ASTROPARTICLE PHYSICS 2020.

Highlights and Annual Report

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

Cover

A microquasar and a gas cloud pulsating with the same rhythm, suggesting a connection between the two.
Picture: DESY, Science Communication Lab

ASTROPARTICLE PHYSICS 2020.

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Chairman's foreword

Dear Colleagues and Friends of DESY,

2020 was a truly unusual year for the global society. In March, the coronavirus brought our accustomed everyday life to a standstill and mercilessly exposed the vulnerability of our modern society to such crisis. We will have to put many of our habits, which have finally proven to be unsustainable, to test and find new ways forward. We have already learned a great deal in recent months, most importantly that our society can rely on science and on decision makers who listen to scientists.

We at DESY reacted quickly and very cautiously to the pandemic and moved the research centre into a safe mode that kept the laboratories and our research largely in operation while protecting all staff from infection as efficiently as possible.

These measures were critical with respect to the user operation of our large-scale research facilities PETRA III and FLASH. Especially the unique analysis capabilities at PETRA III have proven to be most important for the fight against the COVID-19 coronavirus. We have to ensure that these technologies will be even more targeted to molecular drug research and even more crisis-proven in the future. To this end, we have drawn up a major proposal for the establishment of a National Analysis Center for Molecular Infection Research, in which new digital and technical concepts, like artificial intelligence, remote control and robotics, are to be incorporated. "Digital DESY" has become a new building block in our DESY strategy, in response to the challenges of the current pandemic and of future crisis

Figure 1

Part of the DESY staff in Hamburg hold up the DESY-60 logo.

Figure 2
Senate reception for the 60th anniversary of DESY in Hamburg: with forward-looking, cutting-edge research into the new decade.

situations. We will also pay even greater attention to sustainable concepts in all our activities and future projects.

DESY is well on its way into this future. The priority project is PETRA IV, which has now entered the technical design phase. We are very pleased that with Riccardo Bartolini, who joined DESY in April 2020, we have been able to attract an internationally renowned accelerator physicist for this future project. In the next few years, the task will be to prepare all the logistical and personnel prerequisites for the upgrade of the synchrotron radiation source PETRA III and to raise the necessary financial resources for this complex project. Nearly all areas of DESY will be involved here in the upcoming decade.

In 2020, we have made good progress in various projects, such as in the development of the Centre for Molecular Water Science (CMWS), the commissioning of the Detector Assembly Facility (DAF) and the construction of the Start-Up Labs Bahrenfeld, as well as in the Centre for X-ray and Nano Science (CXNS), which will open in 2021. An active innovation culture that interlinks basic research and fast transfer of innovative concepts to the market will remain an integral part of DESY's future strategy.

In the coming years, further projects are on the agenda: Major new construction measures include the DESYUM visitor centre, the building for the accelerator division, the TECHNICUM for technical groups, the DESY Innovation Factory and the Wolfgang Pauli Centre (WPC) for theoretical physics.

Important research and upgrade projects, such as the upgrade of the free-electron laser FLASH to FLASH2020+, the KALDERA-ATHENA project for future accelerator technologies, the Any Light Particle Search experiment ALPS II, the telescope in search of dark-matter particles BabyIAXO as well as the Cherenkov Telescope Array (CTA) and its Data Centre, will be implemented.

Promoting our top scientists and our young talents is an essential component of the DESY strategy. The new Helmholtz graduate school DASHH has been well established in 2020. The aim of the school is to educate the future generation of data scientists who can efficiently analyse measured data using e.g. artificial intelligence or machine learning. In 2020, we have implemented the COAST programme, which will assist our postdocs in shaping their individual career pathways. Our HR department has done a remarkable job in this respect. Over the coming months, we must and will develop concepts to offer our top academic performers new career paths within the research centre.

DESY celebrated its 60th anniversary in the Hamburg city hall at the beginning of 2020. Many congratulations came from the global science community and honoured DESY as a world-leading centre in the exploration of matter. We are well prepared for the coming decades to continue the legacy of DESY.

Even in these challenging times, the extraordinary commitment of the DESY staff and all our users and partners, national and international, made research possible at DESY – I would like to thank all those who contributed to the joint efforts!

Helmut Dosch
Chairman of the DESY Board of Directors

Astroparticle physics at DESY

Director's foreword

Dear friends of DESY,

Despite the COVID-19 pandemic and the restrictions it entailed, 2020 was a very productive year for the Astroparticle Physics division at DESY, marked – alongside major scientific results – by a highly successful Helmholtz evaluation, a decisive lead scientist recruitment and the initiation of the application process to include the IceCube-Gen2 project and the Einstein Telescope in the Research Infrastructure Roadmap of the Helmholtz Association.

The year 2020 at DESY started with two outstanding highlights. January marked the celebration of the 60th anniversary of the research centre with a Senate reception in the Hamburg city hall, attended by around 500 guests, at which DESY presented its ambitious plans for the future. Then, together with the other areas in the Helmholtz research field "Matter" (photon science, particle physics as well as nuclear and hadron physics), the DESY astroparticle physics programme underwent a strategic evaluation for the next programme-oriented funding period (PoF IV) of the Helmholtz Association – with very positive results. The programme earned the rating "outstanding", and thus the highest mark, in three of four categories. Only the category "Impact and Risks" was rated "excellent" because of the inherent risks of the large-scale international projects in which the Astroparticle Physics division is involved, which include the next-generation Cherenkov Telescope Array (CTA) and the IceCube neutrino observatory extension IceCube-Gen2, for which a final project decision is still pending on the US side.

In March 2020, the COVID-19 pandemic swept across Germany, and activities at DESY had to quickly be adapted accordingly. The Astroparticle Physics division fared well during the pandemic. Although more than 80% of staff were working

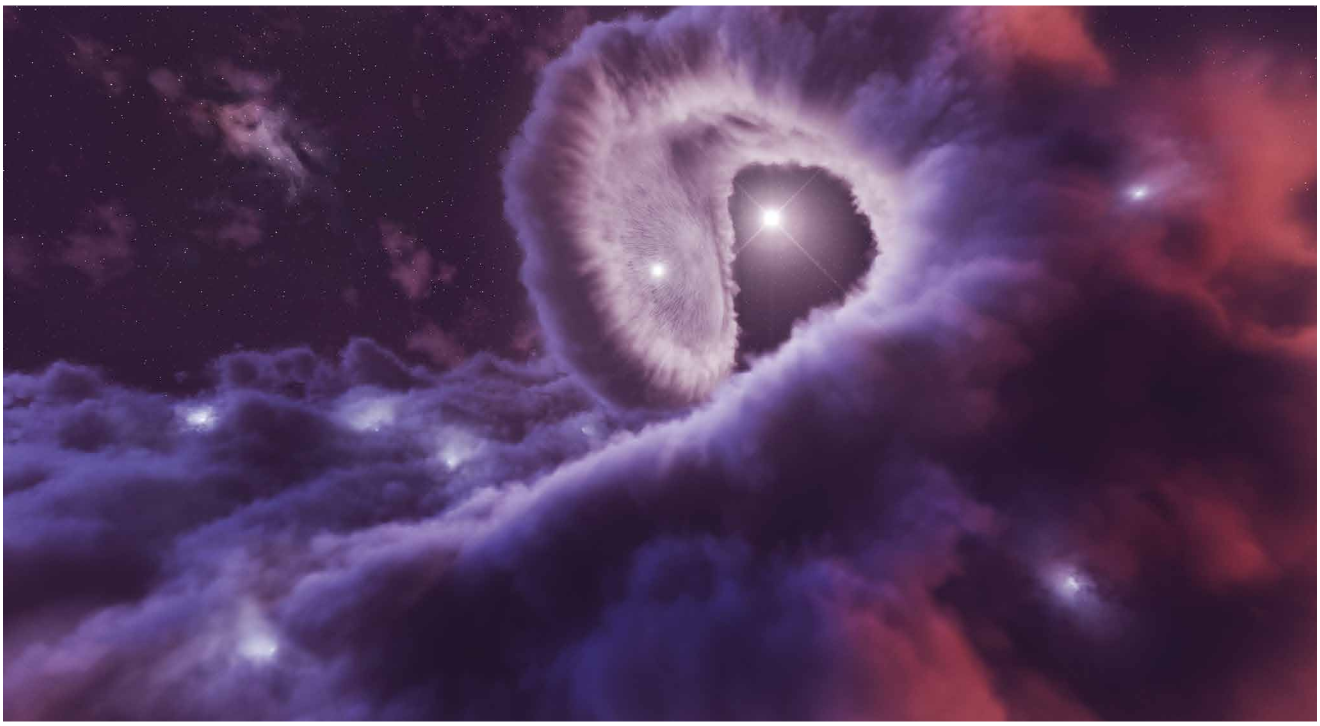


Figure 1

The binary star system Eta Carinae is the first known example of a source in which very-high-energy gamma radiation is generated by colliding stellar winds.

from home during the first COVID-19 wave in spring 2020, the technical services, workshops and administration at DESY in Zeuthen were kept operational – partly in two shifts – obeying rigorous hygiene and distancing rules. Scientific collaborative work went on successfully using video conferencing. Near the lake, outside tents with free WIFI were provided on the Zeuthen campus to enable face-to-face meetings in a well-ventilated environment. All in all, thanks to the remarkable flexibility and dedication of everyone involved, the Astroparticle Physics division was able to quickly adjust to the novel situation and maintain quasi-normal working conditions throughout the various waves of the pandemic and the ensuing lockdowns in Germany.

As a result, several outstanding scientific results were achieved in 2020. The collaboration operating the H.E.S.S. gamma-ray observatory in Namibia, including scientists from DESY, observed a radio galaxy emitting very-high-energy gamma rays over several thousand light years along its jets of plasma. The discovery suggests that the largest cosmic particle accelerators are even bigger than thought, with many radio galaxies with extended jets efficiently accelerating particles up to extreme energies. Another H.E.S.S. discovery concerned the binary star system Eta Carinae, which was observed to emit gamma rays with energies up to 400 GeV, making it the first known example of a source in which very-high-energy gamma radiation is generated by colliding stellar winds. And, using the Fermi Gamma-ray Space Telescope, a team led by DESY detected a mysterious gamma-ray “heartbeat” coming from a cosmic gas cloud. The cloud is beating with the rhythm of a neighbouring precessing black hole at 100 light years distance, indicating a connection between the two objects – but how exactly the black hole powers the cloud’s gamma-ray heartbeat remains unexplained so far.

Astroparticle physics theory at DESY got a further boost in 2020 with the appointment of Rafael Porto, who took up a position as lead scientist in August. Within his multidisciplinary research programme at the interface of astroparticle physics, cosmology and gravitational wave science, he focuses on using novel tools and ideas from particle physics to study, among others, black holes in Einstein’s theory of gravity or the properties of nuclear matter under the unique conditions prevailing in neutron stars. He is also involved in searches for physics beyond the Standard Model of particle physics through gravitational wave “precision data” from present and future detectors, such as the Einstein Telescope.

Finally, another key event of the year was the initiation of the application process to include two major projects with DESY participation in the Research Infrastructure Roadmap of the Helmholtz Association. The IceCube-Gen2 project foresees an extension of the IceCube neutrino observatory at the South Pole to a total detector volume of nearly eight cubic kilometres, increasing the annual rate of cosmic neutrino observations by an order of magnitude and the detector’s sensitivity to point sources to five times that of IceCube. And, to expand gravitational wave research in Europe, DESY, together with non-university and university partners, is promoting German participation in the Einstein Telescope, a third-generation gravitational wave detector planned in Europe that is to be about 500 times more sensitive than the existing detectors LIGO in the USA or Virgo in Italy.

Despite the constraints due to the COVID-19 pandemic, the Astroparticle Physics division thus looks back on a successful year of producing great science. I would like to thank all our staff as well as our partners in Germany and abroad for making this possible in these challenging times.

Christian Stegmann
Director in charge of Astroparticle Physics

News and events

Highlights in 2020

January

Hamburg Senate reception to celebrate 60 years of DESY

On 16 January, about 500 guests attended the Senate reception in celebration of DESY's 60th anniversary in the Hamburg city hall. On the occasion, Katharina Fegebank, Hamburg's Second Mayor and Senator for Science, Research and Equality, paid tribute to DESY as a "world-class research centre" that plays "a major role in shaping Hamburg as a centre of science." Wolf-Dieter Lukas, State Secretary at the German Federal Ministry of Education and Research (BMBF), emphasised that "we need research centres like DESY as 'scientific fact guarantors' in order to jointly find solutions for urgent challenges of the 21st century, which pose enormous tasks for society and politics, economy and science." Otmar Wiestler, President of the Helmholtz Association, acknowledged DESY as "a centre with enormous international appeal" that "makes an essential contribution to solving major societal challenges in line with the Helmholtz mission."

"From the experience of the last 60 years, I am convinced that the centre is well positioned for the future," summarised DESY Director Helmut Dosch. "We are constantly questioning and developing ourselves. But the original mission, to decipher the structure of matter – from the big bang to DNA – this remains."

About 500 guests attended the Senate reception in the Hamburg city hall.

DESY scientist Anna Nelles takes up professorship in Erlangen

After leading her own Emmy Noether group at the Humboldt-Universität zu Berlin and DESY from 2018 to 2019, Anna Nelles took up a professorship on experimental astroparticle physics at the Erlangen Centre for Astroparticle Physics (ECAP) of the Friedrich-Alexander Universität Erlangen-Nürnberg, a position jointly funded by DESY and ECAP. Her research focuses on the radio detection of neutrinos beyond petaelectronvolt energies.

February

Data Science Seminar at DESY in Zeuthen

The newly established Data Science Seminar serves as a forum for all scientists at DESY, but especially for students and postdocs. It provides an opportunity to learn about the activities, problems and methods that the various groups at DESY in Zeuthen are dealing with and to keep abreast of developments in the wider world of data science, scientific computing and software.

Laureates of Dr. Hans Riegel-Stiftung visit DESY in Zeuthen

Laureates of the Dr. Hans Riegel-Stiftung, a foundation that aims to promote the education of young people especially in the STEM fields, visited DESY in Zeuthen to learn more about its current research topics. They were introduced to the field of astroparticle physics and visited the PITZ accelerator beamline and the computing centre.

Laureates of the Dr. Hans Riegel-Stiftung visited DESY in Zeuthen.

CTA prototype moved to DESY in Hamburg

Due to expiring contracts, the mid-sized telescope prototype at the Berlin Adlershof Science City, which had served to test all functions of this telescope type for future operation at the Cherenkov Telescope Array (CTA) gamma-ray observatory, was dismantled and moved to the DESY campus in Hamburg. The positioner and the driving technology of the prototype will be used for the BabyIAXO experiment, which is planned to search for axions and other weakly interacting slim particles (WISPs) emitted by the sun. The camera mount and the mirrors are stored for later use at CTA.

March

DESY in Zeuthen is “Bicycle-Friendly Employer”

As second company in Brandenburg, DESY in Zeuthen was recognised as “Bicycle-Friendly Employer” by the German Cyclists’ Federation (ADFC), which has been awarding the EU-wide certification since 2017. DESY in Zeuthen qualified for certification through its extensive infrastructure, which includes a bike repair station, parking space for bicycles, technical bike checks before the winter season and changing rooms for employees who come to work by bike, and through its various activities, such as participation in city cycling events, the exchange of experience among staff members, individual route advice or staff outings by bike.

Handover of the ADFC certificate

Zwicky Transient Facility collaboration meeting

The spring meeting of the international Zwicky Transient Facility (ZTF) collaboration, in which DESY is a partner, was planned to take place in Berlin but, due to the COVID-19 pandemic, was held as a remote event instead. Located at the Palomar Observatory in California, USA, ZTF is a time-domain, wide-field sky astronomical survey commissioned in 2018 that builds on the highly successful legacy of the Palomar Transient Factory (PTF). ZTF uses a new camera with a 47-square-degree field of view mounted on the Samuel Oschin 48-inch Schmidt telescope. ZTF’s extremely wide field of view and fast readout electronics enable a survey more than an order of magnitude faster than that of PTF. Alongside the collaboration meeting, a workshop on “Enabling novel real-time multi-messenger studies” was also held.

April

Zeuthen campus in corona mode

As a measure against the further spread of the SARS-CoV-2 virus, DESY entered a reduced operating mode on 16 March. Although the DESY sites in Hamburg and Zeuthen remained open, staff were asked to work from home as much as possible, so that staff presence on campus was reduced to what was absolutely necessary. Where possible, the particle accelerators and other facilities were put in safe mode, and user operation at the X-ray sources PETRA III and FLASH

As a measure against the spread of COVID-19, meetings were made possible outside.

was suspended until further notice. PETRA III was powered up only for SARS-CoV-2-relevant measurements. To help fight the pandemic, DESY set up a fast-track access mode for corresponding research projects.

As the situation continued in April, measures were taken at DESY in Zeuthen to maintain “normal” working conditions. Employees were equipped with Zoom licences, regular seminars were switched to remote meetings, and free WIFI was provided at the lake for face-to-face meetings outside. These measures remained in place for the rest of 2020.

Third meeting of Astroparticle Physics Committee

Since the Astroparticle Physics division was established at DESY in 2019, an international committee of scientists, the Astroparticle Physics Committee (APC), has been advising the DESY Directorate on all matters related to astroparticle physics at DESY. Due to the COVID-19 pandemic, the third meeting of the APC was held remotely in April 2020.

Virtual third meeting of the Astroparticle Physics Committee

DESY IT departments support coronavirus research

What do the protein structures and protein bindings of the SARS-CoV-2 virus look like? And which known drugs could dock to these structures? To help fight the pandemic and accelerate the development of therapies against COVID-19, the DESY IT departments supported related research by providing significant computing resources and know-how.

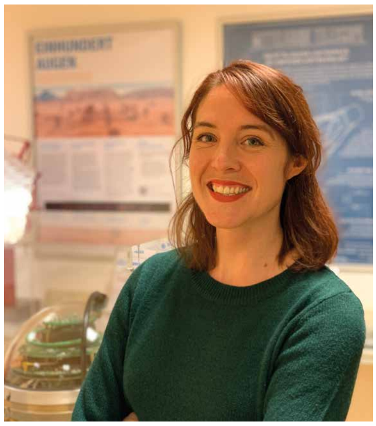
The projects Rosetta@home and Folding@home, for example, were run on the large computer systems in Hamburg and Zeuthen, which contributed about 3.5 million CPU hours in April 2020 – equivalent to the performance of about 1200 laptops calculating day and night for a whole month.

