HELMHOLTZ
ASSOCIATION

Alliance for Astroparticle Physics

Helmholtz Alliance for Astroparticle Physics

CONNECTING SMALLEST PARTICLES AND
LARGEST STRUCTURES IN THE UNIVERSE

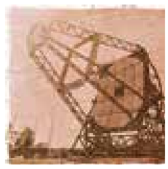
HELMHOLTZ
ASSOCIATION
Alliance for Astroparticle Physics

Helmholtz Alliance for Astroparticle Physics

A snapshot of the period
July 2011 – December 2016

PEOPLE

GET-TOGETHER

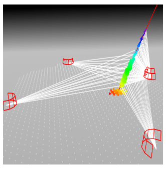


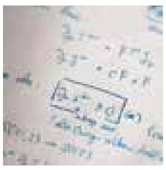




SCIENCE



Welcome to the Helmholtz Alliance for Astroparticle Physics

What is the structure of the Universe? What is the elementary structure of matter? These questions have captivated humanity since its beginnings. In modern physics we see the strong connection between cosmology and the properties of elementary particles. Research on these questions needs both expertise in astrophysics and in particle physics. This is the prosperous field of astroparticle physics. The Helmholtz Alliance for Astroparticle Physics (HAP) is a network bringing together scientists from universities and Helmholtz centers, from astrophysics and particle physics, from theory and experiment to develop technologies and tools, to combine data from different experiments and exchange ideas, to promote young scientists and to foster the field of astroparticle physics in Germany.

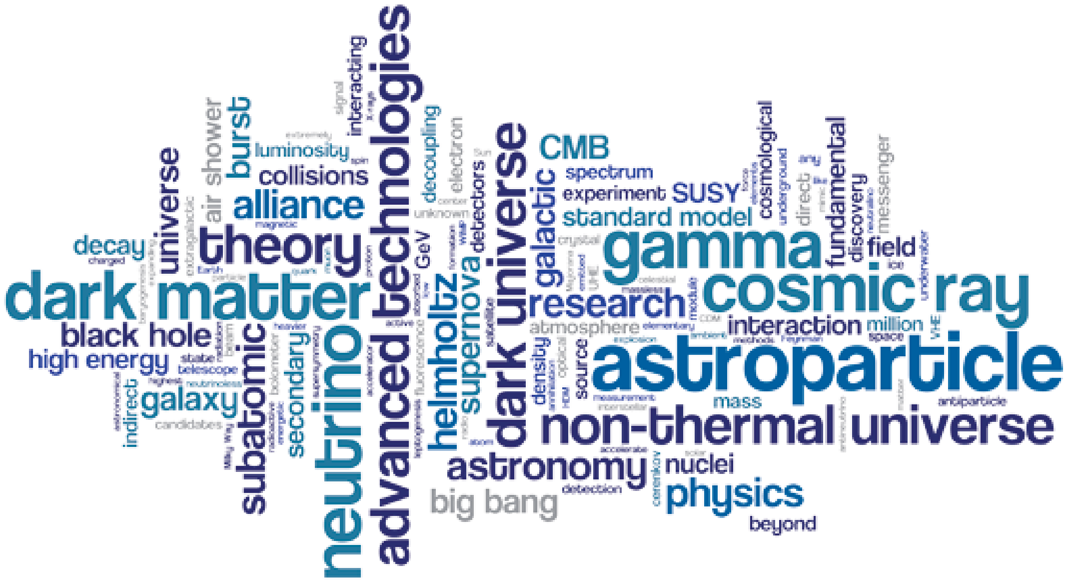
Determining the nature of dark matter and how cosmic rays are accelerated to the extremely high energies observed are the main scientific motivations of HAP.

Just a small fraction of the matter in the Universe is visible to us. Most of the matter in the Universe does not interact via the electromagnetic force, which is why this so-called dark matter is invisible to us. Of the known particles it could only be composed of neutrinos. Due to their strange properties neutrinos are the subject of many studies, but neutrinos as dark matter would not allow the formation of today's structures in the Universe. The existence of dark matter clearly shows that our present understanding of particle physics, the standard model, is incomplete. Particle candidates beyond the standard model are the WIMPs, weakly interacting massive particles, or axions. One needs to identify and to study the known and unknown particles to investigate dark matter. HAP performs these studies by direct and indirect observations.

Cosmic rays are reaching Earth from the deepest Universe with extremely high energies. It is still unclear how nature realizes the particle acceleration to energies orders of magnitude higher than what we can achieve with man-made accelerators. Cosmic rays are expected to come from astrophysical objects either in our Galaxy or even from extragalactic sources. Identifying the sources and the acceleration processes within requires information from charged cosmic rays, neutrinos and gamma rays. Information on the nature of these sources can be gained by studying the composition and arrival directions of charged cosmic rays. Finding high-energy neutrinos from such sources will prove a hadronic acceleration mechanism, while studying the high-energy gamma ray spectra will help to distinguish between leptonic and hadronic acceleration scenarios. Only all messengers together can provide a full insight into the high energy Universe.

