamma Rays Using Data from the Tunka-Grande Experiment.
Bulletin of the Russian Academy of Sciences / Physics, 83(8):959, and PUBDB-2020-00509.
doi: 10.3103/S1062873819080306.

L. R. Morejon Hernandez et al.
Improved photomeson model for interactions of cosmic ray nuclei.
Journal of cosmology and astroparticle physics, 2019(11):007, and PUBDB-2019-03553, DESY 19-123; arXiv:1904.07999.
doi: 10.1088/1475-7516/2019/11/007.

K. Mulrey et al.
Calibration of the LOFAR low-band antennas using the Galaxy and a model of the signal chain.
Astroparticle physics, 111:1, and PUBDB-2020-00251, arXiv:1903.05988.
doi: 10.1016/j.astropartphys.2019.03.004.

K. Murase et al.
High-Energy Emission from Interacting Supernovae: New Constraints on Cosmic-Ray Acceleration in Dense Circumstellar Environments.
The astrophysical journal / 1, 874(1):80, and PUBDB-2020-00493, arXiv:1807.01460.
doi: 10.3847/1538-4357/ab0422.

C. Nigro et al.
Towards open and reproducible multi-instrument analysis in gamma-ray astronomy.
Astronomy and astrophysics, 625:A10, and PUBDB-2019-02716.
doi: 10.1051/0004-6361/201834938.

K.-I. Nishikawa et al.
Relativistic Jet Simulations of the Weibel Instability in the Slab Model to Cylindrical Jets with Helical Magnetic Fields.
Galaxies, 7(1):29, and PUBDB-2019-01535.
doi: 10.3390/galaxies7010029.

J. Nordin et al.
Transient processing and analysis using AMPEL: alert management, photometry, and evaluation of light curves.
Astronomy and astrophysics, 631:A147, and PUBDB-2019-04287.
doi: 10.1051/0004-6361/201935634.

V. S. Paliya.
BAT AGN Spectroscopic Survey. XVI. General Physical Characteristics of BAT Blazars.
The astrophysical journal / 1, 881(2):154, and PUBDB-2019-03549.
doi: 10.3847/1538-4357/ab2f8b.

V. S. Paliya.
Gamma-ray Emitting Narrow-Line Seyfert 1 Galaxies: Past, Present, and Future.
Journal of astrophysics and astronomy, 40(5):39, and PUBDB-2020-00244, arXiv:1909.01444.
doi: 10.1007/s12036-019-9604-3.

V. S. Paliya et al.
Fermi-LAT Stacking Analysis Technique: An Application to Extreme Blazars and Prospects for their CTA Detection.
The astrophysical journal / 2, 882(1):L3, and PUBDB-2019-03436.
doi: 10.3847/2041-8213/ab398a.

A. Palladino et al.
IceCube neutrinos from hadronically powered gamma-ray galaxies.
Journal of cosmology and astroparticle physics, 2019(09):1, and PUBDB-2019-04165, arXiv:1812.04685.
doi: 10.1088/1475-7516/2019/09/004.

A. Palladino et al.
Interpretation of the Diffuse Astrophysical Neutrino Flux in Terms of the Blazar Sequence.
The astrophysical journal / Supplement series, 871(1):41, and PUBDB-2019-00942, arXiv:1806.04769.
doi: 10.3847/1538-4357/aaf507.

E. B. Postnikov et al.
Monte Carlo Simulation of the TAIGA Experiment.
Bulletin of the Russian Academy of Sciences / Physics, 83(8):955, and PUBDB-2019-03717.
doi: 10.3103/S1062873819080331.

V. V. Prosin et al.
Energy Spectrum of Primary Cosmic Rays, According to TUNKA-133 and TAIGA-HiSCORE EAS Cherenkov Light Data.
Bulletin of the Russian Academy of Sciences / Physics, 83(8):1016, and PUBDB-2019-03727.
doi: 10.3103/S1062873819080343.

M. Renschler et al.
Detector developments for a hybrid particle and radio array for cosmic-ray air-shower detection.
26th Extended European Cosmic Ray Symposium, Altai State University, Barnaul-Belokurikha (Russian Federation), 6 Jul 2018 - 10 Jul 2018.
Journal of physics / Conference series, vol. 1181:012075, and PUBDB-2019-04639.
IOP Publ., Bristol.
doi: 10.1088/1742-6596/1181/1/012075.