A high-performance computing cluster operated by DESY, the Maxwell cluster in Hamburg, was used to analyse the data of experiments on the SARS-CoV-2 virus carried out at DESY’s X-ray source PETRA III. Overall, between April and September 2020, about 6% of the available DESY computing resources were dedicated to activities concerning COVID-19 research.

May

IceCube Impact Award for DESY scientist Summer Blot

DESY scientist Summer Blot, who is a member of the IceCube neutrino experiment at the South Pole, received the IceCube Impact Award for her “lasting commitment to promote cooperation and cohesion within the collaboration environment, in particular through leadership in the advancement of the areas of diversity, equity, and inclusion.”



Summer Blot

COAST offers support for postdocs at DESY

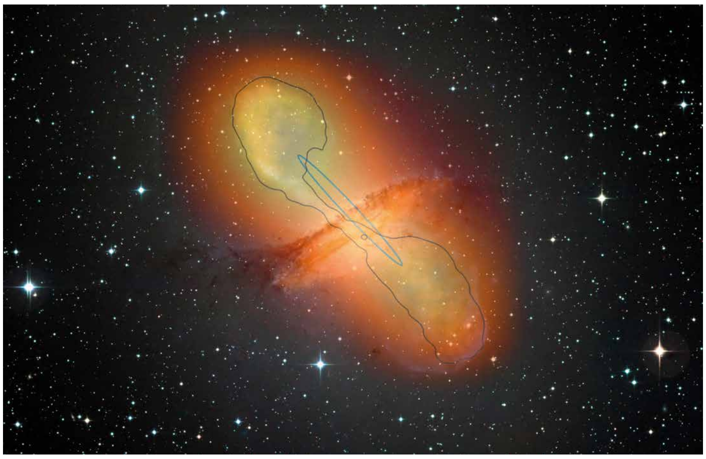
The project COAST – Career Orientation and Skills Training for Postdocs, funded by the Helmholtz Association, was officially launched at DESY. COAST supports young academics in their career planning outside research. Postdocs can take advantage of a wide range of offers and services, such as individual career counselling, workshops, meetings with former DESY postdocs and networking events, so that they can approach their career planning more professionally. With the launch of COAST, DESY enters a new dimension of talent management and establishes a new attraction factor in the global competition for the best scientific talents.

June

Largest cosmic particle accelerators are even bigger than thought

The international collaboration operating the High Energy Stereoscopic System (H.E.S.S.) gamma-ray observatory in Namibia has observed a radio galaxy – a galaxy that is highly luminous when observed at radio wavelengths – for over 200 hours at unparalleled resolution in gamma rays. The observation shows that the very-high-energy gamma-ray emission from galaxies with a highly energetic nucleus is not concentrated in the region close to their central black hole, but extends over several thousand light years along the jets of plasma they emit.

The discovery, which was published in the journal *Nature*, suggests that many radio galaxies with extended jets do indeed efficiently accelerate particles up to extreme energies. The finding also brings crucial new information to the debate on the origin of the jets' X-ray emission.



Superposition of several images of the galaxy Centaurus A in different wavelength ranges from submillimetre waves to X-rays, complemented by gamma-ray observations by H.E.S.S.

Novel gamma-ray telescope detects Crab Nebula

The prototype of the novel Schwarzschild–Couder Telescope (pSCT) has successfully detected the Crab Nebula, the most important standard candle in gamma-ray astronomy. The detection proves the viability of the design of the Schwarzschild–Couder Telescope, which could enhance the capabilities of the upcoming CTA gamma-ray observatory. The success was announced by CTA scientists at the 236th meeting of the American Astronomical Society (AAS).

DESY scientists and engineers have contributed to the pSCT and built the tower and drive of the telescope, which was inaugurated at the Fred Lawrence Whipple Observatory in Arizona, USA, in January 2019. The pSCT is based on a 114-year-old concept by the German physicist Karl Schwarzschild (1873–1916), which has only become feasible today thanks to technical progress. In contrast to conventional gamma-ray telescopes, the pSCT has a double mirror system, which should increase the quality of the focused light and enable the use of compact light sensors.

Inauguration of the pSCT in Januar 2019

Successful participation in city cycling event

In June, the DESY Zeuthen team covered more than 13 000 km in 21 days during the "Stadtradeln" city cycling campaign in the Dahme-Spreewald region. Whether it was the daily ride to the campus, the bike tour around the home office or ambitious weekend excursions, every kilometre counted. The team thus successfully defended its title from 2019 as the largest team with the most kilometres in the region.

July

Binary star is cosmic particle accelerator

Using the H.E.S.S. gamma-ray observatory, a team headed by DESY has proven that a certain type of binary star is a new kind of source of very-high-energy cosmic gamma rays. The binary star system Eta Carinae is located 7500 light years away in the constellation Carina (the ship's keel) in the southern sky and, based on the data collected, emits gamma rays with energies up to 400 GeV, some 100 billion times more than the energy of visible light.

The binary system consists of two blue giants that orbit each other every 5.5 years and fling dense, supersonic stellar winds of charged particles out into space. A huge shock front is formed in the region where the two stellar winds collide, heating up the material in the wind to extremely high temperatures. The H.E.S.S. observation makes the binary star the first known example of a source in which very-high-energy gamma radiation is generated by colliding stellar winds.

In the shock region where the supersonic stellar winds of the two stars collide, subatomic particles are accelerated to such an extent that they produce very-high-energy gamma radiation.

Gamma-ray telescopes measure diameters of far-away stars

By reviving a technique capable of combining specialised gamma-ray telescopes into one giant virtual instrument, scientists have measured the diameters of individual stars hundreds of light years away. The team, which includes researchers from DESY, used the four telescopes of the Very Energetic Radiation Imaging Telescope Array System (VERITAS) in Arizona, USA, as one combined instrument to determine the size of Beta Canis Majoris, a blue giant star located 500 light years from the sun, and Epsilon Orionis, a blue supergiant star 2000 light years from the sun. The stellar intensity interferometry technique, demonstrated for the first time nearly 50 years ago, could allow a promising secondary use of other gamma-ray observatories as well, including the upcoming CTA.

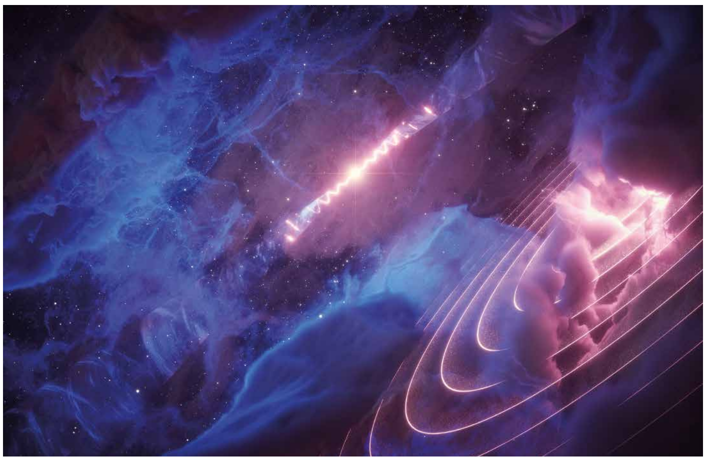
The VERITAS array of imaging atmospheric Cherenkov telescopes for the observation of cosmic gamma rays

August

Strange gamma-ray heartbeat puzzles scientists

A team of scientists led by DESY has detected a mysterious gamma-ray heartbeat coming from a cosmic gas cloud. The cloud is beating with the rhythm of a neighbouring precessing black hole at 100 light years distance, indicating a connection between the two objects. The whole system is located some 15 000 light years away in the Milky Way and consists of a giant star with about 30 times the mass of the sun and a black hole with about 10 to 20 solar masses. The two objects are orbiting each other with a period of 13 days, while the black hole sucks matter from the giant star.

This setting is usually known from quasars with accompanying large black holes with millions of solar masses. As the observed system looks like a scaled-down version of these quasars, it has been dubbed a microquasar. Although the team analysed more than ten years of data from the Fermi Gamma-ray Space Telescope, it is not yet clear how exactly the black hole powers the cloud's gamma-ray heartbeat. Further observations and theoretical work are required to fully explain the system's behaviour.



The microquasar (background) and the gas cloud (foreground), which are about 100 light years apart, pulsate with the same rhythm, suggesting a direct connection.

September

Meeting of Research School for Multimessenger Astronomy

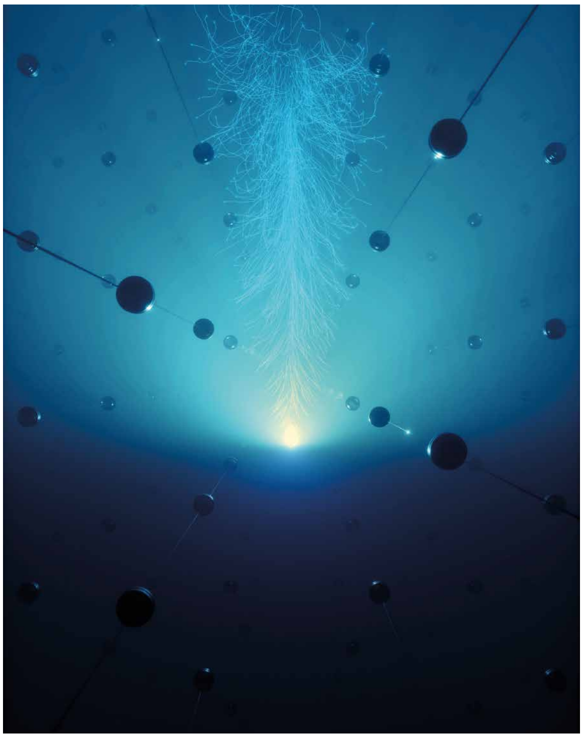
The first annual meeting of the International Helmholtz–Weizmann Research School for Multimessenger Astronomy took place at the end of August. The virtual meeting was the second gathering of all members of the school after its inception in 2019. The students presented the current status of their work, and present and future projects were discussed. The school's international partner is the Weizmann Institute of Science in Rehovot, Israel, and it receives significant funding from the Initiative and Networking Fund of the Helmholtz Association.

Participants of the research school meeting

IceCube extension will open window to the extreme universe

To fully exploit the potential of the IceCube neutrino observatory, the international IceCube collaboration plans a major extension of the detector, which is frozen underground in the eternal ice of the South Pole. The collaboration – of which DESY is the second largest member – submitted a White Paper to the *Journal of Physics G* that outlines the need for and design of IceCube-Gen2, the next-generation extension of IceCube. Through the addition of new optical and radio instruments to the existing detector, IceCube-Gen2 will increase the annual rate of cosmic neutrino observations by an order of magnitude, and its sensitivity to point sources will increase to five times that of IceCube.

The extension is projected to be completed in 2033, with construction costs of around 300 million euros. The first step is already under way with the IceCube Upgrade, funded by the US National Science Foundation (NSF) and the Helmholtz Association. The upgrade will add seven strings with new and enhanced optical modules to the centre of the IceCube array. The next phase will be to add 120 more strings, resulting in a total detector volume of nearly eight cubic kilometres. Near the surface, as a complementary tool to target the very highest neutrino energies, IceCube-Gen2 will have a new radio component made up of detector "stations" covering around 500 square kilometres. This array will detect radio emission generated in the ice by particle showers, allowing scientists to reconstruct the energy of the shower and the arrival direction of the neutrino.



IceCube looks for the light from particle showers triggered by neutrino collisions with the underground ice.

November

Acclaimed German–Russian collaboration

As part of the German–Russian Year of University and Scientific Cooperation, the TAIGA observatory in Siberia's Tunka valley was commended as an outstanding example of bilateral cooperation. DESY project manager Ralf Wischnewski accepted the award on behalf of the entire project at the closing ceremony of the cooperation year, held under the patronage of the Minister of Foreign Affairs of the Russian Federation and the Minister for Foreign Affairs of the Federal Republic of Germany. The Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy (TAIGA) is a complex, hybrid system of detectors for ground-based gamma-ray astronomy.

DESY scientist Ralf Wischnewski (centre) was presented a certificate by Sergey J. Nechayev (left), the Russian ambassador to Germany, and Andreas Goergen (right), the head of the Directorate-General for Culture and Communication of the German Foreign Office.

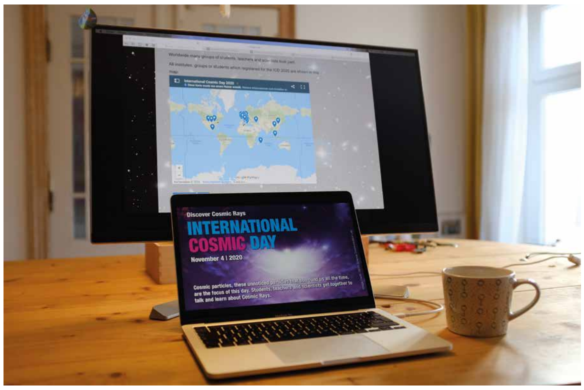
The TAIGA observatory in Siberia's Tunka valley

Farthest black hole from a rare family of galaxies discovered

An international team of astronomers, including scientists from DESY, has identified the farthest example of a rare class of gamma-ray emitting galaxies. The so-called BL Lacertae object appears as it was at cosmic dawn, within the first two billion years of the age of the universe. Today, the cosmos is 13.8 billion years old. Since the speed of light is limited, the farther astronomers look, the earlier the age of the universe they investigate. The newly discovered object is thus substantially farther away than the previous record holder, which was found at a distance corresponding to an age of the universe of about 2.5 billion years. The finding challenges the current scenario of the evolution of gamma-ray emitting galaxies and the knowledge of the cosmic evolution of blazars and active galaxies in general.

International Cosmic Day 2020

The 9th edition of the International Cosmic Day on 4 November brought together teachers, students and researchers to discuss and learn more about the various everyday phenomena involving particles from outer space. Current research projects were also presented. Because of the pandemic, the Cosmic Day 2020 was held as a virtual event.



Virtual International Cosmic Day 2020

Sustainability at DESY and Helmholtz speeds up

On 12 November, the Digital Warm-up for the Helmholtz Sustainability Summit gave a foretaste of the next summit, which is planned to take place in 2021. The online event, which focused on societal responsibility in research, was attended by many employees from various Helmholtz centres, highlighting the great interest in sustainability throughout the centres and the demands for concrete action. At the end of the event, Christian Harringa, Administrative Director at DESY, presented the brand-new commitment to sustainable development of the Helmholtz Association – a voluntary commitment that must now be fulfilled.

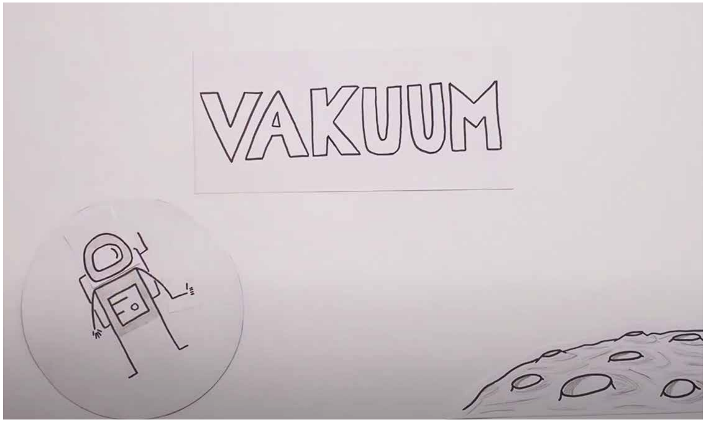
December

DESY PhD student wins dissertation prize of TU Dortmund

Kay Schönwald was awarded the 2020 dissertation prize of the physics faculty of TU Dortmund University. As part of his PhD in the Zeuthen theory group at DESY, Schönwald investigated the effect of heavy particles on deep-inelastic scattering and electron–positron annihilation. These precision results are of great importance for analyses at high-energy accelerators. His dissertation is entitled “Massive two- and three-loop calculations in QED and QCD”.

Videos from DESY Zeuthen School Lab

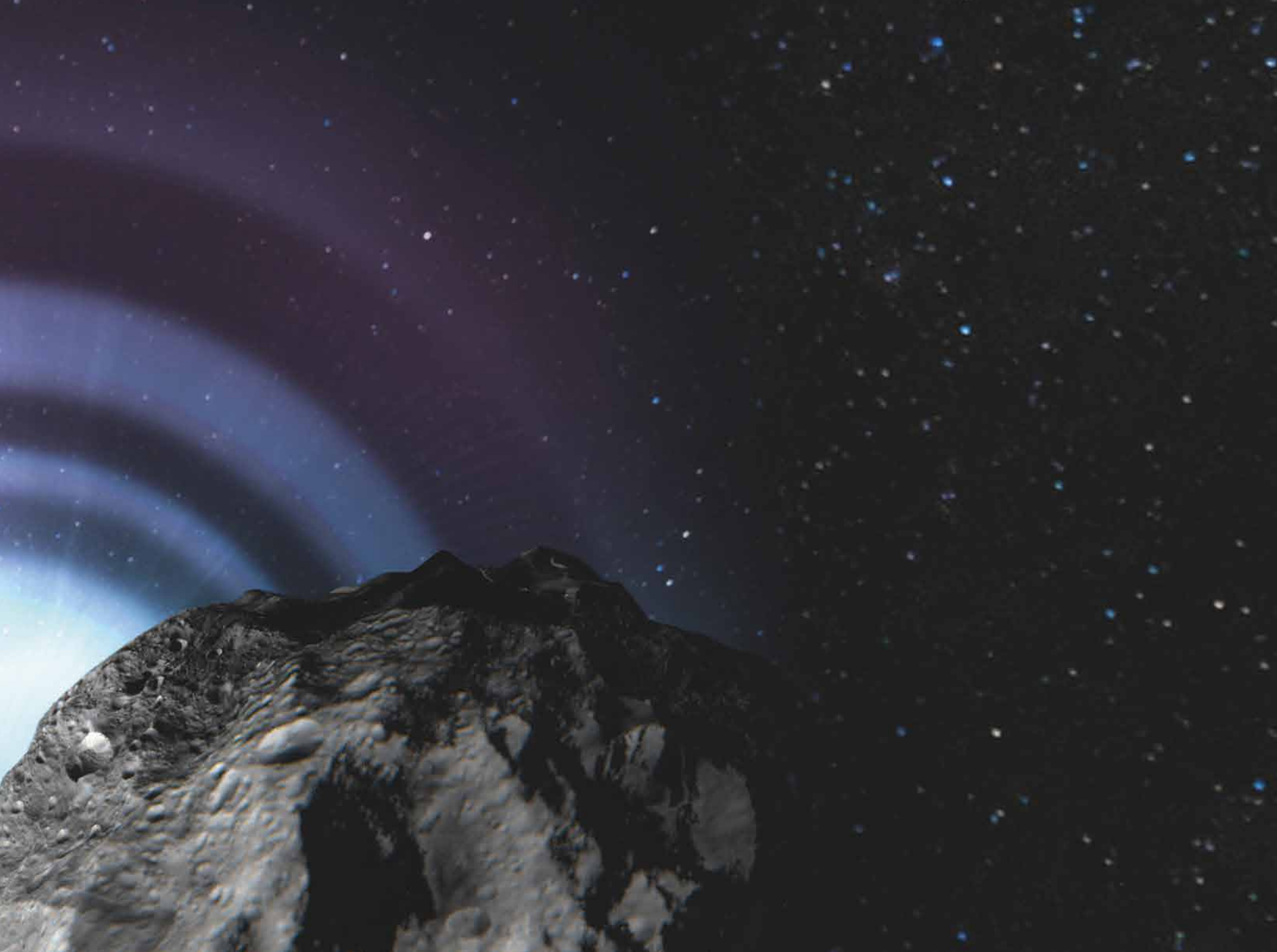
As the School Lab at DESY in Zeuthen was closed during the pandemic, the university students who usually teach the pupils in the lab produced videos to explain phenomena such as vacuum and air pressure. The videos are available for free on YouTube.