With a new generation of detectors reaching unprecedented sensitivity to low rates, HAP scientists are searching for rare scattering events of dark matter particles with nuclei. Such direct detection experiments looking for WIMPs inside our Galaxy are CRESST, EDELWEISS and XENON, to which HAP scientists contribute, often in a leading role. Following novel ideas FUNK is looking for the conversion of axions from the dark matter to so-called dark photons. Wherever there are clumps of dark matter in the center of our Galaxy or of neighboring galaxies, dark matter particles could potentially annihilate to standard model particles. This could leave signatures in the spectra of high energy gamma rays, X-rays, neutrinos or antiparticles, e.g. positrons. The indirect search for dark matter by looking for such signatures is part of the program of HAP. This is done with neutrinos by IceCube and KM3NeT and with the gamma-ray telescopes H.E.S.S., CTA and the Fermi Gamma-ray Space Telescope. Through the combination of these results with findings from particle physics experiments at the LHC and with astrophysical observations of cosmological structures, theorists within HAP build models to understand how our theories of particle physics and cosmology need to be extended or even changed.

Within HAP a rich program based on the diversity of messenger particles to observe the high-energy Universe and on theoretical efforts to understand the production and propagation of cosmic rays brings together the expertise and observational results needed for a complete picture. The Pierre Auger Observatory determines the composition of cosmic rays up to the highest energies and aims to find the sources of high-energy



cosmic rays. While charged cosmic rays do not point back to their sources because of magnetic deflections in galactic and intergalactic fields, gamma rays reach Earth straight, neutrinos even from densest source regions. Gamma rays and neutrinos carry information on the production mechanisms. All messengers are exploited in HAP, cosmic rays with the Auger Observatory, Neutrinos with IceCube, Antares and the future neutrino telescopes KM3NeT and IceCube-Gen2, and gamma rays with the telescopes H.E.S.S., MAGIC, Fermi and the future CTA. The interpretation of the results needs strong support from theory. HAP made it possible to build CRPropa, a software package to simulate the propagation of cosmic rays through the Universe and their interaction with background photons, magnetic fields and clouds of matter.

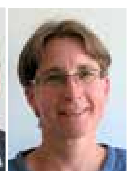
The HAP network of scientists from such a variety of projects could foster cooperation in technology resulting in improved detectors for existing experiments as well as in prototypes of new detection strategies. Light detection plays a role in almost all fields of HAP, dark matter searches, gamma ray and neutrino telescopes as well as in cosmic ray detection. All these projects benefit from HAP by the development of new light sensors. Increasing the purity of the detector materials is another crucial aspect for the sensitivity of direct dark matter experiments. This is addressed by a gas purification system for the XENON project, largely benefiting from the combined expertise brought together by HAP. New schemes for the detection of cosmic rays and neutrinos are being developed exploiting radio emission or the generation of sound waves.

A challenge common to all projects in HAP is to deal with the large amounts of data. Information from a variety of experiments, theoretical models and simulations needs to be combined. The Big Data challenges in astroparticle physics are to gain maximum information out of the data and to increase the data accessibility to foster scientific exchange among experts and with the general public.

HAP is a Helmholtz Alliance initially funded by the Helmholtz Association from July 2011 until December 2016. The network bundles the activities of scientists from the two Helmholtz Centers Karlsruhe Institute of Technology (KIT), Deutsches Elektronen Synchrotron (DESY), 15 German universities (RWTH Aachen, HU Berlin, Bonn, TU Dortmund, TU Dresden, Erlangen-Nürnberg, Hamburg, Mainz, Münster, TU München, Potsdam, Siegen, Tübingen, Würzburg, Wuppertal) and numerous international associated partners. As an important player in astroparticle physics, HAP is reflecting the dynamics of the field by continuously growing in the number of participating groups. Astroparticle physics benefits from networking much more than other field in physics: Exploring the common scientific questions, by a rich diversity of techniques, needs networking and the exchange of people, ideas and methods. The scientific program is therefore complemented by a backbone of activities. Increased networking between places, generations, and ideas is achieved by a number of topical workshops, schools, travel support, guest visits, an exchange program for young scientists and a senior fellow award. The HAP outreach program has a particular focus on young people – our science is discussed in social media and students in high schools profit from exchange with scientists by dedicated classes and projects.

HAP is addressing fundamental science questions with a rich variety of experimental and observational channels, each providing a piece of complementary information. By building a network of many groups in Germany and abroad – active in experiment and in theory – HAP puts together the pieces to a complete picture in this scientific puzzle.