D. Rodgers-Lee et al.
Stellar cosmic rays as an important source of ionisation in protoplanetary disks: a disk mass dependent process.
Monthly notices of the Royal Astronomical Society, 419:4742, and PUBDB-2020-00112.
doi: 10.1093/mnras/stz3266.

X. Rodrigues et al.
Leptohadronic Blazar Models Applied to the 2014–2015 Flare of TXS 0506+056.
The astrophysical journal / 2, 874(2):L29, and PUBDB-2019-01965, DESY-19-019; arXiv:1812.05939.
doi: 10.3847/2041-8213/ab1267.

N. L. Strotjohann, M. Kowalski and A. Franckowiak.
Eddington bias for cosmic neutrino sources.
Astronomy and astrophysics, 622:L9, and PUBDB-2020-00343, arXiv:1809.06865; DESY-18-164.
doi: 10.1051/0004-6361/201834750.

L. G. Sveshnikova et al.
First Season of Operation of the TAIGA Hybrid Cherenkov Array.
Bulletin of the Russian Academy of Sciences / Physics, 83(8):962, and PUBDB-2019-03728.
doi: 10.3103/S1062873819080379.

S. Taubenberger et al.
SN 2012dn from early to late times: 09dc-like supernovae reassessed.
Monthly notices of the Royal Astronomical Society, 488(4):5473, and PUBDB-2020-00257, arXiv:1907.06753.
doi: 10.1093/mnras/stz1977.

D. F. Torres et al.
Synchro-curvature modelling of the multi-frequency non-thermal emission of pulsars.
Monthly notices of the Royal Astronomical Society, 489(4):5494, and PUBDB-2020-00247, arXiv:1908.11574.
doi: 10.1093/mnras/stz2403.

N. Tsuji et al.
NuSTAR Observations of the Supernova Remnant RX J1713.7–3946.
The astrophysical journal / 1, 877(2):96, and PUBDB-2020-00097.
doi: 10.3847/1538-4357/ab1b29.

S. Vafin, M. Riazantseva and M. Pohl.
Coulomb Collisions as a Candidate for Temperature Anisotropy Constraints in the Solar Wind.
The astrophysical journal / 2, 871(1):L11, and PUBDB-2019-04209.
doi: 10.3847/2041-8213/aafb11.

S. Vafin et al.
Revisit of Nonlinear Landau Damping for Electrostatic Instability Driven by Blazar-induced Pair Beams.
The astrophysical journal / 1, 873(1):10, and PUBDB-2019-04207.
doi: 10.3847/1538-4357/ab017b.

S. van Velzen et al.
The First Tidal Disruption Flare in ZTF: From Photometric Selection to Multi-wavelength Characterization.
The astrophysical journal / 1, 872(2):198, and PUBDB-2019-01534.
doi: 10.3847/1538-4357/aafe0c.

P. Veres et al.
Observation of inverse Compton emission from a long γ-ray burst.
Nature / Physical science, 575(7783):459, and PUBDB-2020-00033.
doi: 10.1038/s41586-019-1754-6.

VERITAS Collaboration.
Measurement of the Extragalactic Background Light Spectral Energy Distributions with VERITAS.
The astrophysical journal / 1, 885(2):150, and PUBDB-2019-04456, arXiv:1910.00451.
doi: 10.3847/1538-4357/ab4817.

A. van Vliet, R. A. Batista and J. R. Hörandel.
Determining the fraction of cosmic-ray protons at ultrahigh energies with cosmogenic neutrinos.
Physical review / D, 100(2):021302, and PUBDB-2019-04163, arXiv:1901.01899.
doi: 10.1103/PhysRevD.100.021302.

X.-Y. Wang et al.
Synchrotron self-Compton emission from external shocks as the origin of the sub-TeV emission in GRB 180720B and GRB 190114C.
The astrophysical journal / 1, 884(2):117, and PUBDB-2020-00207, arXiv:1905.11312.
doi: 10.3847/1538-4357/ab426c.

C. Welling, C. Glaser and A. Nelles.
Reconstructing the cosmic-ray energy from the radio signal measured in one single station.
Journal of cosmology and astroparticle physics, 2019(10):075, and PUBDB-2019-04316, arXiv:1905.11185.
doi: 10.1088/1475-7516/2019/10/075.

R. Xue et al.
A two-zone model for blazar emission: implications for TXS 0506+056 and the neutrino event IceCube-170922A.
The astrophysical journal / 1, 886(1):23, and PUBDB-2020-00252, arXiv:1908.10190.
doi: 10.3847/1538-4357/ab4b44.