QR code for the YouTube videos of the DESY Zeuthen School Lab

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

Resolving extended emission from the jets of Centaurus A

First discovery of extended extragalactic object in very-high-energy gamma rays

The international H.E.S.S. collaboration, in which DESY is involved, has discovered that the very-high-energy gamma-ray emission from the jets of accreting black hole systems is not concentrated in the region close to their central black hole. Instead, the emission was found to extend over several thousand light years along the fast outflowing jets of plasma produced by the central black hole. The discovery shakes up current scenarios on the nature of this cosmic accelerator region.

Jets from accreting black holes

Galaxies with actively accreting nuclei often show collimated relativistic outflows (jets), which exhibit non-thermal photon emission. The radio emission originates from relativistic electrons in the magnetic fields (synchrotron) of the jet. The origin of the extended X-ray emission, however, is still a matter of debate, although in the case of the galaxy Centaurus A, the X-ray emission has been suggested to be synchrotron in origin. The other possible explanation is that it originates from inverse Compton (IC) scattering of cosmic microwave background (CMB) photons. Synchrotron radiation at X-ray energies needs ultrarelativistic electrons (~50 TeV) and, given the fast time scale of their energy loss, would require a continuous re-acceleration mechanism to be active. An IC scattering origin of the X-ray emission, on the other hand, does not require very energetic electrons, but needs jets that stay highly relativistic on large scales (1 Mpc) and that remain well aligned with the line of sight. Some recent evidence disfavours IC CMB models, although other evidence seems to be compatible with them. The detection of extended gamma-ray emission, directly probing the presence of ultrarelativistic electrons, can be used to distinguish between these two options. So far, however, instruments have been unable to resolve the relevant structures.

At a distance of 3.8 Mpc, Centaurus A is the closest known radio galaxy, offering a unique opportunity to better resolve the processes at play in the jets. Its small-scale radio morphology exhibits two inflated inner radio lobes extending to about 5 kpc from the nucleus. Along much of the length of the radio jet, from within 50 pc to 4 kpc, X-ray emission has been detected with the Chandra satellite. The source is also positionally close to a hotspot in the ultrahigh-energy cosmic-ray sky map.

H.E.S.S. observations and analysis

To probe a possible extension at very high gamma-ray energies (VHE, $E > 100$ GeV), a total of 202 hours of observations of Centaurus A between 2004 and 2016 with the High-Energy Stereoscopic System (H.E.S.S.) gamma-ray telescope array in Namibia were selected, corresponding to a high-quality data set suitable for probing a possible extension.

The point spread function (PSF) for the data set and configuration was simulated. It was convolved with different morphology models and fitted to the data. The different best-fit models were compared using the test statistic (TS) value as the figure of merit. In addition to the assumption of point-like emission, the data were also fitted using a radially symmetric Gaussian and an elliptical Gaussian model. Compared to a point-like source, the radially symmetric Gaussian was preferred with a TS of 6.1 and the elliptical Gaussian with a TS of 19.4. The considerable difference of the TS values implies a strong preference for the elliptical model over the radially symmetric model. The result obtained from the fitting is illustrated in Fig. 1. The physical extension of the semi-major axis of the best-fit elliptical Gaussian exceeds 2.2 kpc, implying that a major part of the VHE emission arises on large scales, far away from the black hole.

Modelling and interpretation

The derived alignment with the jet direction and the known spectral characteristics are in line with models where the VHE gamma-ray emission originates from IC upscattering of low-energy photons by very energetic electrons accelerated along the jet. Figure 2 shows a reproduction of the spectral energy distribution (SED) from radio to gamma-ray energies for jet scales close to 2.2 kpc. The IC emission on these scales is dominated by upscattering of infrared photons

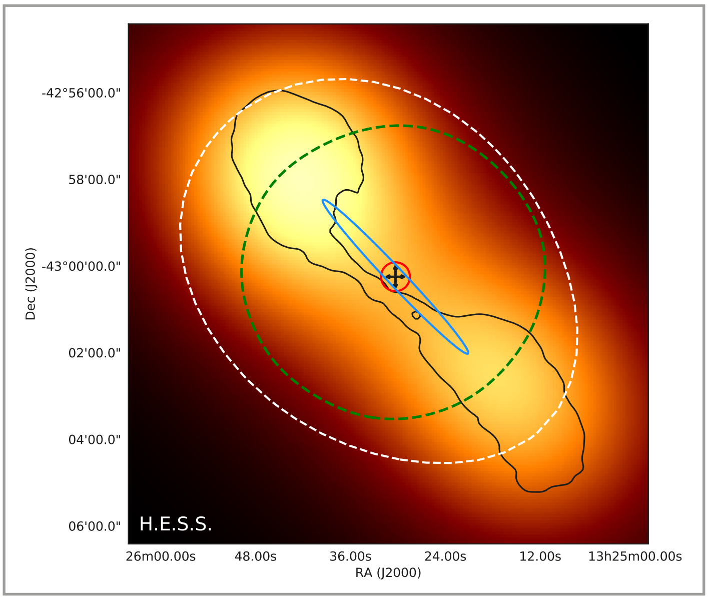


Figure 1

Multiwavelength image of the galaxy Centaurus A. The colour map represents the radio (21 cm) Very Large Array (VLA) map of Centaurus A after convolution with the H.E.S.S. PSF. Contours of the unconvolved VLA map, with levels adjusted to highlight the core (corresponding to 4 Jy/beam) as well as the kpc-scale jet (0.5 Jy/beam), are drawn in black. The VHE gamma-ray morphology of Centaurus A is represented by a white dashed contour, which is derived from the 5 excess significance level of the H.E.S.S. sky map. The result of the best fit of an elliptical Gaussian to the H.E.S.S. measurement is shown in blue. The dashed green line denotes the 68% containment contour of the H.E.S.S. PSF. From [1].

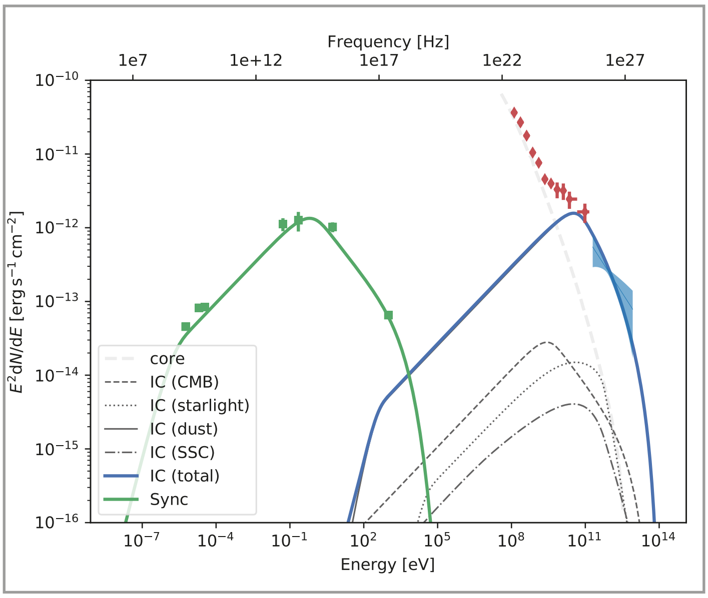


Figure 2

Observed and modelled spectral energy distribution from radio to gamma-ray energies for the inner, kpc-scale jet of Centaurus A. The green curve designates the synchrotron emission of the inferred broken-power-law electron distribution in a magnetic field of characteristic strength $B = 23$ μG. The blue butterfly corresponds to the H.E.S.S. spectra, while green data points mark radio, infrared and X-ray measurements and reported uncertainties from the inner region of the Centaurus A jet. A breakdown is provided of the full IC contribution. From [1].

emitted by dust, with the scattering occurring predominantly in the Thomson regime. Note that the considered large-scale model is not intended to reproduce the high-energy emission below a few GeV, as this part of the SED is usually attributed to emission from the core.

The observed VHE extension provides the first direct evidence for the presence of ultrarelativistic electrons with Lorentz factors of around 10^8 within an extragalactic large-scale jet. Assuming a synchrotron origin, the observed X-ray spectral slope translates into a photon index of around 2.4, which is close to that derived from Chandra observations (2.29 ± 0.05 and 2.44 ± 0.07 for the inner and middle region, respectively). The results thus substantiate the synchrotron interpretation of the X-ray emission seen in the large-scale jet of Centaurus A, which was originally motivated largely by similarities between the radio and X-ray morphologies. Given that the synchrotron lifetimes of these extremely energetic electrons can be as low as a few hundred years, i.e. considerably less than the travel time down the jet, which is on the order of thousands of years, the detection of extended X-ray emission on kpc scales related to synchrotron emission requires the existence of an efficient, extended or distributed (re-)acceleration mechanism far away from the black hole, such as stochastic or shear particle acceleration.

Interestingly, IC emission of the kpc-scale jet is found to make a major contribution to the unexpected spectral hardening seen in the high-energy gamma-ray emission of Centaurus A (Fig. 2). With its superior resolution and sensitivity, the next-generation Cherenkov Telescope Array (CTA) will, in a few years time, be able to probe deeper into the VHE extension and search for potential VHE variability that would impose constraints on the ratio of the extended gamma-ray flux to the one from the core region.

Contact:
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Reference:
[1] H. Abdalla et al., Nature 582, 356–359 (2020)

Multimessenger astronomy with AMPEL

Software for discoveries

Real-time multimessenger observations probe the most energetic, distant and rare phenomena in the universe, with recent discoveries ranging from the observation of the counterparts of the gravitational waves generated by the merger of two neutron stars to the identification of the first source of high-energy cosmic neutrinos – a bright gamma-ray blazar. The key data come in the form of real-time streams, which need to be analysed as the data arrive, and where new detections require quick and efficient dissemination to the scientific community. Researchers are currently faced with the challenge of how to harness the large and heterogeneous data streams generated by modern astronomical facilities, while at the same time adhering to the scientific principles of reproducibility and information sharing. DESY researchers, together with collaborators from Humboldt-Universität zu Berlin, have developed the AMPEL software platform to address these challenges [1]. An early version has already led to a wide range of important results.

AMPEL is designed to provide astronomers and astrophysicists with a framework in which complex real-time data streams can be processed without needing to compromise on either analysis power or transparency. AMPEL connects multi-messenger observatories in the FAIR way for the first time (i.e. the data meet the principles of findability, accessibility, interoperability and reusability). Its approach has already led to transformative research.

The AMPEL live instance is hosted at the DESY computer centre in Zeuthen, ingesting streams from the Zwicky Transient Facility (ZTF), the IceCube neutrino observatory and the LIGO/Virgo gravitational wave detectors. It serves a broad range of users, who are provided with a convenient framework to perform real-time analyses. FAIR data principles have guided the AMPEL development, which manifests in a system that consistently records real-time decisions and responses, while also allowing all decisions performed in real time to be reproduced at a later stage in the “offline” mode of the framework. Some early results include:

- Neutrino sources:
  AMPEL continuously searches for coincidences between signs of neutrinos hitting the IceCube detector embedded in the South Pole ice and optical light captured by the ZTF telescope in California, USA. This succeeded in 2019, when AMPEL connected a high-energy, cosmic muon neutrino (GCN 25913) with the disruption of a star close to a black hole [2]. This is only the second high-energy neutrino that could be traced to its source, and the first to this kind of rare event. In the meantime, a second such system has been identified through the AMPEL program.

- Gravitational wave sources:
  One of the most spectacular scientific successes in recent times is the detection of gravitational waves through the LIGO/Virgo detectors and the identification of a kilonova as an electromagnetic counterpart. AMPEL has now become a standard tool for subsequent searches for more counterparts, where gravitational wave signals are combined with other astronomical observation [3, 4] (Fig. 1).

- Autonomous detection of supernovae:
  Supernovae, i.e. stars exploding at the end of their life, are bright enough to be visible through most of the history of the universe, while allowing physicists to probe temperatures and densities not accessible in labs on Earth. AMPEL has pioneered the autonomous selection of such events and is making them immediately public to the community for possibly in-depth observation. About 1300 supernovae, or a third of discoveries worldwide, have so far been parsed in real time from more than 200 million alerts (Fig. 2). The AMPEL real-time reaction pipeline now regularly discovers supernovae mere hours after their explosion and triggers immediate follow-up through robotic telescope networks.

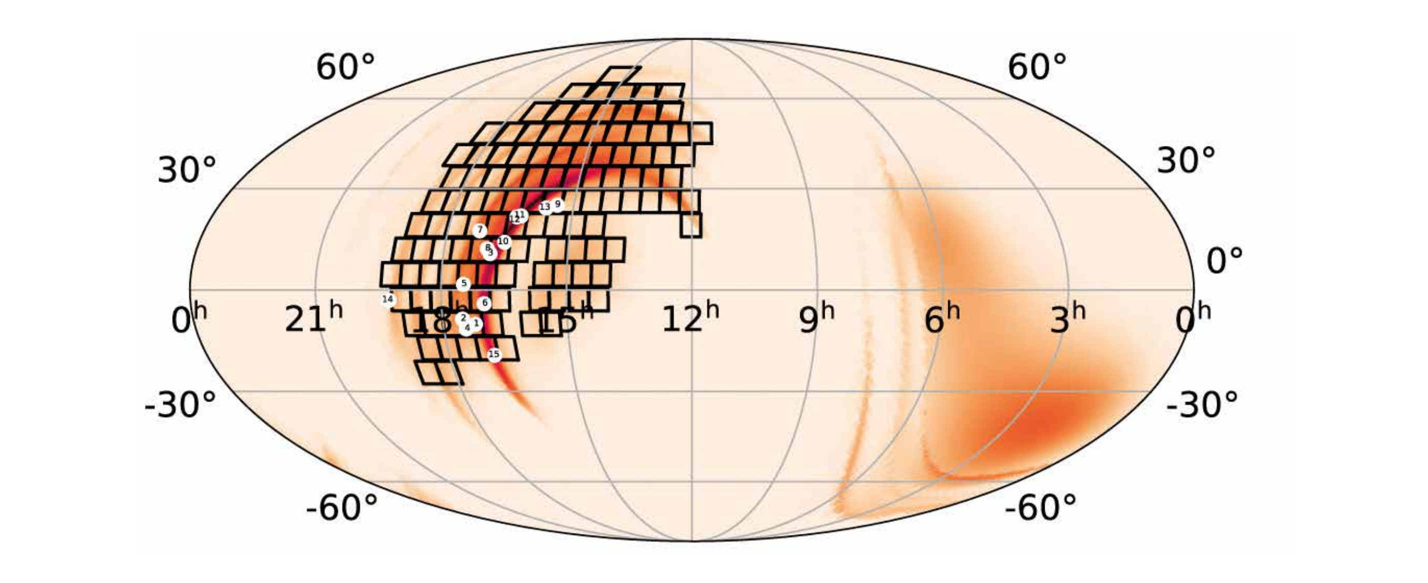

Figure 1

Coverage of the LIGO/Virgo gravitational wave event S190425z. The squares show the ~47 deg^2 ZTF tiling of the search area on the sky from which the gravitational wave signal is expected. No plausible counterpart was detected [3].

While these specific scientific results are at the forefront of research in astronomy and astrophysics, the long-term implication of AMPEL is even greater in terms of how science programs are carried out. The core innovation of AMPEL is the separation between the data infrastructure and the algorithms developed for scientific analysis. The first aspect requires expert know-how of reliable, high-performance software design, while the second entails in-depth knowledge of different aspects of physics and astronomical sciences. AMPEL creates an environment that combines these aspects into a full framework capable of processing data from large astronomical observatories.

The modularity and open access of AMPEL provide a way for other scientists to directly access and work with real-time data. This is true for multiple aspects of astronomy: Smaller telescope facilities can integrate their data with those of larger facilities, scientific software developers can publish their code as modules for general use, and observers can fine-tune selection filters. Theorists and modellers can use the offline AMPEL data archives to compare their ideas with the observed data sets. Current efforts are directed at making AMPEL more user-friendly and accessible, and hence broadening its user base.

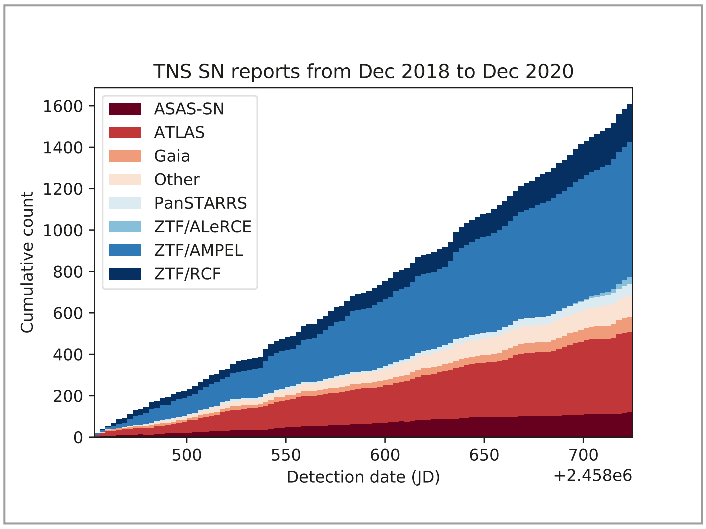

Figure 2

Since 2019, about 1300 supernovae, or a third of discoveries worldwide, have been submitted through AMPEL to the Transient Name Server (TNS, the official IAU mechanism for reporting new astronomical transients such as supernova candidates).