Scientific Spokespersons of HAP
Prof. Josef Jochum, U Tübingen
Astroteilchenphysik, CRESST, GERDA
Dr. Bianca Keilhauer, KIT, Auger Observatory

The Genesis of HAP and its Future

The Helmholtz Association consists of eighteen large German research centers. Our joint mission is to solve major and pressing problems of society, science and industry by conducting high-level research. We research highly complex systems in cooperation with national and international partners using our large-scale facilities and scientific infrastructure. In my opinion, Helmholtz Alliances have been one of the most effective and efficient instruments to help us carry out our mission. Here are some personal recollections concerning HAP, the Helmholtz Alliance for Astroparticle Physics.

Prof. Johannes Blümer KIT
Scientific Spokesperson of HAP 2011-2015
Spokesperson of the Helmholtz programme Matter and the Universe

A new Kid on the Block

The roots of the Helmholtz Alliance for Astroparticle Physics go back to the early 1990's. It took less than a decade for astroparticle physics to emerge from nuclear and particle physics, astrophysics, astronomy and cosmology as a research section in its own right. In retrospect I see three factors for the success of the new kid on the block: the interconnected science itself, luck or rather serendipity and the driving forces of several visionary people. Let me mention one example for each of these factors. Cosmic ray research had been a niche activity between the advent of particle accelerators in the 1950s and the possibility to build inexpensive particle detectors to instrument large areas. Cosmic ray detectors began to cover a hundred – and finally thousands – of square kilometers. They gave access to particle physics at 10^{20} eV equivalent beam energy, or up to several tens of TeV center-of-mass energy. This research experienced real renaissance and the marriage with particle physics at accelerators and colliders is still going on.

A serendipity factor was the explosion of supernova 1987A in the Large Magellanic Cloud. It triggered thousands of papers on stellar evolution, element synthesis, the explosion mechanism, neutrino physics and speculative ideas. It laid the foundation to the design of really large projects, many of them coined as 'underground physics'. SN 1987A was also a striking personal event for myself. At the time I was in transit from neutrino oscillations to CP violation, but this cosmic explosion stroke me such that twelve years later I took the occasion and moved to the newborn field Astroparticle Physics.

Third, I experienced Hermann Friedrich Wagner as a driving force to create Astroparticle Physics. He was physicist, science manager and division head in the Federal Ministry for Education and Science, BMBF. He encouraged people to think of a new, interdisciplinary field – and to imagine dedicated funding! All of this led to the creation of Astroparticle Physics as a research programme in the newly created Helmholtz Association.

Two virtual Institutes became real

Walter Kröll, President of the Helmholtz Association of German Research Centers between 2001 and 2005, created the so-called Virtual Institutes, close cooperations between Helmholtz research centers and university groups. It was easy to convince him and the evaluaters that we needed actually two, one for Dark Matter and Neutrino Physics (VIDMAN) and one for High-energy Cosmic rays (VIHKOS). They became very real and brought people from different communities closer together. They were the anchestors of the first Alliance. This term was introduced by Jürgen Mlynek, second Helmholtz President (from 2005 to 2015). He convinced me that I must think beyond a simple

continuation of the Virtual Institutes: "think big, act big". Well, that's what we tried, and we failed.
The Helmholtz Alliance for Cosmic Particles HCP was a good proposal. But there were many good ideas in the competition for relatively few funding opportunities. The proposal Physics at the Terascale made it in 2007. It was coordinated by Rolf Heuer, who became Director General of CERN in 2009. Without envy one must admit that the Terascale was an excellent network of Helmholtz Centers and universities, featuring an impressive mix of (tenured) positions, startup funding and exchange actions like schools and workshops. The next success story began in 2008 with the Extreme Matter Institute EMMI, established by Peter Braun-Munzinger and colleagues of the nuclear and hadron physics community. EMMI and Terascale had distinctive impressive features – how could astroparticle physicists hope for yet another alliance?
The ghost of HCP lived on for an amazingly long period of time. The idea was so inspiring and designed so much to match our needs that nobody gave up. Finally, the Helmholtz Alliance for Astroparticle Physics was born on July 1, 2011. Meanwhile the funding scale for Alliances had been cut to half of what it was in the beginning. Still, ten million euros from the Helmholtz Network und Initiative Fund was a lot of money, which we complemented with matching funds of close to 20 M€ raised by all Alliance partners. Naturally we couldn't create or even sustain a large number of permanent positions. We distributed part of the budget among the partner groups, somewhat proportional to the group size. No group received less than one doctoral researcher over a certain period of time. An important asset was the so-called backbone fund, which provided 200 k€ per annum for joint actions. The decision on these actions were taken in regular telephone conferences, which proved to be very effective in building up mutual understanding, finding consensus and planning ahead.