R. Xue et al.
On the minimum jet power of TEV BL Lac objects in the $p-\gamma$ model.
The astrophysical journal / 1, 871(1):81, and PUBDB-2019-00261, arXiv:1812.02398.
doi: 10.3847/1538-4357/aaf720.

R.-z. Yang, F. Aharonian and E. de Oña Wilhelmi.
Massive star clusters as the an alternative source population of galactic cosmic rays.
Rendiconti lincei / Scienze fisiche e naturali Scienze fisiche e naturali, 30(S1):159, and PUBDB-2020-00187.
doi: 10.1007/s12210-019-00819-3.

M. Zacharias et al.
The VHE γ-Ray View of the FSRQ PKS 1510-089.
Galaxies, 7(1):41, and PUBDB-2019-01897.
doi: 10.3390/galaxies7010041.

Ph.D. Thesis

D. Biehl.
Nuclear Cascades and Neutrino Production in the Sources of Ultra-High Energy Cosmic Ray Nuclei.
Humboldt University, 2019.

Y.-J. Chen.
Light-induced ultrafast tunneling dynamics of a many-electron system: from weak to strong fields.
Universität Hamburg, Hamburg, 2019.

E. Leser.
Eta Carinae detection and characterisation of the first colliding-wind binary in very-high-energy gamma-rays with H.E.S.S.Eta Carinae Detektion und Charakterisierung des ersten Binärsternsystems mit kollidierenden Sternwinden in sehr hochenergetischer Gammastrahlung mit H.E.S.S.
University Potsdam, 2019.

X. de Sousa Ferreira Rodrigues.
Blazars as Sources of Neutrinos and Ultra-high-energy Cosmic Rays.
Humboldt University, 2019.

Master Thesis

R. Konno.
Modeling and search of γ-ray emission from Galactic colliding wind binaries.
Humboldt University of Berlin, 2019.

Photographs and graphics

Ulrike Behrens, DESY
Itai Belson, Weizmann Institute of Science
Gesine Born, DESY
Sinje Hasheider, DESY
Ashley Jones, DESY
Alexander Kappes, University of Münster
Marta Mayer, DESY
Anna Nelles, DESY
Susann Niedworok, DESY
Ekrem Oguzhan Angüner
Amy Oliver, Fred Lawrence Whipple Observatory,
Center for Astrophysics / Harvard & Smithsonian
Rafael A. Porto, DESY
Elisa Pueschel, DESY
Olaf Scholten, University of Groningen
Dae Seon Seo, DESY
Martin Wolf, IceCube/NSF
Mattias Zeising, neonrausch

DESY
DESY, Lucid.Studio
DESY, Science Communication Lab
Dr. Hans Riegel-Stiftung
H.E.S.S. Collaboration
Heinle Wischer und Partner Freie Architekten GbR, Berlin
with Ulrich Krüger Landschaftsarchitekten, Dresden
NASA
pSCT team

The figures were reproduced by permission of authors or journals.

Acknowledgement

We would like to thank all authors and everyone who helped in the creation of this annual report.

Imprint

Publishing and Contact:
Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

Hamburg location:
Notkestr. 85, 22607 Hamburg, Germany
Tel.: +49 40 8998-0, Fax: +49 40 8998-3282
desyinfo@desy.de

Zeuthen location:
Platanenallee 6, 15738 Zeuthen, Germany
Tel.: +49 33762 7-70, Fax: +49 33762 7-7413
desyinfo-zeuthen@desy.de

www.desy.de

ISBN 978-3-945931-32-5
DOI 10.3204/PUBDB-2020-01613

Online version:
https://www.desy.de/about_desy/annual_reports/

Realisation:
Ulrike Behrens, Johannes Knapp

Editing:
Ilka Flegel, Johannes Knapp

Layout:
Kay Fürstenberg

Printing: vierC print+mediafabrik, Berlin

Copy deadline: 15 April 2020

Editorial note:
The authors of the individual articles published in this report are fully responsible for the contents.

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

The Helmholtz Association is a community of 19 scientific-technical and biological-medical research centres. These centres have been commissioned with pursuing long-term research goals on behalf of the state and society. The Association strives to gain insights and knowledge so that it can help to preserve and improve the foundations of human life. It does this by identifying and working on the grand challenges faced by society, science and industry. Helmholtz Centres perform top-class research in strategic programmes in six core fields: Energy, Earth & Environment, Health, Aeronautics, Space and Transport, Matter, and Key Technologies.

www.helmholtz.de