Contact:

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References:

[1] J. Nordin et al., Astron. Astrophys. 631, A147 (2019)
[2] R. Stein et al., Nat. Astron. (2021), arxiv:2005.05340 [astro-ph.HE]
[3] M. W. Coughlin et al., Astrophys. J. Lett. 885 1, L19 (2019)
[4] M. M. Kasliwal et al., Astrophys. J. 905 2, 145 (2020)

Preparing for the next big leap in neutrino astronomy

IceCube-Gen2 science White Paper published

The IceCube detector at the South Pole, in which DESY is strongly involved, was the first neutrino telescope to reach dimensions of 1 km^3, a size that is critical for the discovery of cosmic neutrinos. After 10 years of successful operation, the time has now come to plan the generation ahead. IceCube-Gen2 will feature an eight times larger optical sensor array than IceCube and a novel radio detector for neutrinos that will cover an area of nearly 500 km^2. In 2020, the IceCube-Gen2 collaboration published a summary of the capabilities and design of the new instrument. It will not only be able to detect five times fainter sources than IceCube, but also allow the collaboration to explore the cosmos for neutrinos with energies beyond 10^{18} eV, which can only originate from the interactions of highest-energy cosmic rays. Last but not least, it will also be a unique particle physics instrument capable of studying neutrino flavour mixing over baselines of gigaparsecs to hunt for physics beyond the Standard Model (BSM).

The IceCube-Gen2 observatory

To realise IceCube-Gen2 [1], the existing IceCube detector will be expanded through the installation of more than 10 000 newly designed optical sensors (IceCube has only about 5000!). They will be deployed in 120 new boreholes around IceCube, each 2.6 km deep. The new sensor design is closely based on the multipixel digital optical modules (mDOMs) developed in Germany and built at DESY for the IceCube Upgrade currently under way. They collect more than twice as much light as the IceCube sensors and will be arranged with a distance of 240 m (IceCube: 125 m) between the boreholes. In total, this will result in an eight times larger optical sensor array.

The new radio array targets the highest energies, where optical sensors would neither be cost-effective nor logistically possible. A single radio station can scan a volume for neutrinos that is comparable to the entire IceCube detector, albeit only for energies above around 100 PeV. The radio stations will have antennas on and 100 m below the surface to detect the radio waves from electromagnetic and hadronic particle showers produced in the ice by the ultrahigh-energy neutrinos.

Figure 1 shows an artist's impression of the new IceCube-Gen2 facility. Once construction starts, DESY will be a key player for the assembly and testing of the optical sensors as well as for the instrumentation and calibration of the radio array.

Science highlights

It is impossible to describe the science of such a large-scale facility in a short highlight article. As a small teaser, Fig. 2 shows the energy range and the precision of the measurement of the cosmic neutrino spectrum, in relation to the spectrum of cosmic rays and extragalactic gamma rays. Tens of neutrino sources are expected to be identified with the new instrument, directly or through multimessenger observations with new survey facilities that are currently being constructed, such as the Cherenkov Telescope Array (CTA), the Vera C. Rubin Observatory, or the Square Kilometre Array (SKA). Analysis of the flavour composition of the high-statistics cosmic neutrino "beam" allows tight constraints to be placed on astrophysical production environments, but also on BSM physics effects that the neutrinos encounter on their billion-year-long journey to Earth.

The full science programme is summarised in the recently published White Paper [2], a collective effort of the IceCube-Gen2 collaboration, led by DESY scientists.

From design to construction

While the full IceCube-Gen2 facility is presently only a vision, the IceCube Upgrade currently under way is already a critical step towards this long-term goal, enabling the test of new sensor technologies. IceCube-Gen2 is planned as a large international science facility under the leadership of the US National Science Foundation (NSF) with major contributions from Germany and Japan. After funding approval, construction of IceCube-Gen2 could start in 2024, with the final configuration reached in 2033.

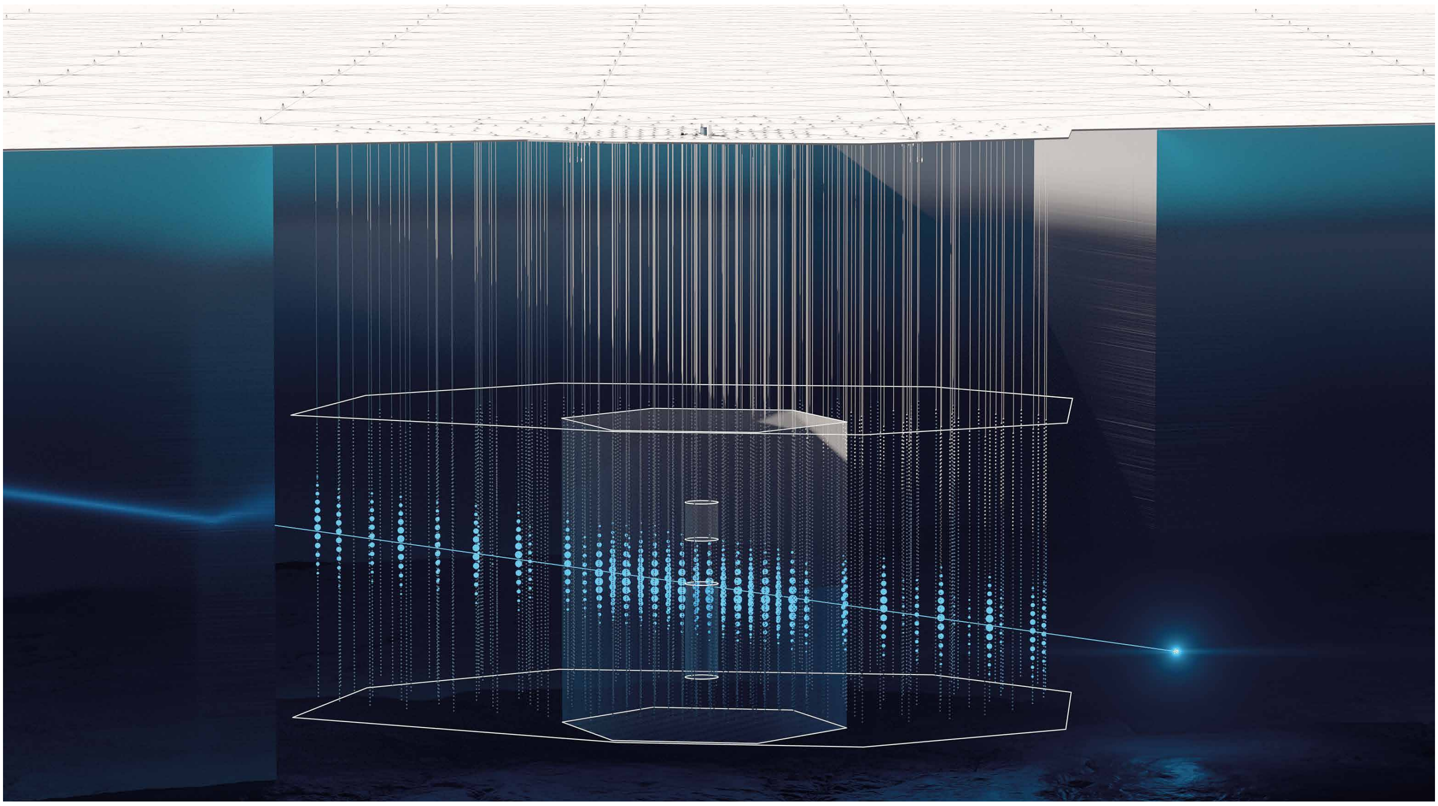

Figure 1

Artist's impression of the new IceCube-Gen2 observatory. The current IceCube detector is surrounded by the IceCube-Gen2 optical array. The radio stations visible on the surface stretch out over an area of 500 km².

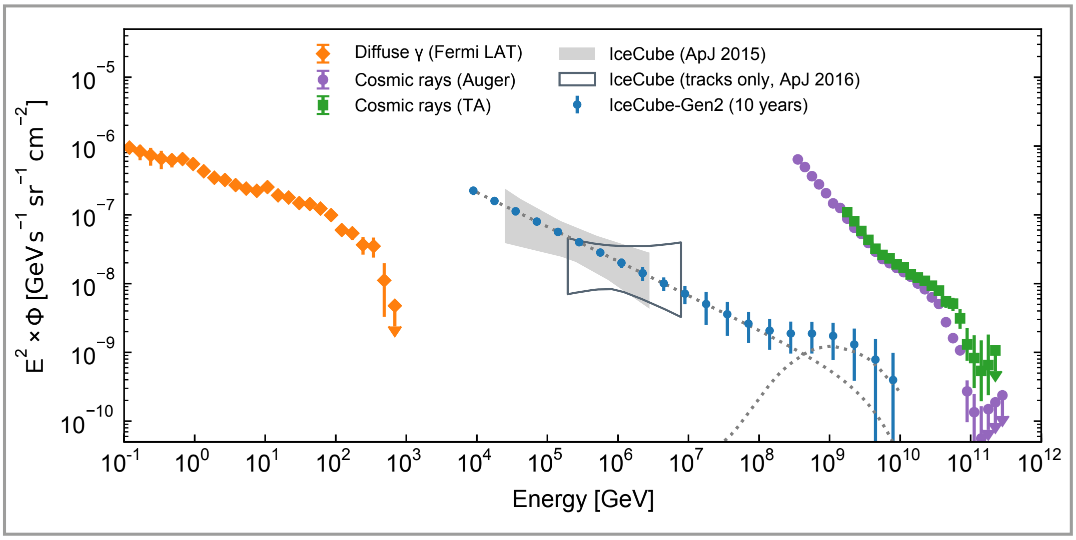

Figure 2

The blue data points indicate the expected energy range and precision of the measurement of the cosmic neutrino spectrum with IceCube-Gen2, in comparison to current IceCube results and in relation to the extragalactic gamma-ray and ultrahigh-energy cosmic-ray spectrum.

Contact:

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References:

[1] https://www.icecube-gen2.de

[2] M. G. Aartsen et al., J. Phys. G: Nucl. Part. Phys. 48, 060501 (2021)

Very intense and highly variable gamma-ray activity of a nearby blazar

Investigating short time scale electromagnetic explosions in blazars

Very-high-energy (VHE) gamma rays are among the highest-energy forms of electromagnetic radiation. They can originate in extreme astrophysical environments harbouring very powerful cosmic particle accelerators. The MAGIC gamma-ray telescopes on the island of La Palma, Spain, in which DESY is involved, have detected an extremely bright VHE gamma-ray outburst from a nearby blazar. The registered emission was the historically highest from this source since 2002. Moreover, the observed gamma rays were highly variable within very short time scales. The observations constrained the physical processes driving the radiation and acceleration of high-energy particles within this source.

Blazars as VHE gamma-ray emitters

Blazars are among the most powerful objects in our known universe. At the centre of these active galactic nuclei resides a supermassive black hole, with a billion times more mass than our sun. The black hole swallows the surrounding matter, which forms an accretion disk around it. Perpendicular to the black hole and the accretion disk, relativistic outflows of plasma are ejected, known as jets. In the case of blazars, these jets point towards Earth.

Blazar jets are among the most efficient particle accelerators in our universe. They can carry huge amounts of power to large distances, not only in the form of radiation but also as kinetic energy of matter and fields.

The origin of the highest-energy cosmic rays, which are mainly composed of protons, is one of the biggest unsolved mysteries in astrophysics. Whether blazar jets are efficient production factories of such high-energy protons is still being actively researched. Observing and interpreting a blazar's electromagnetic emission is of paramount importance in this respect. It can provide a wealth of information regarding the emission mechanisms, the nature of the emitting particles and the acceleration processes driving them.

The electromagnetic emission from blazars is mainly dominated by the non-thermal radiation from the jet. The radiation spans a broad range of frequencies from radio up to VHE gamma rays (with energies above 50 GeV). The origin of the high-energy radiation component is still a mystery. Moreover, blazars are highly variable objects, i.e. their electromagnetic radiation shows sudden episodes of increased brightness, popularly known as flares. The flares indicate an exceptional state of the source. If they are fast enough, they often carry information from the innermost regions of the jet lying close to the central black hole.

The MAGIC gamma-ray telescopes, located on the Canary Island of La Palma, Spain, are one of the key instruments observing the VHE gamma radiation from blazars. The observations are performed in two modes – the long-term monitoring mode lasting several months to years and the response to short-term flaring events from a particular source.

Exceptional gamma activity from a nearby blazar

1ES 1959+650 is a blazar closely monitored by the MAGIC telescopes. It is quite bright in VHE gamma rays and located nearby, thus providing an ideal target for a detailed investigation of blazar jets. This source is particularly interesting because it exhibited an "orphan" gamma-ray flare in 2002 – a huge increase in the VHE gamma-ray output without a simultaneous rise in any of the other frequencies. Such a behaviour is difficult to explain using the conventional framework, in which highly relativistic electrons are assumed to be the primary source of the overall photon output. Since then, a lot of curiosity has arisen to investigate whether the source could be a potential accelerator of high-energy cosmic rays.

In the summer of 2016, the MAGIC telescopes detected episodes of extreme flaring activities from 1ES 1959+650. A team of researchers from Japan, including DESY scientists, has been monitoring the evolution of the source since January 2016. In [1], the researchers provide a detailed characterisation of the source during its intense flaring activities in 2016.

The energy flux output of a VHE gamma-ray source is measured in terms of the flux from the Crab Nebula, which is a quite bright and stable source of gamma rays. In June 2016, the VHE gamma-ray flux from 1ES 1959+650 measured by MAGIC reached values as high as three times that of the Crab Nebula. The highest observed photon energy was measured to be around 10 TeV. The intense activity period

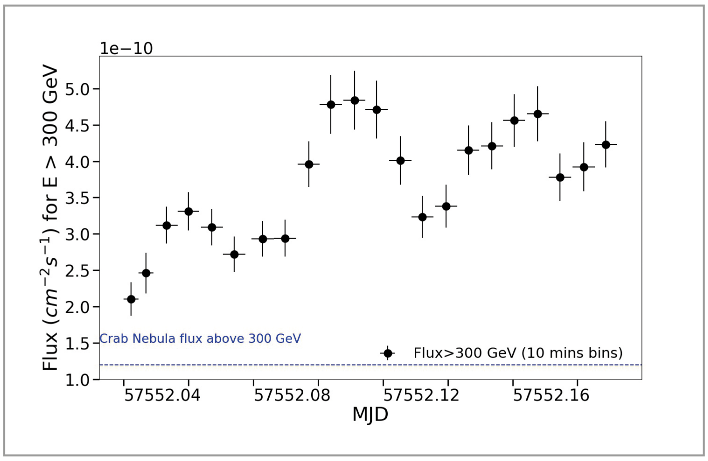

Figure 1

Fast, very high energy variability on sub-hour time scales of the blazar 1ES 1959+650, observed on 13 June 2016. The black data points indicate the flux above 300 GeV observed from the source with a 10 min time binning. The flux of the Crab Nebula above the same energy threshold is shown as the blue dotted line for comparison.

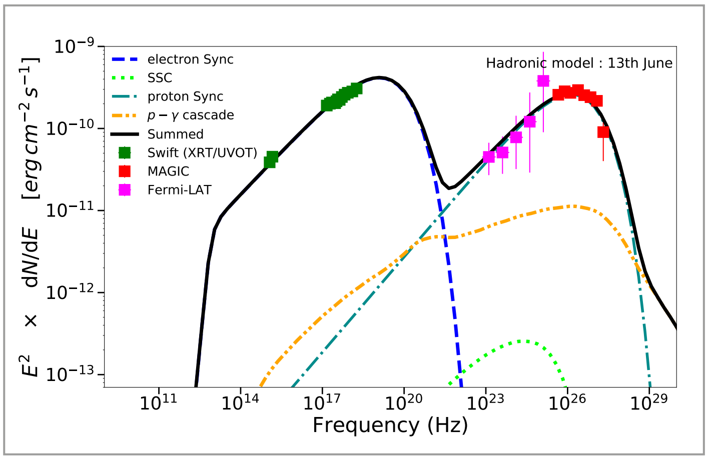

Figure 2

Spectral energy distribution of 1ES 1959+650 on 13 June 2016. The MAGIC (red squares) and Fermi-LAT (magenta squares) data fully characterise the high-energy electromagnetic component. This component could be explained by synchrotron radiation from relativistic protons (cyan dot-dashed line) accelerated to ultrahigh energies in a dense magnetic environment with high acceleration efficiency.

continued for two days on 13 and 14 June, followed by a similar activity on 1 July 2016. These observations represent the brightest state of 1ES 1959+650 in the last 18 years. Throughout the year 2016, the source showed a high rate of activity compared to its typical behaviour.

Interestingly, the flares on 13 June (Fig. 1) and 1 July 2016 showed a very fast variability. In their publication, the authors provide a detailed investigation of the variability properties of the source. The time scale of the fast variability was estimated to be less than an hour, indicating a rapid change in the gamma-ray flux of the source within short time scales. Thanks to the brightness of the flares, the flux variability could be resolved in such fine time bins with high precision.

The VHE gamma-ray data obtained by MAGIC was combined with data from multiple instruments covering a wide energy band, including the Large Area Telescope (LAT, high-energy gamma rays) on board the Fermi Gamma-ray Space Telescope and the instruments on board the Neil Gehrels Swift Observatory (X-ray and optical/ultraviolet). During the highest flaring episodes in June 2016, simultaneous data from all the measuring instruments were available. Such a simultaneous data set is crucial in order to gain a detailed understanding of the blazar's underlying quickly varying physical state.

Implications for the physical jet environment

The accumulated broadband data set showed that during the exceptional flaring activities, X-rays and VHE gamma rays dominated the overall electromagnetic output from the source, i.e. the broadband spectra peaked at these two energies.

The measured fast variability time scales indicate that the flaring activities could have originated from small compact regions in the inner part of the jet. The authors also investigate different possible frameworks that could explain the VHE gamma-ray emission, which extended up to energies of several TeV. Although the standard scenario of relativistic electrons giving rise to the gamma-ray output could not be ruled out, it was postulated that the origin of the gamma rays could also be attributed to an accelerated proton population (Fig. 2). This physically viable scenario could arise in the presence of dense magnetic field regions in the inner part of the jet, where protons could efficiently be accelerated to ultrahigh energies. In such dense magnetic environments, the accelerated protons can cool down sufficiently fast within short time scales compatible with the observed very high energy variability.