International Networking

The international dimension of HAP was important to us from the outset. We created formal links to institutions in Argentina, France, the Netherlands, Russia and the USA, seven altogether. Along the same line we asked seven wise colleagues from all over the world to serve in our Advisory Board. This is a good place to thank all our colleagues for the dedication and engagement: you made HAP better than it would have been without your help.
Towards the third period of programme-oriented funding the end of HAP funding was drawing near. During the evaluation the ‚ultimate network' was conceived to preserve the best features of all three Alliances in the Research Field Matter. The idea was not so much to prolong the Alliances, but to harvest the fruits of the manifold links that had been established. The network idea was called MUTLink, but it remained an idea. It would have comprised the particle physics, nuclear physics and astroparticle physics communities, maybe 2,000 people altogether. We wrote a proposal for 2.5 M€/a, but it wasn't formally submitted in those changing times.
However, again the spirit of a really vivid web of scientists survived. The Research Field Matter is currently preparing for the fourth POF period. A strategic element will be the ‚Matter Forum', in which the Programme Spokespersons will decide on joint actions – not so much different from the HAP and MUTLink practises or plans, respectively. Indeed, they will have one percent of the Research Fields LK1 budget at their disposal. I am deeply confident that this important feature will set a trend in other Research Fields, too. It would not have been possible to conceive and implement such an idea without the Alliances.

Together we achieve more!

Dark Matter Searches within HAP

A major goal of the alliance was to bring together scientists with different dark matter (DM) search strategies in order to develop a coherent approach towards DM detection. Here, we report on two examples of experiments extracting information on potential DM candidates and on topical workshops to share knowledge and train young researchers within the alliance.

The standard model of cosmology implies a 'Dark Universe', where non-baryonic DM is the dominant form of gravitationally interacting matter. With a fraction of 23 % of the total matter-energy density of the Universe, DM is playing a key role in the formation and evolution of large-scale structures. Its identity has remained a fundamental problem in particle physics and cosmology. The four major search strategies for DM are highly complementary: direct detection instruments look for DM particles interacting inside a detector, indirect measurements search for signals of DM annihilation or decay in the Universe, colliders searches for indications of physics beyond the standard models, and astrophysical probes explore the distribution of matter in the Universe.

Direct DM Search

In the so-called direct DM search, a signal from DM consists of an atomic nucleus recoiling within a detector after being hit by a DM particle. Such a scattering process is expected to be extremely rare, with a tiny signal which can be registered as a light flash, as free charges or as a short rise of the detector temperature. The experimentalist´s challenge is to reduce as much as possible all other spurious events and finally to identify individual signals as signatures of DM particles. Scientists within HAP were involved in the EDELWEISS experiment searching for such collisions in Germanium crystals cooled to an operating temperature of 18mK.
In 2014 and 2015, data were acquired over a period of more than 9 months. A complex analysis chain, a so-called maximum likelihood method, was developed in order to separate various background sources from a potential signal. In workshops as well as in direct discussions among HAP scientists, many features of

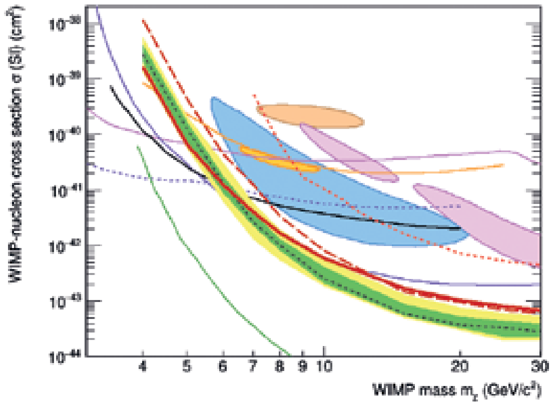


Fig. 1: Results of a DM search with EDELWEISS, excluding DM parameters above the red line. The data analysis was supported by HAP via a PhD position of the principal author (L. Hehn et al., EPJ C (2016) 76:548).

the analysis were evaluated assuring an optimal sensitivity to DM. The results of EDELWEISS-III are shown in Fig. 1 where all DM parameter regions above the thick red line can be excluded. The green and yellow bands demonstrate the achieved experimental sensitivity. Earlier indications of a possible DM signal (shown as coloured regions) are thus discarded as detection of DM.

Indirect DM Searches

Annihilation or decay of dark matter particles might lead to a characteristic flux of neutrinos, gamma rays, and charged secondaries from regions of increased

dark matter density in our Universe. Such regions are for example the Galactic center and halo, spheroidal dwarf galaxies, and massive nearby objects like our Sun. The aim of indirect dark matter searches is to detect these secondary particles with modern observatories like the IceCube neutrino observatory or the current and future gamma-ray observatories like the Cherenkov Telescope Array (CTA). The expected signal is weak and its separation from the dominating background flux of astrophysical origin is challenging (see Fig. 2). The common approach of the HAP groups was to combine the results from dark matter searches in different channels and to find a coherent understanding of the experimental challenges.