The observation of a high-energy neutrino from the direction of 1ES 1959+650 coincident in time with the observed electromagnetic flares would provide concrete evidence regarding the possibility of proton acceleration within the source. This is because neutrinos are unambiguous signatures of proton interactions, while gamma rays can originate from emission by both electrons and protons. The authors conclude that the level of neutrino emission expected from the source, even during its exceptional outburst state, falls below the sensitivity of the current generation of neutrino telescopes and hence cannot be measured directly. However, the potential of 1ES 1959+650 to accelerate protons to high energies still remains a physically plausible scenario, albeit open to tests by future generations of neutrino telescopes with improved sensitivity.

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Reference:

[1] V. A. Acciari et al., Astron. Astrophys. 638, A14 (2020)

Gamma-ray heartbeat powered by a microquasar

Discovery of a periodic gamma-ray signal from the microquasar SS 433

A team of scientists led by researchers from DESY have detected a mysterious gamma-ray heartbeat coming from a cosmic gas cloud. The inconspicuous cloud in the constellation Aquila beats to the rhythm of a neighbouring, precessing black hole, indicating a connection between the two objects, despite the large distance of around 100 light years between them. How the influence of the black hole can reach these distances remains a mystery.

The microquasar SS 433

Microquasars, the local siblings of the much larger extragalactic quasars, are binary systems comprising a black hole and a massive companion star. By accreting matter from their companions, microquasars launch powerful winds and jets into space, changing the interstellar environment around them. In such outflows, particles can attain relativistic velocities, which result in an increase of their energies to extreme values, up to more than TeV.

SS 433 [1] is a unique galactic microquasar containing a compact object, most probably a black hole of ~10–20 solar masses orbiting a supergiant star with about 30 times the mass of our sun. The two objects are orbiting each other with a period of 13 days, while the black hole sucks matter from the giant star. The material accumulates in an accretion disc and is shot out at high speed in two narrow jets, similar to those in active galaxies with much larger black holes in their centre. As SS 433 looks like a scaled-down version of quasars, it has been dubbed a microquasar.

Since the accretion disc does not lie exactly in the plane of the orbit of the two objects, the outflow precesses with a period of ~162 days, and the two jets spiral into the surrounding space.

Observations

The high-speed particles and the ultrastrong magnetic fields in the jet produce radio waves, X-rays and gamma rays [2, 3]. A detailed analysis from data obtained during more than 10 years with the Large Area Telescope (LAT) on board the Fermi Gamma-Ray Space Telescope resulted in an unexpected discovery: A gamma-ray signal [4] (dubbed Fermi J1913+051) in the GeV regime was found, located relatively far from the region that is believed to be affected by the microquasar. In an attempt to explore whether this excess was linked to SS 433, the research team investigated the time imprint of the gamma-ray emission, analysing the light curve or variation of the emission. The signal was found to be modulated with the same precession period displayed by the jets, suggesting a direct connection between the two phenomena. The precessional-phase light curve is shown in Fig. 2.

To investigate the origin of the gamma-ray source and the connection with the microquasar, the DESY researchers scrutinised multiwavelength images in radio waves and X-rays. Images obtained in the X-ray regime (0.9–2 keV band) with the ROSAT X-ray satellite revealed two clear helical patterns, which mirror at large scales the precession of the jets from SS 433. Fermi J1913+0515 is not located within the extrapolated jet cone, however, rendering a direct illumination of the region by the microquasar outflows difficult.

Furthermore, the large-scale gas residing in the region was analysed using the Galactic ALFA H I (GALFA) survey data from the 305 m telescope of the Arecibo Observatory: At the same distance to Earth than the microquasar (~4 kpc), an excess of atomic gas was found, coinciding with the gamma-ray source. The cloud, with a size of ~20 pc, has an average density of ~22 cm^{-3} and is not particularly prominent compared with other massive structures in our galaxy.

Interpretation

The large distance (~30 pc) and lack of clear physical connection between the gamma-ray source and the microquasar pose a significant interpretation challenge: What is the mechanism powering the GeV emission? How is this periodic signal generated?

The overlapping position of the gamma-ray source and the gas excess suggests a hadronic mechanism powering the gamma-ray emission. Protons accelerated in the central

Figure 1

Artistic representation of the emission of the microquasar SS 433, swaying and illuminating the gas cloud Fermi J1913+0515. The cloud, which is about 35 pc away from the black hole, pulsates with the same rhythm, indicating a direct connection.

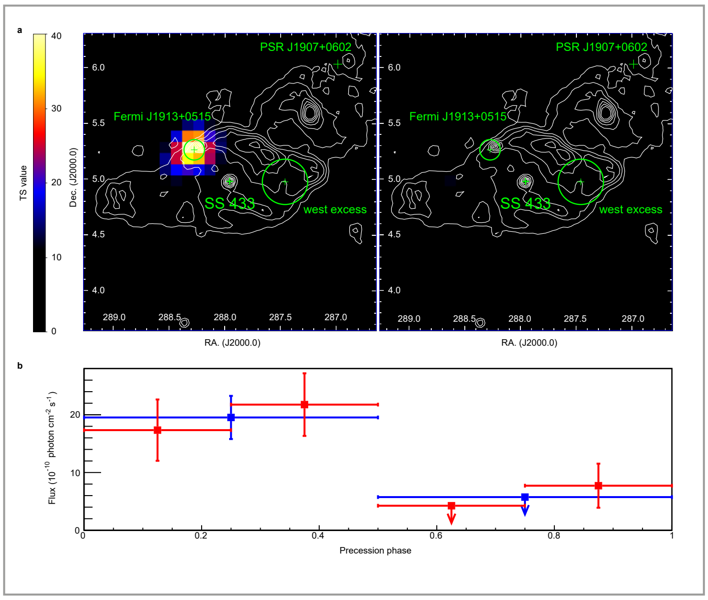

Figure 2

Analysis of Fermi-LAT data in precessional phases. a) Test statistic (TS) maps of the SS 433 region in the 1–300 GeV band for the precessional phases 0.0–0.5 (left) and 0.5–1.0 (right). The white contours show the radio continuum emission as measured by the Effelsberg telescope at 11 cm wavelength. The 95% confidence level circle of the positions of Fermi J1913+0515 and the west excess are shown in green. b) Precessional-phase light curve of Fermi J1913+0515 in the 1–300 GeV band for bin sizes of 0.5 (blue) and 0.25 (red). The vertical error bars indicate the 68% credible interval, and the upper limits are at the 95% confidence level. Image from [4].

region of the microquasar or at its outflows (jets or the equatorial outflow recently characterised by the NuSTAR X-ray telescope [5]) can diffuse from their injection point and produce hadronic gamma rays when encountering appropriate targets. Energetically, this scenario can easily account for the observed radiation (~3 x 10^{34} erg/s), but the expected times can hardly explain the periodicity. Even assuming a periodic, impulsive injection of cosmic rays containing most of the jet energy released in a single period, these injections would not be energetically relevant individually, providing a cosmic-ray density that is smaller than the cosmic-ray background in our galaxy.

Direct periodic illumination of the cloud region by the eastern jet also seems unlikely. On the one hand, the coherence of the radio jet seems to be sustained on the arcsecond scale only. Simulations confirm that the jet loses the helical morphology after a few precession cycles, due to the interaction with the surrounding medium. On the other hand, the location of Fermi J1913+0515 away from the jet cone disfavours this idea, unless there is a larger, so far unobserved cone.

Future observations with the satellite-based eROSITA X-ray telescope and with high-energy gamma-ray observatories such as the Cherenkov Telescope Array (CTA) should reveal further pieces of the puzzle. The game is still ongoing, and SS 433 continues to amaze observers and theorists alike at all frequencies. It will certainly provide a test bed for our ideas on cosmic-ray production and propagation near microquasars for years to come.

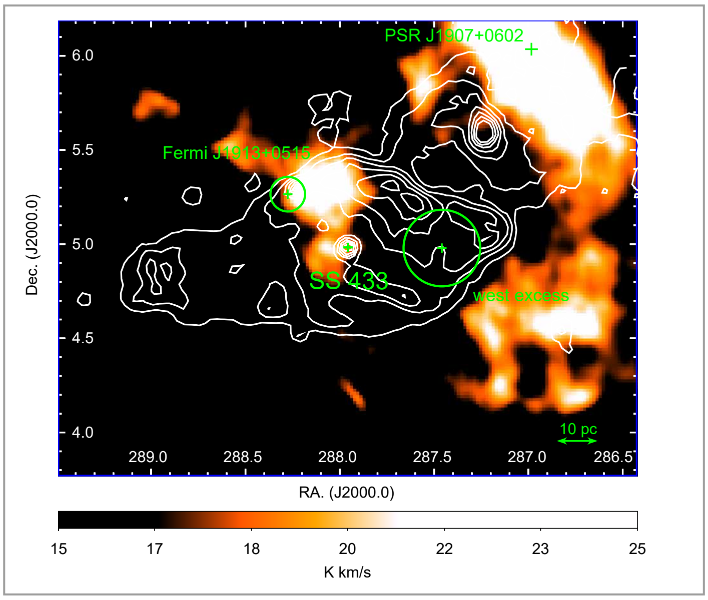

Figure 3

Map of the hydrogen 21 cm (H I) line emission as measured by the Arecibo Observatory, integrated in the interval 65–82 km/s (colour scale). The contours and labels are as in Fig. 2. Image from [4].

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References:

[1] S. Fabrika et al., Astrophys. Space Phys. Rev. 12, 1 (2004)
[2] G. M. Dubner et al., Astron. J. 116, 1842 (1998)
[3] S. Safi-Harb et al., Astrophys. J. 483, 868–881 (1997)
[4] J. Li et al., Nat. Astron. V. 4, 1177 (2020)
[5] M. J. Middleton et al., preprint, arXiv:1810.10518 [astro-ph.HE] (2018)

CTA prototype telescopes

Big steps towards a major new science facility

The installation and operation of prototypes for the next-generation gamma-ray observatory, the Cherenkov Telescope Array (CTA), are crucial steps towards the construction of this novel instrument. Prototype telescopes, many with significant contributions by DESY, are successfully demonstrating the technical concept of CTA and the feasibility of building large arrays of telescopes in remote environments. The astronomical standard candle of the field, the Crab Nebula – a pulsar wind nebula powered by a rotating neutron star – has been detected by three prototype installations, while the DESY-led mid-sized telescope successfully measured Cherenkov light from air showers in Berlin.

The Cherenkov Telescope Array

The next-generation gamma-ray observatory CTA will improve sensitivity by up to one order of magnitude over the current generation of imaging air Cherenkov telescopes (IACTs). CTA, built with worldwide contributions under the leadership of the CTA Observatory, will be able to observe celestial gamma-ray sources from a northern site located on the island of La Palma, Spain, and a southern array located near Paranal, Chile. CTA will be sensitive to gamma rays over an energy range from 20 GeV to beyond 300 TeV. This wide energy range, unreached by any previous instrument, requires the deployment of telescopes of different sizes, from gigantic large-sized telescopes (LSTs) with a mirror diameter of 23 m over 12 m mid-sized telescopes (MSTs) to small-sized telescopes (SSTs) with roughly 4 m mirror diameter. CTA will consist of at least nine telescopes on La Palma and at least 40 telescopes in Chile. Building and operating the telescopes in these remote environments is challenging and requires extensive prototyping.

Large-sized telescopes

The LST prototype is the first CTA telescope built on the Roque de los Muchachos, CTA's northern site on La Palma. The prototype has been in operation since early 2020, and all technical requirements, especially regarding the optical image capabilities and the performance of the sophisticated trigger to suppress night sky background light, have been met. During the commissioning runs, the LST prototype detected several gamma-ray sources, including the Crab Nebula [1]. Measurements of pulsed gamma-ray emission from the pulsar located inside the Crab Nebula and from the Geminga pulsar during several engineering runs demonstrated the detection power of the LST concept.

The LST prototype is regularly operated together with the nearby MAGIC gamma-ray telescopes, allowing for a detailed characterisation of its performance. The production of the components for the additional three LSTs to be built on La Palma is ongoing.

Small-sized telescopes

Extensive air showers at the highest energies – above several TeV – emit a large amount of Cherenkov light, so much smaller telescopes are sufficient to measure them. An SST prototype was successfully operated on the slopes of Mount Etna in Sicily and detected gamma rays from the Crab Nebula at energies above several TeV [2]. The SST camera, equipped with 2048 silicon photomultiplier pixels, allows Cherenkov light from air showers to be captured in hundreds of frames, each lasting one billionth of a second. The successful prototyping and the smooth integration of the telescope structure, camera and auxiliary instruments are important milestones for the deployment of up to 50 SSTs at CTA's southern site in Chile.

Mid-sized telescopes

The energy range between 100 GeV and tens of TeV is covered by an array of MSTs, with a telescope structure developed under the leadership of DESY. The MST prototype in Berlin-Adlershof demonstrated the mechanical and optical capabilities of the concept, and air showers were measured with two different camera designs installed temporarily on the prototype (Fig. 1, see also annual report *DESY Astroparticle Physics 2019*, [3]). The first MSTs on the CTA site on La Palma will be assembled starting in mid-2022, so as to complete the CTA northern array of four LSTs and at least five MSTs by 2024.

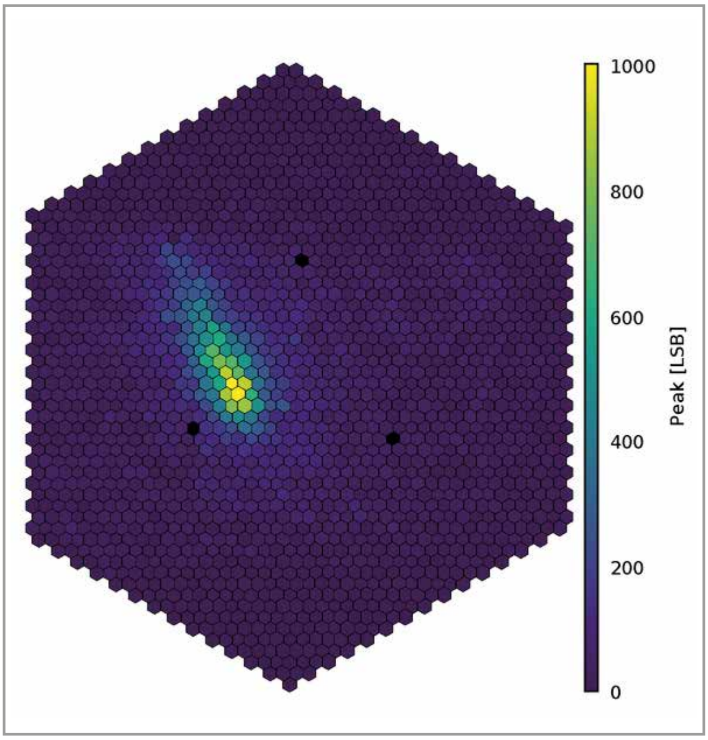

Figure 1

First measurements of Cherenkov light from extensive air showers with the MST prototype in Berlin-Adlershof and the FlashCam camera system [1]. Each hexagon depicts a photomultiplier. The colour scale indicates the measured brightness of the air shower. Exposure time in this image is roughly 10 ns.

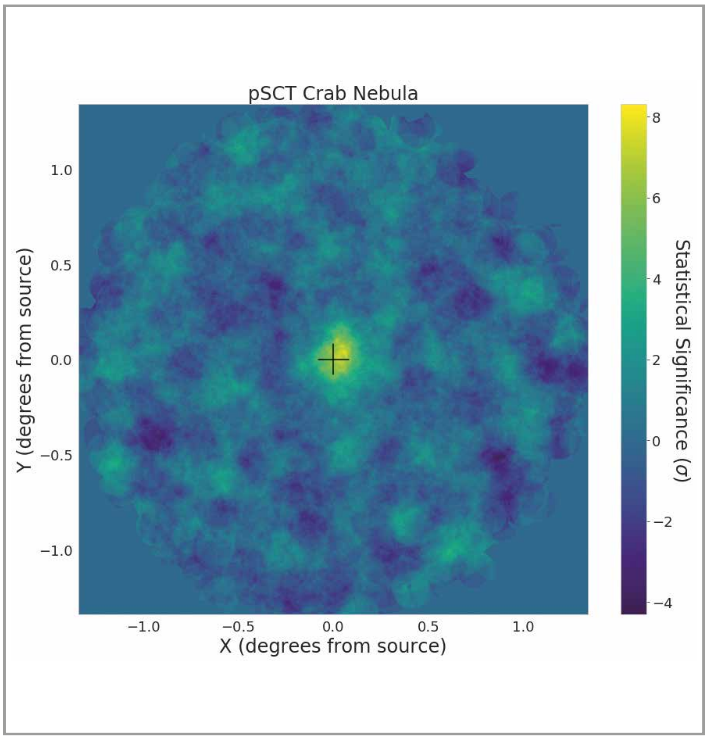

Figure 2

Sky map recorded with the pSCT over a region centred on the Crab Nebula, with the detection of the Crab Nebula marked at the centre

The prototype Schwarzschild–Couder Telescope (pSCT) establishes a new technology that allows gamma rays to be measured with extraordinary precision. The pSCT, a dual-mirror MST candidate equipped with a 9.7 m primary mirror and a secondary smaller mirror, uses the same positioner and drive technology that DESY developed for the MSTs. The prototype is operated next to the VERITAS gamma-ray telescopes at the Fred Lawrence Whipple Observatory in Arizona, USA. The detection of the Crab Nebula in early 2020, a first for such a large dual-mirror installation, established this novel design (Fig. 2) and can be seen as a breakthrough for future installation [4]. The SCT optics provides improved optical quality over a larger field of view in the sky and allows the use of a compact camera equipped with highly efficient photo sensors.

In summary, the prototype installations have demonstrated the maturity of the design of all the CTA telescope types. The focus in 2021 will be on the development of the necessary infrastructure at both sites and the installation of the first telescopes. CTA is expected to be fully operational in 2025.

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References:

[1] https://www.mpi-hd.mpg.de/mpi/de/nachrichten/nachricht/mit-flashcam-bestuecktes-teleskop-sieht-erstmals-tscherenkow-licht-aus-der-atmosphaere
[2] https://www.cta-observatory.org/lst1-detects-vhe-emission-from-crab-pulsar/
[3] https://www.cta-observatory.org/chec-achieves-first-light-on-astri/
[4] https://www.cta-observatory.org/mst-prototype-records-first-light/

How do driving mechanisms change turbulence properties and cosmic-ray transport?

Deciphering plasma mode composition with simulations and observations

Turbulence is ubiquitous in astrophysical plasmas, owing to their vast size span and the resulting huge Reynolds numbers. The diversity of driving mechanisms and the multiphase nature of astrophysical environments naturally lead to spatial variations of the turbulence properties. Scientists from DESY and the University of Potsdam, Germany, have developed a novel method, called signature from polarisation analysis (SPA), for unveiling the plasma modes in interstellar turbulence. The application of SPA to synchrotron polarisation data from the galactic medium has revealed for the first time that interstellar turbulence is magnetised according to the different compositions of the plasma modes. Our results pinpoint the necessity to account for the plasma property of turbulence, which is neither hydrodynamic nor purely Alfvénic, but depends on local physical conditions, particularly the process driving the turbulence.

Composition of turbulence depends on driving

Astrophysical turbulence is often assumed to be only Alfvénic, or even hydrodynamic. Our theoretical and observational studies invalidate these assumptions. In many earlier studies, turbulence was driven only by incompressible forcing. Employing turbulence driven by generalised forcing [1], we found that the proportion of magnetosonic fast and slow modes in the mode mixture increases with increasing compressive forcing (Fig. 1). We found a transition from weak to strong Alfvénic turbulence in the low Alfvén Mach number (M_A) regime. On the other hand, the fast mode did not show any transition from the trans-Alfvenic to the sub-Alfvénic regime. We also verified the isotropic nature of fast modes. Our numerical study identified the conditions under which magnetosonic modes can be substantial, including the regime of weak turbulence.

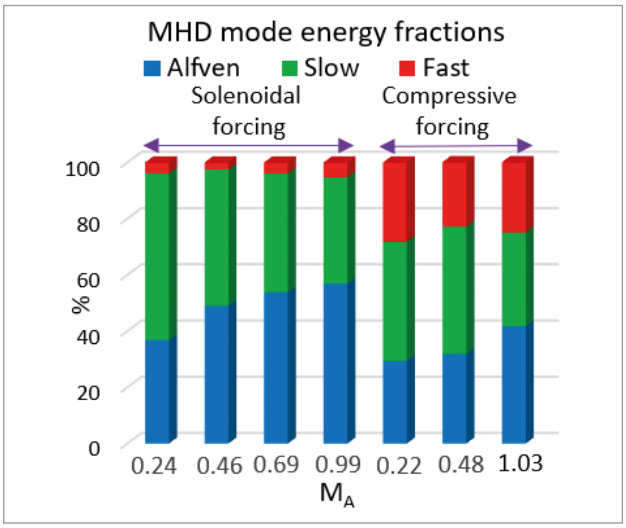

Figure 1

The composition of magnetohydrodynamic (MHD) turbulence depends on driving [1].

SPA reveals plasma mode information of turbulence

Using the novel SPA method, we observed the composition of plasma modes in the interstellar medium [2]. SPA links the synchrotron polarisation properties to different plasma modes (Fig. 2). In the study, the diagnosis routine was established by combining analytical derivations and extensive numerical simulations of synthetic polarisation signals from turbulent magnetic data cubes in different regimes. The SPA method was then applied to the observational data of the Urumqi 6 cm polarisation survey of the galactic disk at 6 cm wavelength. We analysed the polarisation data from the Cygnus X region and a region near the Rosette Nebula, known for massive star formation and supernova remnants in our galaxy [3]. We found various plasma modes in these regions, with different dispersion relations and characteristics. This discovery clearly points out the diversity of interstellar turbulence caused by the differences in turbulence driving mechanisms and local environments [1], invalidating the single-mode assumption commonly made in studies involving astrophysical turbulence.

Cygnus X gamma-ray cocoon and turbulence plasma properties

More excitingly, we found a high degree of consistency between the magnetosonic modes we detected and the Cygnus X gamma-ray cocoon (Fig. 3), a region of intense gamma-ray emission, detected by the Large Area Telescope (LAT) on board the Fermi Gamma-Ray Space Telescope, whose origin has been a matter of debate. The unveiled consistency points to the key role of magnetosonic turbulence in cosmic-ray transport, perfectly in line with our earlier theoretical prediction [4] based on the modern understanding of magnetohydrodynamic turbulence [5, 6].

The application of SPA to synchrotron polarisation data from the galactic medium has thus revealed for the first time that

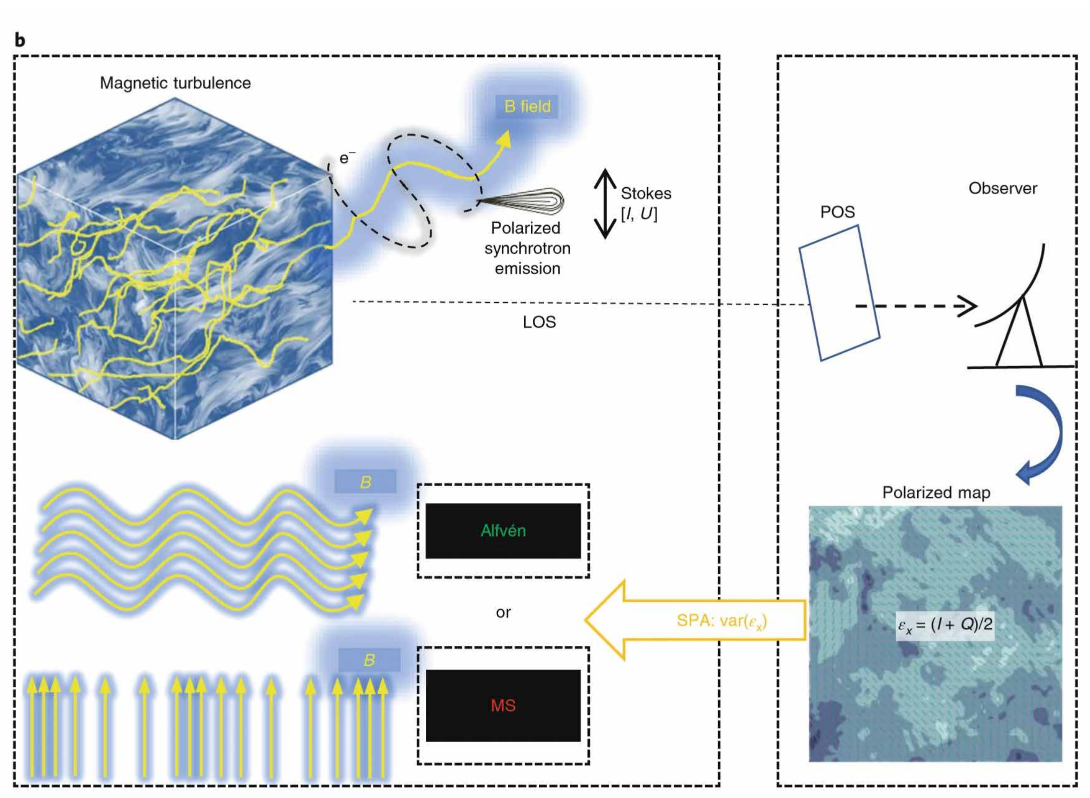

Figure 2

Schematics for SPA analysis of radio observational data. Relativistic electrons produce polarised synchrotron emission, which exhibits the statistics of the turbulent magnetic field embedded in the medium [2].

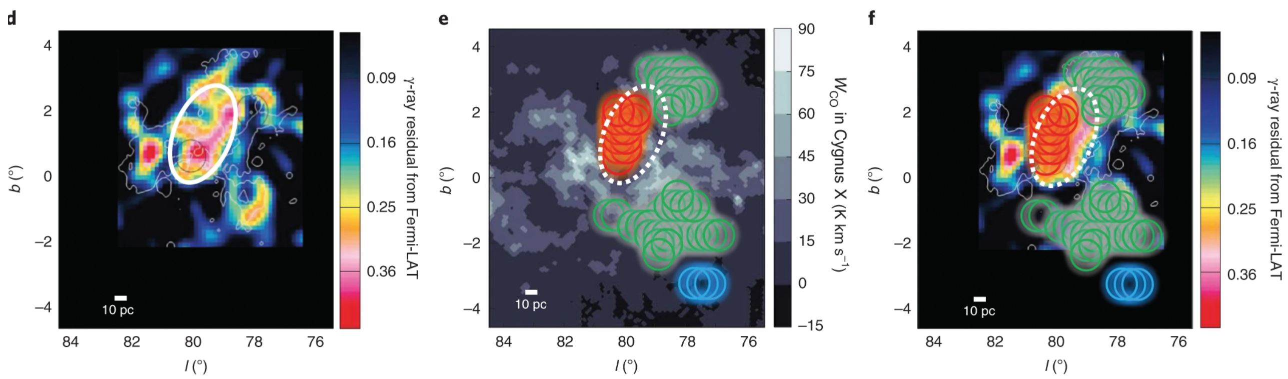

Figure 3

Turbulence modes identified in the Cygnus X region plotted over the Fermi-LAT gamma-ray map. Green: Alfvénic, red: magnetosonic, blue: isotropic turbulence. The distance of the object is 1.4 kpc. The radius of the eddy is ~15 pc [2].

interstellar turbulence is magnetised according to the different compositions of the plasma modes, pinpointing the necessity to account for the plasma property of turbulence. These results have important implications for relevant astrophysical processes, such as cosmic-ray physics and star formation. A highly promising research field is foreseen to unfold, with ample results anticipated from the advanced analysis of high-resolution synchrotron polarisation data and multiple-wavelength comparison, which will shed light on the role of turbulence in various physical processes.

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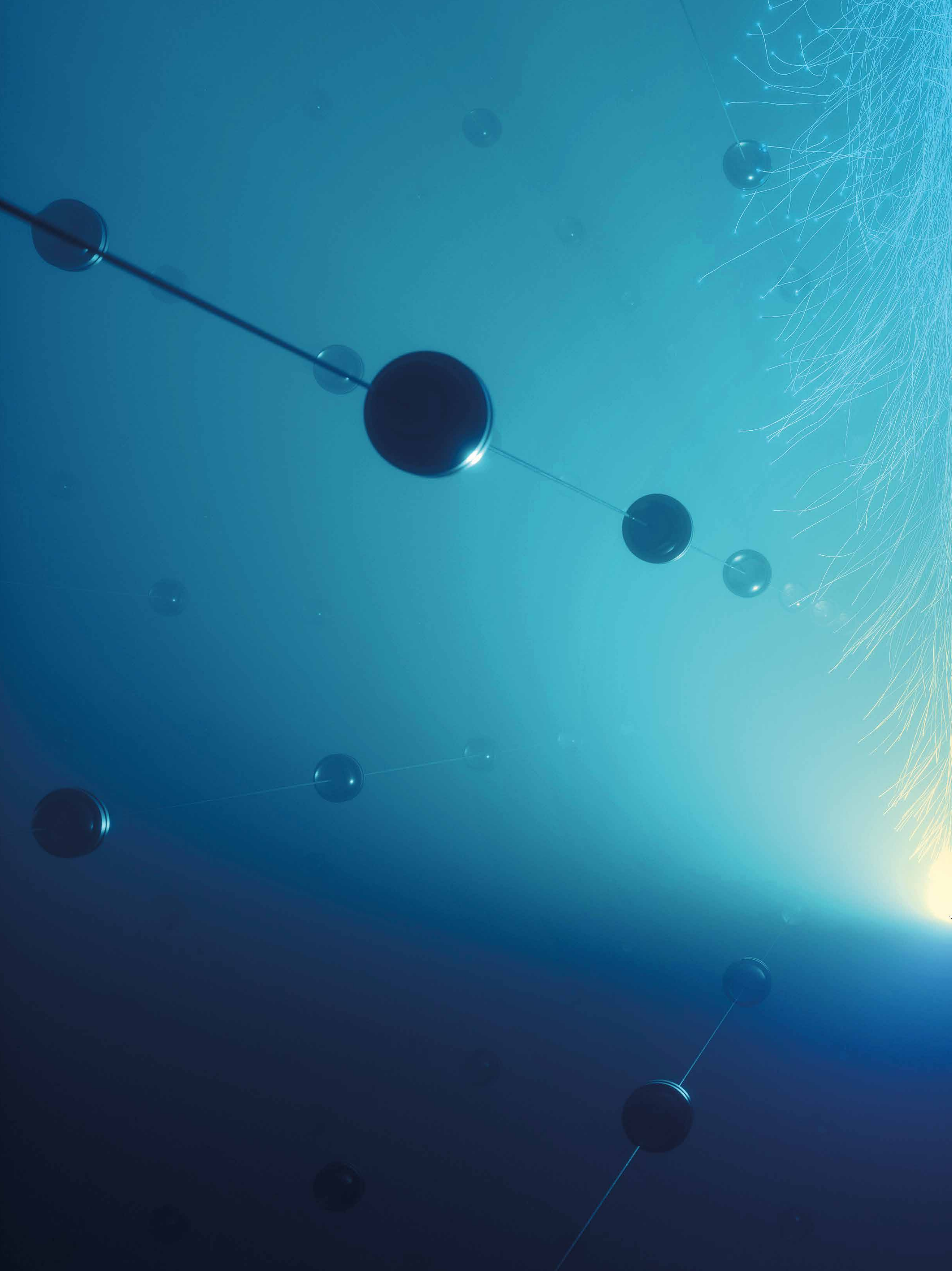
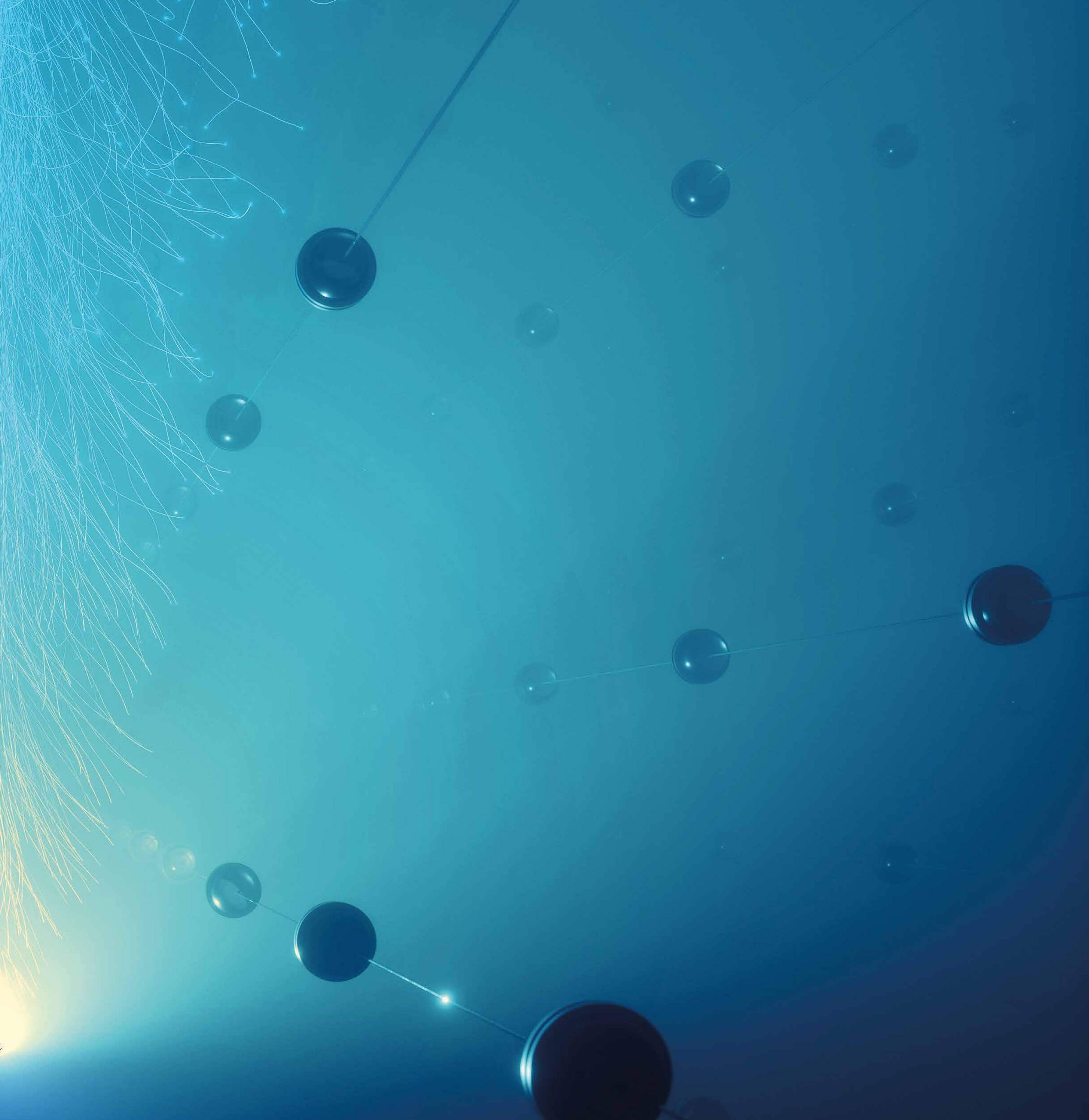
References:

[1] K. D. Makwana and H. Yan, Phys. Rev. X 10, 031021 (2020)
[2] H. Zhang et al., Nat. Astron. 4, 1001–1008 (2020)
[3] I. M. Beerer et al., Astrophys. J 720, 679 (2010)
[4] H. Yan and A. Lazarian, Astrophys. J 614, 757 (2004)
[5] P. Goldreich and S. Sridhar, Astrophys. J 438, 763 (1995)
[6] J. Cho and A. Lazarian, MNRAS 345, 325 (2003)





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doi: 10.3847/1538-4365/ab6bcb.

A. U. Abeysekara et al.
Demonstration of stellar intensity interferometry with the four VERITAS telescopes.
Nature astronomy, 4(12):1164, and PUBDB-2021-00147, arXiv:2007.10295.
doi: 10.1038/s41550-020-1143-y.

A. U. Abeysekara et al.
Evidence for proton acceleration up to TeV energies based on VERITAS and Fermi-LAT observations of the Cas A SNR.
The astrophysical journal, 894(1):1, and PUBDB-2020-02987, arXiv:2003.13615.
doi: 10.3847/1538-4357/ab8310.