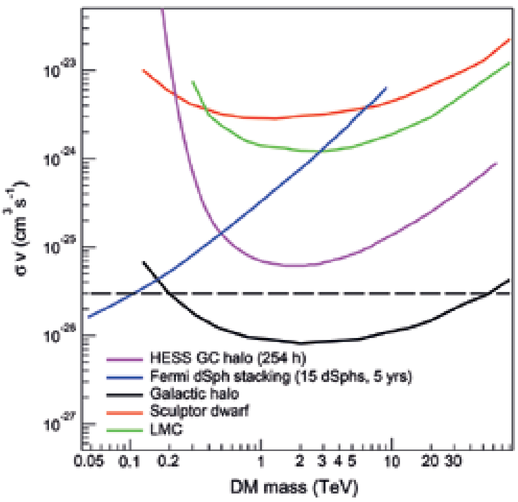


Fig. 2: The sensitivity of the gamma-ray observatories Fermi LAT, H.E.S.S., and CTA to DM annihilation from the direction of the indicated targets. W-W+ annihilation channels and a NFW dark matter profile is assumed in all cases.

One of the main observation channel for the IceCube neutrino observatory are annihilations of dark matter in the Sun. These observations lead to the currently most constraining limits on the spin-dependent WIMP-nucleon cross section. The most constraining searches for spin-independent WIMP interactions are performed by gamma-ray observatories like H.E.S.S. towards the Galactic centre region. The future CTA with its extraordinary increase in sensitivity and precision will allow to test dark matter models below the natural limit and will in combination with direct searches, particle accelerators, and indirect searches shed new light onto the enigmatic nature of dark matter.

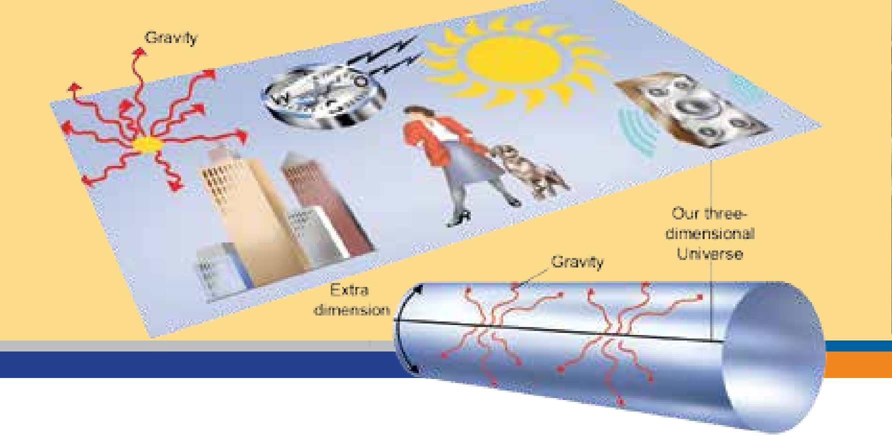
Topical Workshop „Data Analysis and Detector Technologies“

In a first topical workshop which took place November 18-23, 2012 in the Black Forest, 40 scientists participated, among them 23 PhD students. In 4 mini-workshops, participants were actively involved in training sessions on topics such as programmable hardware, data storage and analysis, and statistics of a few events. Short presentations by the PhD students stimulated discussions and the exchange of ideas. Feedback by the participants was overwhelmingly positive.

Topical Workshop on Indirect Searches

The HAP Workshop on data analysis for indirect searches took place in March 2014 at the Humboldt University in Berlin. The emphasis was to teach 45 students and young scientists from cosmic-ray, neutrino, and gamma-ray experiments the major ingredients of DM analyses and go one step further towards common analysis standards in the field. The topics were: 1. calculation of annihilation and decay spectra of dark-matter particles; 2. distribution of dark matter in the Universe derived from astronomical measurements; 3. statistical methods to understand the experimental data.

Dr. Klaus Eitel KIT
EDELWEISS, EURECA, KATRIN
Dr. Gernot Maier DESY in Zeuthen
CTA, VERITAS