A. U. Abeysekara et al.
The Great Markarian 421 Flare of February 2010: Multi-wavelength variability and correlation studies.
The astrophysical journal, 890(2):97 (1, and PUBDB-2020-04500, arXiv:2002.03567.
doi: 10.3847/1538-4357/ab6612.

V. A. Acciari et al.
Monitoring of the radio galaxy M 87 during a low-emission state from 2012 to 2015 with MAGIC.
Monthly notices of the Royal Astronomical Society, 492(4):5354, and PUBDB-2020-04794, arXiv:2001.01643.
doi: 10.1093/mnras/staa014.

V. A. Acciari et al.
New Hard-TeV Extreme Blazars Detected with the MAGIC Telescopes.
The astrophysical journal / Supplement series, 247(1):16, and PUBDB-2020-01399, arXiv:1911.06680.
doi: 10.3847/1538-4365/ab5b98.

M. Ajello et al.
Fermi and Swift Observations of GRB 190114C: Tracing the Evolution of High-Energy Emission from Prompt to Afterglow.
The astrophysical journal, 890(1):9, and PUBDB-2020-04014, arXiv:1909.10605.
doi: 10.3847/1538-4357/ab5b05.

M. Ajello et al.
The γ-ray Emission of Star-Forming Galaxies.
The astrophysical journal, 894(2):1, and PUBDB-2020-02970, arXiv:2003.05493.
doi: 10.3847/1538-4357/ab86a6.

S. Anand et al.
Optical follow-up of the neutron star-black hole mergers S200105ae and S200115j.
Nature astronomy, 387:38, and PUBDB-2020-04537, arXiv:2009.07210.
doi: 10.1038/s41550-020-1183-3.

ANTARES Collaboration and IceCube Collaboration.
ANTARES and IceCube Combined Search for Neutrino Point-like and Extended Sources in the Southern Sky.
The astrophysical journal, 892(2):92, and PUBDB-2020-03253, arXiv:2001.04412.
doi: 10.3847/1538-4357/ab7afb.

ANTARES Collaboration and IceCube Collaboration and LIGO Scientific Collaboration and VIRGO Collaboration.
Search for Multi-messenger Sources of Gravitational Waves and High-energy Neutrinos with Advanced LIGO during its first Observing Run, ANTARES and IceCube.
The astrophysical journal, 870(2):1, and PUBDB-2020-04065.
doi: 10.3847/1538-4357/aaf21d.

A. Archer et al.
Probing the Properties of the Pulsar Wind in the Gamma-Ray Binary HESS J0632+057 with NuSTAR and VERITAS Observations.
The astrophysical journal / 1, 888(2):115, and PUBDB-2020-00349, arXiv:1911.09434.
doi: 10.3847/1538-4357/ab59de.

A. Archer et al.
VERITAS Discovery of VHE Emission from the Radio Galaxy 3C 264: A Multi-Wavelength Study.
The astrophysical journal, 896(1):41, and PUBDB-2020-02515, arXiv:2005.03110.
doi: 10.3847/1538-4357/ab910e.

ARIANNA Collaboration.
A search for cosmogenic neutrinos with the ARIANNA test bed using 4.5 years of data.
Journal of cosmology and astroparticle physics, 2020(03):053, and PUBDB-2020-04167, arXiv:1909.00840.
doi: 10.1088/1475-7516/2020/03/053.

ARIANNA Collaboration.
Probing the angular and polarization reconstruction of the ARIANNA detector at the South Pole.
Journal of Instrumentation, 15(09):P09039, and PUBDB-2020-04029, arXiv:2006.03027.
doi: 10.1088/1748-0221/15/09/P09039.

T. Ashton et al.
A NECTAr-based upgrade for the Cherenkov cameras of the H.E.S.S. 12-meter telescopes.
Astroparticle physics, 118:102425, and PUBDB-2020-00672, arXiv:2001.04510.
doi: 10.1016/j.astropartphys.2019.102425.

I. Astapov et al.
An approach for identification of ultrahigh energy extensive air showers with scintillation detectors at TAIGA experiment.
09. International Conference on Instrumentation for Colliding Beam Physics, Novosibirsk (Russian Federation), 24 Feb 2020 - 28 Feb 2020.
Journal of Instrumentation, vol. 1509:C09037, and PUBDB-2021-00179.
Inst. of Physics, London.
doi: 10.1088/1748-0221/15/09/C09037.

D. Baumann et al.
Gravitational Collider Physics.
Physical review / D, 101(8):083019, and PUBDB-2020-01596, arXiv:1912.04932. DESY-19-221.
doi: 10.1103/PhysRevD.101.083019.

M. Bhatt et al.
Production of secondary particles in heavy nuclei interactions in supernova remnants.
Astroparticle physics, 123:102490, and PUBDB-2020-04604, arXiv:2006.07018.
doi: 10.1016/j.astropartphys.2020.102490.

J. Biteau et al.
Progress in unveiling extreme particle acceleration in persistent astrophysical jets.
Nature astronomy, 4(2):124, and PUBDB-2020-00840, arXiv:2001.09222.
doi: 10.1038/s41550-019-0988-4.

A. Bohdan et al.
Kinetic Simulation of Nonrelativistic Perpendicular Shocks of Young Supernova Remnants. IV. Electron Heating.
The astrophysical journal / 1, 904(1):12, and PUBDB-2020-04605, DESY 20-136. arXiv:2008.05920.
doi: 10.3847/1538-4357/abbc19.

A. Borodin et al.
Imaging Atmospheric Cherenkov Telescope for the TAIGA Observatory—JINR Participation.
Physics of atomic nuclei, 83(2):268, and PUBDB-2020-03245.
doi: 10.1134/S1063778820020076.

J. W. Broderick et al.
LOFAR 144-MHz follow-up observations of GW170817.
Monthly notices of the Royal Astronomical Society, 494(4):5110, and PUBDB-2020-02149, arXiv:2004.01726.
doi: 10.1093/mnras/staa950.

R. Brose et al.
Cosmic-ray acceleration and escape from post-adiabatic supernova remnants.
Astronomy and astrophysics, 634:A59, and PUBDB-2020-01392, arXiv:1909.08484.
doi: 10.1051/0004-6361/201936567.

N. Budnev et al.
TAIGA—A hybrid array for high-energy gamma astronomy and cosmic-ray physics.
15th Vienna Conference on Instrumentation, Vienna (Austria), 18 Feb 2019 - 22 Feb 2019.
Nuclear instruments & methods in physics research / A, vol. 958:162113, and PUBDB-2021-00171.
North-Holland Publ. Co., Amsterdam.
doi: 10.1016/j.nima.2019.04.067.

N. Budnev et al.
TAIGA—an advanced hybrid detector complex for astroparticle physics and high energy gamma-ray astronomy in the Tunka valley.
Journal of Instrumentation, 15(09):26, and PUBDB-2021-00170.
doi: 10.1088/1748-0221/15/09/C09031.

R. Buehler et al.
Search for the imprint of axion-like particles in the highest-energy photons of hard γ-ray blazars.
Journal of cosmology and astroparticle physics, 2009(09):1, and PUBDB-2020-03505, arXiv:2004.09396.
doi: 10.1088/1475-7516/2020/09/027.

F. Coti Zelati et al.
Spectral characterization of the non-thermal X-ray emission of gamma-ray pulsars.
Monthly notices of the Royal Astronomical Society, 492(1):1025, and PUBDB-2021-00256, arXiv:1912.03953.
doi: 10.1093/mnras/stz3485.

R. Pillera et al.
A fast muon tagger method for Imaging Atmospheric Cherenkov Telescopes.
18th Incontri di Fisica delle Alte Energie, Naples (Italy), 8 Apr 2019 - 10 Aug 2019.
Il nuovo cimento / C, vol. 43:90, and PUBDB-2021-00382.
Ed. Compositori, Bologna [u.a.]
doi: 10.1393/ncc/i2020-20090-7.

M. Rigault et al.
Strong Dependence of Type Ia Supernova Standardization on the Local Specific Star Formation Rate.
Astronomy and astrophysics, 644:A176 (1, and PUBDB-2021-00136, arXiv:1806.03849.
doi: 10.1051/0004-6361/201730404.

R. A. Fallows et al.
A LOFAR observation of ionospheric scintillation from two simultaneous travelling ionospheric disturbances.
Journal of space weather and space climate, 10:10, and PUBDB-2021-00345.
doi: 10.1051/swsc/2020010.

Fermi-LAT Collaboration.
The Fourth Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope.
The astrophysical journal, 892(2):105, and PUBDB-2021-00152, arXiv:1905.10771.
doi: 10.3847/1538-4357/ab791e.

A. Franckowiak et al.
Patterns in the multi-wavelength behavior of candidate neutrino blazars.
The astrophysical journal / 1 Part 1, 893(2):162, and PUBDB-2020-02147, arXiv:2001.10232.
doi: 10.3847/1538-4357/ab8307.

D. García-Fernández, A. Nelles and C. Glaser.
Signatures of secondary leptons in radio-neutrino detectors in ice.
Physical review / D, 102(8):083011, and PUBDB-2020-03984, arXiv:2003.13442.
doi: 10.1103/PhysRevD.102.083011.

F. de Gasperin et al.
Cassiopeia A, Cygnus A, Taurus A, and Virgo A at ultra-low radio frequencies.
Astronomy and astrophysics, 635:A150, and PUBDB-2021-00259, arXiv:2002.10431.
doi: 10.1051/0004-6361/201936844.

C. Glaser et al.
NuRadioMC: Simulating the radio emission of neutrinos from interaction to detector.
The European physical journal / C, 80(2):77 (1, and PUBDB-2020-04162, arXiv:1906.01670.
doi: 10.1140/epjc/s10052-020-7612-8.

D. Green and R. A. Porto.
Signals of a Quantum Universe.
Physical review letters, 124(25):251302, and PUBDB-2021-00150, arXiv:2001.09149. arXiv:2001.09149.
doi: 10.1103/PhysRevLett.124.251302.

H. E. S. S. Collaboration.
An extreme particle accelerator in the Galactic plane: HESS J1826−130.
Astronomy and astrophysics, 644:A112, and PUBDB-2021-00193, arXiv:2010.13101.
doi: 10.1051/0004-6361/202038851.

H. E. S. S. Collaboration.
An extreme particle accelerator in the Galactic plane: HESSJ1826-130.
PUBDB-2020-04665, arXiv:2010.13101.
doi: 10.3204/PUBDB-2020-04665.

H. E. S. S. Collaboration.
H.E.S.S. and Fermi-LAT observations of PSR B1259-63/LS 2883 during its 2014 and 2017 periastron passages.
Astronomy and astrophysics, 633:A102, and PUBDB-2020-00085, arXiv:1912.05868.
doi: 10.1051/0004-6361/201936621.

H. E. S. S. Collaboration.
Probing in the Magnetic Field in the GW170817 Outflow Using H.E.S.S Observations.
The astrophysical journal / 1, 894(2):1, and PUBDB-2020-02137, arXiv:2004.10105.
doi: 10.3847/2041-8213/ab8b59.

H. E. S. S. Collaboration.
Resolving acceleration to very high energies along the jet of Centaurus A.
Nature / Physical science, 582(7812):356, and PUBDB-2020-04663, arXiv:2007.04823.
doi: 10.1038/s41586-020-2354-1.

H. E. S. S. Collaboration.
Search for dark matter signals towards a selection of recently detected DES dwarf galaxy satellites of the Milky Way with H.E.S.S.
Physical review / D, 102(6):062001 (1, and PUBDB-2020-03507, arXiv:2008.00688.
doi: 10.1103/PhysRevD.102.062001.

H. E. S. S. Collaboration.
Very high energy γ-ray emission from two blazars of unknown redshift and upper limits on their distance.
Monthly notices of the Royal Astronomical Society, 494(4):5590, and PUBDB-2020-04669, arXiv:2004.03306.
doi: 10.1093/mnras/staa999.

H. E. S. S. Collaboration and NuSTAR Collaboration and Fermi-LAT Collaboration and Swift Collaboration.
Simultaneous observations of the blazar PKS 2155−304 from ultra-violet to TeV energies.
Astronomy and astrophysics, 639:A42, and PUBDB-2020-04667, arXiv:1912.07273.
doi: 10.1051/0004-6361/201936900.

B. M. Hare et al.
Radio Emission Reveals Inner Meter-Scale Structure of Negative Lightning Leader Steps.
Physical review letters, 124(10):105101, and PUBDB-2021-00190.
doi: 10.1103/PhysRevLett.124.105101.

J. Heinze et al.
Systematic parameter space study for the UHECR origin from GRBs in models with multiple internal shocks.
Monthly notices of the Royal Astronomical Society, 498(4):5990, and PUBDB-2020-03930, arXiv:2006.14301.
doi: 10.1093/mnras/staa2751.

HESS Collaboration.
Detection of very-high-energy γ-ray emission from the colliding wind binary η Car with H.E.S.S.
Astronomy and astrophysics, 635:A167 (1, and PUBDB-2020-04670, arXiv:2002.02336.
doi: 10.1051/0004-6361/201936761.

J. Hoang et al.
MAGIC-II's central pixel system for simultaneous optical and gamma-ray observation.
Journal of astronomical telescopes, instruments, and systems, 6(3):14, and PUBDB-2021-00383.
doi: 10.1117/1.JATIS.6.3.036002.

IceCube Collaboration.
A search for IceCube events in the direction of ANITA neutrino candidates.
The astrophysical journal, 892(1):53 (1, and PUBDB-2021-00384, arXiv:2001.01737.
doi: 10.3847/1538-4357/ab791d.

IceCube Collaboration.
A Search for MeV to TeV Neutrinos from Fast Radio Bursts with IceCube.
The astrophysical journal, 890(2):111, and PUBDB-2020-04022, arXiv:1908.09997.
doi: 10.3847/1538-4357/ab564b.

IceCube Collaboration.
A Search for Neutrino Point-source Populations in 7 yr of IceCube Data with Neutrino-count Statistics.
The astrophysical journal, 893(2):102 (1, and PUBDB-2021-00378, arXiv:1909.08623. LCTP-19-19.
doi: 10.3847/1538-4357/ab7af9.

IceCube Collaboration.
An eV-scale sterile neutrino search using eight years of atmospheric muon neutrino data from the IceCube Neutrino Observatory.
Physical review letters, 125(14):141801 (1, and PUBDB-2020-03696, arXiv:2005.12942.
doi: 10.1103/PhysRevLett.125.141801.

IceCube Collaboration.
Characteristics of the diffuse astrophysical electron and tau neutrino flux with six years of IceCube high energy cascade data.
Physical review letters, 125(12):121104 (1, and PUBDB-2020-03506, arXiv:2001.09520.
doi: 10.1103/PhysRevLett.125.121104.

IceCube Collaboration.
Computational techniques for the analysis of small signals in high-statistics neutrino oscillation experiments.
Nuclear instruments & methods in physics research / A, 977:164332, and PUBDB-2021-00145, arXiv:1803.05390.
doi: 10.1016/j.nima.2020.164332.

IceCube Collaboration.
Constraints on neutrino emission from nearby galaxies using the 2MASS redshift survey and IceCube.
Journal of cosmology and astroparticle physics, 07(07):042, and PUBDB-2021-00385, arXiv:1911.11809.
doi: 10.1088/1475-7516/2020/07/042.

IceCube Collaboration.
In-situ calibration of the single-photoelectron charge response of the IceCube photomultiplier tubes.
Journal of Instrumentation, 15(06):P06032, and PUBDB-2020-02976, arXiv:2002.00997.
doi: 10.1088/1748-0221/15/06/P06032.

IceCube Collaboration.
Neutrinos below 100 TeV from the southern sky employing refined veto techniques to IceCube data.
Astroparticle physics, 116:102392, and PUBDB-2020-00328, arXiv:1902.05792. arXiv:1902.05792.
doi: 10.1016/j.astropartphys.2019.102392.

IceCube Collaboration.
Search for PeV Gamma-Ray Emission from the Southern Hemisphere with 5 Years of Data from the IceCube Observatory.
The astrophysical journal, 891(1):9, and PUBDB-2020-04006, arXiv:1908.09918.
doi: 10.3847/1538-4357/ab6d67.

IceCube Collaboration.
Searching for eV-scale sterile neutrinos with eight years of atmospheric neutrinos at the IceCube neutrino telescope.
Physical review / D, D102(5):052009 (1, and PUBDB-2020-03695, arXiv:2005.12943.
doi: 10.1103/PhysRevD.102.052009.

IceCube Collaboration.
Time-integrated Neutrino Source Searches with 10 years of IceCube Data.
Physical review letters, 124(5):051103 (1, and PUBDB-2020-04159, arXiv:1910.08488.
doi: 10.1103/PhysRevLett.124.051103.

Icecube Collaboration.
Cosmic ray spectrum from 250 TeV to 10 PeV using IceTop.
Physical review / D, 102(12):122001, and PUBDB-2020-05257, arXiv:2006.05215.
doi: 10.1103/PhysRevD.102.122001.

Icecube Collaboration.
Design and Performance of the first IceAct Demonstrator at the South Pole.
Journal of Instrumentation, 15(02):T02002, and PUBDB-2020-04572, arXiv:1910.06945.
doi: 10.1088/1748-0221/15/02/T02002.

Icecube Collaboration.
IceCube Search for High-Energy Neutrino Emission from TeV Pulsar Wind Nebulae.
The astrophysical journal, 898(2):117 (1, and PUBDB-2020-04501, arXiv:2003.12071.
doi: 10.3847/1538-4357/ab9fa0.

Icecube collaboration.
Development of an analysis to probe the neutrino mass ordering with atmospheric neutrinos using three years of IceCube DeepCore data.
The European physical journal / C, C80(1):9, and PUBDB-2020-00189.
doi: 10.1140/epjc/s10052-019-7555-0.

Icecube collaboration and ANTARES Collaboration.
Combined search for neutrinos from dark matter self-annihilation in the Galactic Center with ANTARES and IceCube.
Physical review / D, 102(8):082002 (1, and PUBDB-2020-04573, arXiv:2003.06614.
doi: 10.1103/PhysRevD.102.082002.

IceCube Collaboration and IceCube Collaboration.
IceCube Search for Neutrinos Coincident with Compact Binary Mergers from LIGO-Virgo's First Gravitational-Wave Transient Catalog.
The astrophysical journal, 898(1):1, and PUBDB-2020-02971, arXiv:2004.02910.
doi: 10.3847/2041-8213/ab9d24.

IceCube Collaboration and PICO Collaboration.
Velocity Independent Constraints on Spin-Dependent DM-Nucleon Interactions from IceCube and PICO.
The European physical journal / C, 80(9):819, and PUBDB-2020-03981, arXiv:1907.12509.
doi: 10.1140/epjc/s10052-020-8069-5.

IceCube-Gen2 Collaboration and Members, JUNO Collaboration.
Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU.
Physical review / D, 101(3):032006 (1, and PUBDB-2020-04176, arXiv:1911.06745.
doi: 10.1103/PhysRevD.101.032006.

A. Ivanova et al.
Design features and data acquisition system of the TAIGA-Muon scintillation array.
06. International Conference on Instrumentation for Colliding Beam Physics, Novosibirsk (Russia), 24 Feb 2020 - 28 Feb 2020.
Journal of Instrumentation, vol. 1506:C06057 (1, and PUBDB-2021-00184.
Inst. of Physics, London.
doi: 10.1088/1748-0221/15/06/C06057.

G. W. Kaelin and R. A. Porto Pereira.
Post-Minkowskian Effective Field Theory for Conservative Binary Dynamics.
Journal of high energy physics, 11(11):106, and PUBDB-2020-04985, arXiv:2006.01184. DESY20-077. SLAC-PUB-17529.
doi: 10.1007/JHEP11(2020)106.

G. Kälin and R. A. Porto.
From boundary data to bound states.
Journal of high energy physics, 2020(1):72, and PUBDB-2020-00619, arXiv:1910.03008. UUITP-40/19. DESY-19-167.
doi: 10.1007/JHEP01(2020)072.

G. Kälin and R. A. Porto.
From boundary data to bound states. Part II. Scattering angle to dynamical invariants (with twist).
Journal of high energy physics, 2020(2):120, and PUBDB-2020-01333, arXiv:1911.09130. SLAC-PUB-17487. UUITP-46/19. DESY-19-201.
doi: 10.1007/JHEP02(2020)120.

R. G. Lang et al.
Revisiting the distance to the nearest UHECR source: Effects of extra-galactic magnetic fields.
Physical review / D, 102(6):063012 (1, and PUBDB-2020-03504, arXiv:2005.14275.
doi: 10.1103/PhysRevD.102.063012.

J. Li et al.
Gamma-ray heartbeat powered by the microquasar SS 433.
Nature astronomy, 4:1177, and PUBDB-2020-04819.
doi: 10.1038/s41550-020-1164-6.

R.-Y. Liu and H. Yan.
On the unusually large spatial extent of the TeV nebula HESS J1825−137: implication from the energy-dependent morphology.
Monthly notices of the Royal Astronomical Society, 494(2):2618, and PUBDB-2020-05079.
doi: 10.1093/mnras/staa911.

K. J. Luken et al.
Radio Observations of Supernova Remnant G1.9+0.3.
Monthly notices of the Royal Astronomical Society, 492(2):2606, and PUBDB-2021-00387, arXiv:1912.01771.
doi: 10.1093/mnras/stz3439.

MAGIC Collaboration.
A search for dark matter in Triangulum II with the MAGIC telescopes.
Physics of the Dark Universe, 28:100529, and PUBDB-2020-01395, arXiv:2003.05260.
doi: 10.1016/j.dark.2020.100529.

MAGIC Collaboration.
Detection of the Geminga pulsar with MAGIC hints at a power-law tail emission beyond 15 GeV.
Astronomy and astrophysics, 643:L14 (1, and PUBDB-2021-00188, arXiv:2011.10412.
doi: 10.1051/0004-6361/202039131.

MAGIC Collaboration.
MAGIC very large zenith angle observations of the Crab Nebula up to 100 TeV.
Astronomy and astrophysics, 635:A158 (1, and PUBDB-2020-04797, arXiv:2001.09566.
doi: 10.1051/0004-6361/201936899.

MAGIC Collaboration.
Study of the variable broadband emission of Markarian 501 during the most extreme Swift X-ray activity.
Astronomy and astrophysics, 637:A86, and PUBDB-2020-02366, arXiv:2001.07729.
doi: 10.1051/0004-6361/201834603.

MAGIC Collaboration.
Studying the nature of the unidentified gamma-ray source HESS J1841−055 with the MAGIC telescopes.
Monthly notices of the Royal Astronomical Society, 497(3):3734, and PUBDB-2020-04788, arXiv:2007.09321.
doi: 10.1093/mnras/staa2135.

MAGIC Collaboration.
Testing two-component models on very-high-energy gamma-ray emitting BL Lac objects.
Astronomy and astrophysics, 640:A132, and PUBDB-2020-03249, arXiv:2006.04493.
doi: 10.1051/0004-6361/202037811.

MAGIC Collaboration.
Unravelling the complex behavior of Mrk 421 with simultaneous X-ray and VHE observations during an extreme flaring activity in April 2013.
The astrophysical journal / Supplement series, 248(2):29, and PUBDB-2020-02368, arXiv:2001.08678.
doi: 10.3847/1538-4365/ab89b5.

MAGIC Collaboration and Armenian Consortium: ICRANet-Armenia at NAS RA, A. Alikhanyan National Laboratory and ESO, Finnish MAGIC Consortium: Finnish Centre of Astronomy with.
Bounds on Lorentz invariance violation from MAGIC observation of GRB 190114C.
Physical review letters, 125(2):1, and PUBDB-2020-02983, arXiv:2001.09728.
doi: 10.1103/PhysRevLett.125.021301.

MAGIC Collaboration and ESO, MAGIC Finnish Consortium: Finnish Centre of Astronomy with.
MAGIC observations of the diffuse γ -ray emission in the vicinity of the Galactic center.
Astronomy and astrophysics, 642:A190, and PUBDB-2020-04802, arXiv:2006.00623.
doi: 10.1051/0004-6361/201936896.

MAGIC Collaboration and FACT Collaboration.
An intermittent extreme BL Lac: MWL study of 1ES 2344+514 in an enhanced state.
Monthly notices of the Royal Astronomical Society, 496(3):3912, and PUBDB-2020-04804, arXiv:2006.06796.
doi: 10.1093/mnras/staa1702.

MAGIC Collaboration and Fermi-LAT Collaboration.
Broadband characterisation of the very intense TeV flares of the blazar 1ES 1959+650 in 2016.
Astronomy and astrophysics, 638:A14, and PUBDB-2020-02510, arXiv:2002.00129.
doi: 10.1051/0004-6361/201935450.

MAGIC Collaboration and Observatory, Finnish MAGIC Consortium: Tuorla and ESO, Finnish Centre of Astronomy with.
Statistics of VHE γ -rays in temporal association with radio giant pulses from the Crab pulsar.
Astronomy and astrophysics, 634:A25, and PUBDB-2020-00671, arXiv:1911.00634.

K. D. Makwana and H. Yan.
Properties of Magnetohydrodynamic Modes in Compressively Driven Plasma Turbulence.
Physical review / X, 10(3):031021, and PUBDB-2020-05076.
doi: 10.1103/PhysRevX.10.031021.

L. Marcotulli et al.
NuSTAR perspective on high-redshift MeV blazars.
The astrophysical journal, 889(2):164, and PUBDB-2021-00238, arXiv:2001.01956.
doi: 10.3847/1538-4357/ab65f5.

G. Martí-Devesa et al.
Hints of γ-ray orbital variability from γ^2 Velorum.
Astronomy and astrophysics, 635:A141 (1, and PUBDB-2021-00257, arXiv:2001.02708.
doi: 10.1051/0004-6361/202037462.

E. Mestre et al.
The Crab nebula variability at short timescales with the Cherenkov Telescope Array.
Monthly notices of the Royal Astronomical Society, 509(1):337, and PUBDB-2020-04552, arXiv:2011.08586.
doi: 10.1093/mnras/staa3599.

D. M.-A. Meyer, M. Petrov and M. Pohl.
Wind nebulae and supernova remnants of very massive stars.
Monthly notices of the Royal Astronomical Society, 493(3):3548, and PUBDB-2020-04608.
doi: 10.1093/mnras/staa554.

D. M.-A. Meyer et al.
On the ring nebulae around runaway Wolf–Rayet stars.
Monthly notices of the Royal Astronomical Society, 496(3):3906, and PUBDB-2020-04606.
doi: 10.1093/mnras/staa1700.

P. Mitra et al.
Reconstructing air shower parameters with LOFAR using event specific GDAS atmospheres.
Astroparticle physics, 123:102470, and PUBDB-2020-02977, arXiv:2006.02228.
doi: 10.1016/j.astropartphys.2020.102470.

R. Monroe et al.
Self-triggered radio detection and identification of cosmic air showers with the OVRO-LWA.
Nuclear instruments & methods in physics research / A, 953:163086, and PUBDB-2020-00350, arXiv:1907.10193.
doi: 10.1016/j.nima.2019.163086.

K. Mori et al.
Multiwavelength Observations of 2HWC J1928+177: Dark Accelerator or New TeV Gamma-Ray Binary?
The astrophysical journal, 897(2):129 (1, and PUBDB-2021-00344, arXiv:2005.12343.
doi: 10.3847/1538-4357/ab9631.

K. Mulrey et al.
On the cosmic-ray energy scale of the LOFAR radio telescope.
Journal of cosmology and astroparticle physics, 11(11):017, and PUBDB-2021-00140, arXiv:2005.13441.
doi: 10.1088/1475-7516/2020/11/017.

K. Nishikawa et al.
Rapid particle acceleration due to recollimation shocks and turbulent magnetic fields in injected jets with helical magnetic fields.
Monthly notices of the Royal Astronomical Society, 493(2):2652, and PUBDB-2020-04609.
doi: 10.1093/mnras/staa421.

E. de Oña Wilhelmi et al.
SNR G39.2−0.3, an hadronic cosmic rays accelerator.
Monthly notices of the Royal Astronomical Society, 497(3):3581, and PUBDB-2020-04820, arXiv:2007.04627.
doi: 10.1093/mnras/staa2045.

V. S. Paliya et al.
The First Gamma-ray Emitting BL Lacertae Object at the Cosmic Dawn.
The astrophysical journal, 903(1):L8, and PUBDB-2021-00177, arXiv:2010.12907.
doi: 10.3847/2041-8213/abbc06.

V. S. Paliya et al.
TXS 2116−077: A Gamma-ray Emitting Relativistic Jet Hosted in a Galaxy Merger.
The astrophysical journal, 892(2):133 (1, and PUBDB-2021-00390, arXiv:2004.02703.
doi: 10.3847/1538-4357/ab754f.

V. S. Paliya et al.
Blazars at the Cosmic Dawn.
The astrophysical journal, 897(2):177, and PUBDB-2020-02980, arXiv:2006.01857.
doi: 10.3847/1538-4357/ab9c1a.

A. Palladino, M. Spurio and F. Vissani.
Neutrino Telescopes and High-Energy Cosmic Neutrinos.
Universe, 6(2):30, and PUBDB-2020-00934.
doi: 10.3390/universe6020030.

A. Palladino et al.
Can astrophysical neutrinos trace the origin of the detected ultra-high energy cosmic rays?
Monthly notices of the Royal Astronomical Society, 494(3):4255, and PUBDB-2020-03348, 1911.05756. arXiv:1911.05756.
doi: 10.1093/mnras/staa1003.

A. Papitto et al.
The INTEGRAL view of the pulsating hard X-ray sky: from accreting and transitional millisecond pulsars to rotation-powered pulsars and magnetars.
New astronomy reviews, 91:101544, and PUBDB-2021-00137, arXiv:2012.01346.
doi: 10.1016/j.newar.2020.101544.

R. D. Parsons and S. Ohm.
Background Rejection in Atmospheric Cherenkov Telescopes using Recurrent Convolutional Neural Networks.
The European physical journal / C Particles and fields C, C80(5):363, and PUBDB-2020-02146, arXiv:1910.09435.
doi: 10.1140/epjc/s10052-020-7953-3.

P. Peñil et al.
Systematic Search for γ-Ray Periodicity in Active Galactic Nuclei Detected by the Fermi Large Area Telescope.
The astrophysical journal, 896(2):134 (1, and PUBDB-2021-00185, arXiv:2002.00805.
doi: 10.3847/1538-4357/ab910d.

M. Pohl, M. Hoshino and J. Niemiec.
PIC simulation methods for cosmic radiation and plasma instabilities.
Progress in particle and nuclear physics, 111:103751, and PUBDB-2020-04610, DESY-19-230. arXiv:1912.02673.
doi: 10.1016/j.ppnp.2019.103751.

M. Rajagopal et al.
NuSTAR Observations and multi-wavelength modeling of the high-redshift BL Lac Object 4FGL J2146.5-1344.
The astrophysical journal, 889(2):102 (1, and PUBDB-2021-00250, arXiv:2001.05020.
doi: 10.3847/1538-4357/ab6226.

F. Riehn et al.
Hadronic interaction model sibyll 2.3d and extensive air showers.
Physical review / D, 102(6):063002, and PUBDB-2020-03247, arXiv:1912.03300.
doi: 10.1103/PhysRevD.102.063002.

C. Righi et al.
EeV Astrophysical neutrinos from FSRQs?
Astronomy and astrophysics, 642:A92 (1, and PUBDB-2020-03929, arXiv:2003.08701. arXiv:2003.08701.
doi: 10.1051/0004-6361/202038301.

D. Rodgers-Lee et al.
The Galactic cosmic ray intensity at the evolving Earth and young exoplanets.
Monthly notices of the Royal Astronomical Society, 499(2):2124, and PUBDB-2021-00386.
doi: 10.1093/mnras/staa2737.

M. Rongen, R. C. Bay and S. Blot.
Observation of an optical anisotropy in the deep glacial ice at the geographic South Pole using a laser dust logger.
The Cryosphere, 14(8):2537, and PUBDB-2021-00255.
doi: 10.5194/tc-14-2537-2020.

A. Rudolph et al.
Impact of the collision model on the multimessenger emission from gamma-ray burst internal shocks.
The astrophysical journal / Supplement series, 893:72, and PUBDB-2020-01586, arXiv:1907.10633.
doi: 10.3847/1538-4357/ab7ea7.

I. Sadeh.
Data-driven Detection of Multimessenger Transients.
The astrophysical journal, 894(2):L25 (1, and PUBDB-2020-04557.
doi: 10.3847/2041-8213/ab8b5f.

M. T. Soumagnac et al.
Early Ultraviolet Observations of Type IIn Supernovae Constrain the Asphericity of Their Circumstellar Material.
The astrophysical journal, 899(1):51 (1, and PUBDB-2021-00258, arXiv:2001.05518.
doi: 10.3847/1538-4357/ab94be.

D. T. Strauss et al.
The mini-neutron monitor: a new approach in neutron monitor design.
Journal of space weather and space climate, 10:39 (1, and PUBDB-2021-00191.
doi: 10.1051/swsc/2020038.

The Nearby Supernova Factory.
SUGAR: An improved empirical model of Type Ia Supernovae based on spectral features.
Astronomy and astrophysics, 636:A46, and PUBDB-2020-01726, arXiv:1909.11239.
doi: 10.1051/0004-6361/201834954.

T. N. G. Trinh et al.
Determining Electric Fields in Thunderclouds With the Radiotelescope LOFAR.
Journal of geophysical research / D, 125(8):20, and PUBDB-2021-00236.
doi: 10.1029/2019JD031433.

J. Valverde et al.
A Decade of Multiwavelength Observations of the TeV Blazar 1ES 1215+303: Extreme Shift of the Synchrotron Peak Frequency and Long-term Optical–Gamma-Ray Flux Increase.
The astrophysical journal / 1 Part 1, 891(2):170, and PUBDB-2020-01405, arXiv:2002.04119.
doi: 10.3847/1538-4357/ab765d.

VERITAS Collaboration.
VERITAS Detection of LS 5039 and HESS J1825-137.
Astroparticle physics, 117:102403, and PUBDB-2020-00185, arXiv:2001.03522.
doi: 10.1016/j.astropartphys.2019.102403.

K. Wang et al.
Limiting Superluminal Neutrino Velocity and Lorentz Invariance Violation by Neutrino Emission from the Blazar TXS 0506+056.
Physical review / D, D102(6):063027 (1, and PUBDB-2020-03697, arXiv:2009.05201.
doi: 10.1103/PhysRevD.102.063027.

R. White et al.
Gamma-ray and X-ray constraints on non-thermal processes in η Carinae.
Astronomy and astrophysics, 635:A144, and PUBDB-2020-04664, arXiv:1911.01079.
doi: 10.1051/0004-6361/201937031.

A. Wilhelm et al.
Stochastic re-acceleration and magnetic-field damping in Tycho ’s supernova remnant.
Astronomy and astrophysics, 639:A124, and PUBDB-2020-04607, arXiv:2006.04832.
doi: 10.1051/0004-6361/201936079.

H.-M. Zhang et al.
Discovery of a spatially extended GeV source in the vicinity of the TeV halo candidate 2HWC J1912+099: a TeV halo or supernova remnant ?
The astrophysical journal, 889(1):1, and PUBDB-2021-00260, arXiv:1909.13185.
doi: 10.3847/1538-4357/ab5af6.

H. Zhang et al.
Discovery of Ground-state Absorption Line Polarization and Sub-Gauss Magnetic Field in the Post-AGB Binary System 89 Her.
The astrophysical journal / 2, 902(1):L7, and PUBDB-2020-04073.
doi: 10.3847/2041-8213/abb8e1.

H. Zhang et al.
Identification of plasma modes in Galactic turbulence with synchrotron polarization.
Nature astronomy, 4(10):1001, and PUBDB-2020-05077.
doi: 10.1038/s41550-020-1093-4.

S. J. Zhu et al.
Characterizing the continuous gravitational-wave signal from boson clouds around Galactic isolated black holes.
Physical review / D, 102(6):063020, and PUBDB-2020-03980, arXiv:2003.03359.
doi: 10.1103/PhysRevD.102.063020.

Ph.D. Thesis

G. P. Gallardo Romero.
Search for axion-like particles through their effects on the transparency of the universe with the fermi large area telescope.
Humboldt-Universität zu Berlin, 2020.

J. Heinze.
Ultra-high-energy cosmic-ray nuclei and neutrinos in models of gamma-ray bursts and extragalactic propagation.
Humboldt University, 2020.

N. Kelley-Hoskins.
A Search for Extended Gamma-Ray Emission from the Galactic Center with VERITAS.
Humboldt-Universität zu Berlin, 2020.

Master Thesis

F. Zhang.
The Performance of Double Cascades Identification in IceCube-Gen2.
Humboldt University Berlin, 2020.

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