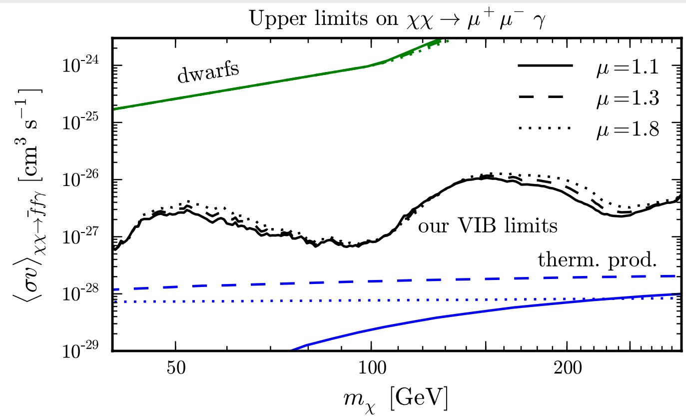
Dark Matter Candidates and Signatures

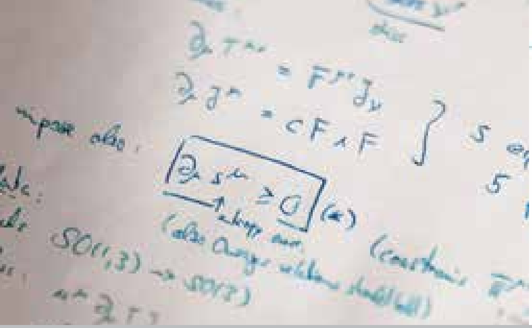
Dark matter has revealed its existence so far only through gravitational interactions. These indicate that it is much more copious in our Universe today than ordinary matter and that it might have played a major role in the formation of galaxies. Over the last six years, HAP theorists have left no stone unturned to identify its fundamental nature.

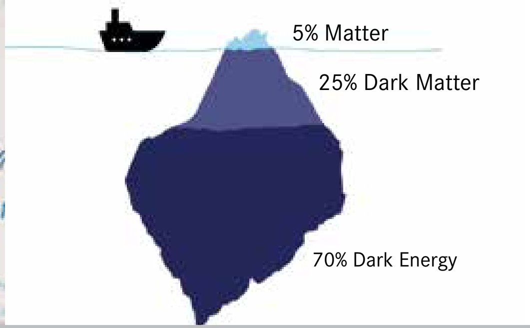
The Higgs boson, discovered at CERN in 2012, is believed to be responsible for the masses of all known fundamental particles. Yet, together they account for less than 5% of the total energy content of our Universe and for less than a fifth of all matter. This stunning fact, deduced from astronomical observations at very different length scales, from rotational spectra of galaxies to the cosmic microwave background, has inspired theoretical astroparticle physicists to imagine a large variety of possible dark matter candidates.
Celestial bodies such as MACHOs (MAssive Compact Halo Objects) are no longer very popular, to the contrary: for many years, WIMPs (Weakly Interacting Massive Particles) have taken the leading role as candidates for cold dark matter. They would in particular lead to the observed number of normal-sized galaxies. Predicted by many more fundamental theories like Supersymmetry, Grand Unified Theory, or Extra Dimensions, the experimental discovery of WIMPs would point theoretical research in particle physics in completely new directions.
This is why HAP theorists have been collaborating very closely with experimentalists in Geneva, at Gran Sasso or even Antarctica, where WIMPs could be produced at CERN's Large Hadron Collider (LHC), detected directly in large cryogenic detectors such as Xenon1T and CRESST-III or indirectly in large strings of photomultiplier tubes with the IceCube experiment. In most cases, signals from different detectors would have to be combined with each other, astronomical observations and previous knowledge on the Standard Model particles to uniquely identify the mass and couplings of the new particle(s).
So far, the model-dependent searches for the sophisticated theories mentioned above proved to be too

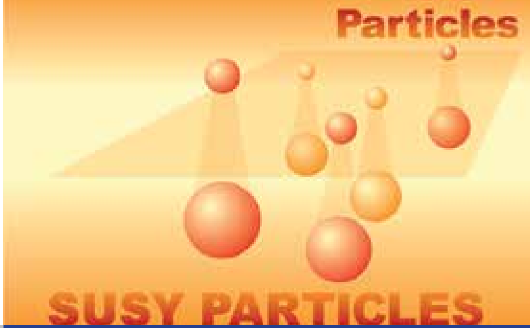
Fermi LAT Limits

The annihilation of dark matter in the galactic centre through virtual internal bremsstrahlung (VIB) can lead to gamma rays with pronounced spectral features. A dedicated search for the latter in the first 43 months of data from the Fermi LAT space telescope has allowed to set limits on the dark matter annihilation cross section (black lines), that are stronger than those from the observation of dwarf galaxies (green lines), and they now approach those expected for the thermal production of dark matter with masses m_χ between 40 and 300 GeV. This result does not depend significantly on the mass ratio squared of the mediating and dark matter particle μ [T. Bringmann et al., JCAP1207 (2012) 054].



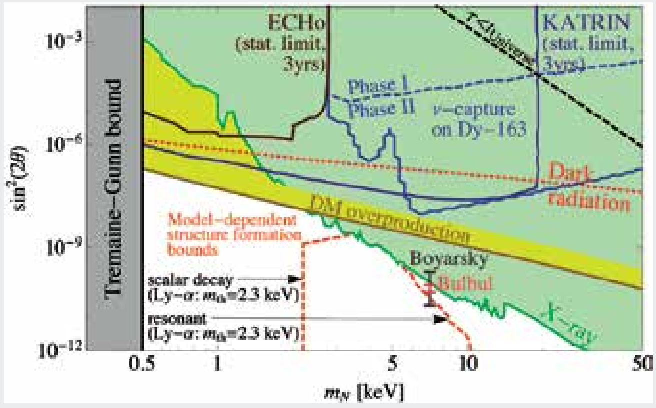






Sterile Neutrinos

Sterile neutrinos could well account for dark matter, but astronomical and cosmological observations constrain their masses m_N to the keV range and their mixings with ordinary neutrinos to very small angles θ. The strongest constraints here come from the observed amount of dark matter (yellow band) and the non-observation of X-ray photons from sterile neutrino decays (green line). If sterile neutrinos mix mostly with electron neutrinos, the ECHo (brown line) and KATRIN (purple line) experiments would be sensitive to larger regions in the upper half of the figure. The newest idea for a laboratory experiment is sterile neutrino capture on the otherwise stable isotope Dy-163 (blue lines) [M. Drewes et al., JCAP 1701 (2017) 025].



ambitious, with occasional flickers of hope from experiments soon turning out to be nothing but statistical fluctuations. HAP theorists have therefore more recently shifted their attention to simplified or even minimal models of dark matter. While these do not aspire to be complete theories that could eventually replace the Standard Model, they focus on the most intriguing aspects of dark matter: its mass – possibly also generated by a Higgs mechanism – and its hopefully not only gravitational, but also weak interactions – shared in particular with the neutrinos.

Although the absolute mass of neutrinos is yet to be determined, it is already clear that they can only account for a small fraction of dark matter. They would also constitute hot dark matter and thus first lead to very large cosmological structures, contrary to observation. They could, however, have heavier, sterile siblings in the keV mass range, that have no Standard Model interactions and would thus only be detected through their mixings with ordinary neutrinos or through their cosmological impact. Support for this idea comes from astronomical simulations of dwarf galaxies that would be produced in correct numbers by this type of warm dark matter.

HAP theorists and experimentalists have discussed many of the afore mentioned ideas at two widely noticed workshops, first at the University of Münster in 2013, then at the Karlsruhe Institute of Technology in 2015. Co-organised by Klaus Eitel of the KIT and Michael Klasen of Münster, the about 100 participants each included senior German dark-matter scientists, many postdocs and students, as well as experts from neighbouring countries such as Belgium, Denmark, France, the Netherlands, Spain, Sweden, Switzerland and the UK.

In part as a result of these workshops, HAP theorists Michael Klasen, Martin Pohl and Günter Sigl published a review dedicated to theoretical analyses of indirect and direct dark matter searches [Prog.Part.Nucl.Phys. 85 (2015) 1], while HAP theorist Manuel Drees, together with Saclay's Gilles Gerbier, regularly updated the Particle Data Group's review on dark matter. In total, the HAP Midterm Review in 2014 listed 81 scientific theory papers, many of them related to dark matter, and that number has almost doubled towards the end of HAP. Two papers are highlighted in the grey boxes.

Prof. Michael Klasen
Institut für Theoretische Physik, U Münster
Prof. Martin Pohl
Institut für Physik und Astronomie, U Potsdam

The Origin of Cosmic Rays

Whereas low energy cosmic rays are thought to origin within our own Milky Way the highest energy particles are most probable of extragalactic origin. A key to understand the entire physics of cosmic rays is the detailed study of the energy range of the transition of the actual sources of cosmic rays.

A clear understanding of the origin of cosmic rays at different regimes in primary energy, namely if they are of galactic or of extragalactic origin, is of paramount importance unveiling the nature of the sources of these particles. The observed energy spectrum of cosmic rays has approximately a power-law behaviour for 11 orders of magnitude in energy with several features that needs to be linked with particle propagation and acceleration. This power-law behavior is most probably indicative of a power-law acceleration spectra, while spectral features may be assigned to changes in the origin of particles, their propagation and acceleration mechanisms.
The most prominent features are the steepening (knee) of the spectrum at about 4 x 10^{15} eV and its recovery to a harder slope (ankle) at about 4 x 10^{18} eV (Fig. 1). The knee was discovered by the MSU (Moscow State University) array in 1958. In the standard picture, the knee is explained by the maximum acceleration energy for protons in our own Milky Way. In the framework of a charge dependent acceleration and propagation model

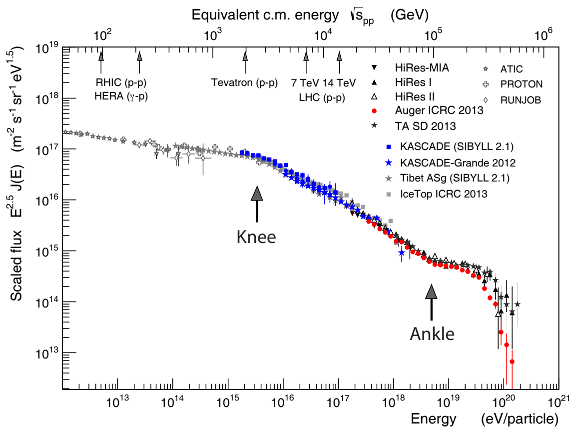
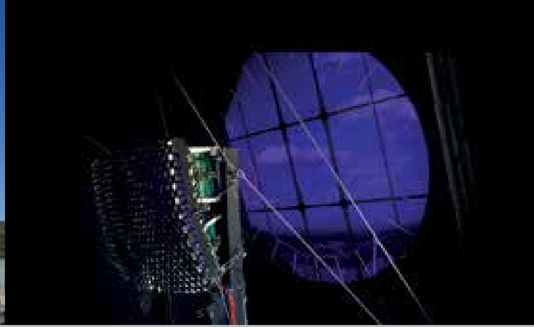


Fig. 1: The cosmic-ray energy spectrum.

it was predicted that then a knee of the most abundant heavy primary, i.e. iron nuclei, should be located at Z_{Fe} = 26 times higher energy, hence at ≈10^{17} eV. If this is found, it assigns the "formal" end of the Galactic Cosmic Ray spectrum. However, if only above the ankle cosmic rays are of extragalactic origin, a gap occurs between 10^{17} eV and 10^{18} eV, which is not well understood by present experimental results and which gives room for new theories and speculations. HAP contributes to resolve this puzzle mainly by two different experimental approaches:

KASCADE-Grande

The KASCADE-Grande cosmic ray experiment was located at the Karlsruhe Institute of Technology. It comprised in addition to the original KASCADE experiment 37 scintillation detector stations with an average spacing of 137 m for the measurements of cosmic rays in the energy range from the knee up to the ankle. The KASCADE-Grande experiment has significantly contributed to investigations of the energy spectrum and chemical composition of cosmic rays, in particular in the transition region from galactic to extragalactic origin of cosmic rays: interesting features were found including that the knee is originating from the decrease of flux of light primaries (Fig. 2). A 'heavy knee' at an energy a factor 26 (= the charge of an iron nucleus) higher than the first knee confirms the standard picture of galactic cosmic rays. In addition, an order of magnitude below the standard ankle an ankle-like feature was found for the light (proton and helium nuclei) primaries, which can be interpreted as a first signature of particles of extragalactic origin.


HEAT

For cosmic-ray studies in the energy range in which the transition of galactic to extragalactic cosmic rays is presumed to happen, the Pierre Auger Observatory enhanced the capabilities of its fluorescence detector by installing three additional **H**igh **E**levation **A**uger **T**elescopes (HEAT). With these telescopes, cosmic rays can be observed below the trigger threshold of the standard Auger design at energies where KASCADE-Grande was too small to collect enough statistics. First results on the average composition measured with HEAT show a smooth transition from the heavy (presumably galactic) component reported by the KASCADE-Grande Collaboration toward the predominantly light extragalactic cosmic rays.

Not yet concluding Physics …

We have learned that the knee-region in the cosmic ray energy spectrum can be explained as a charge dependent feature of primary cosmic rays. If this is due to a leakage of particles inside the Milky Way, which have been accelerated before to higher energies, or due to reaching the maximum acceleration energy at galactic sources is still an open question. For an improved understanding more data with increased composition sensitivity is required. In addition, data from the Pierre Auger Observatory indicate that cosmic rays above the ankle are accelerated outside of our own Galaxy. However, if indeed the transition from Galactic to extragalactic cosmic rays happens in such a wide energy range from knee to ankle is very questionable. Though astrophysical models are existing to describe this scenario, e.g. by acceleration in nearby starburst galaxies. In future, information from many experiments have to be combined by a so-named multi-messenger approach to finally reveal the secrets of the origin of high-energy cosmic rays.

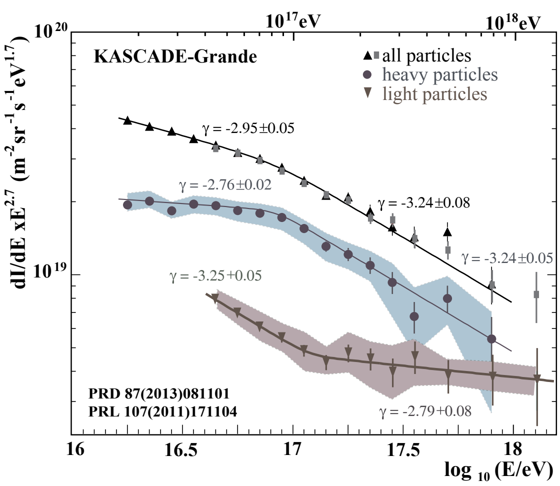


Fig. 2: Cosmic-ray spectra from KASCADE-Grande for all particles, light (electron-rich) and heavy (electron-poor) primaries.

KASCADE-Grande

252 stations on 200x200 m^2; multi-detector device to measure air-showers between 10^{14}-10^{17} eV; hadronic calorimeter and muon detection at four threshold energies; operation between 1994 and 2013; 2003 extension with the Grande array (sensitive up to 10^{18} eV) by installation of 36 large detector stations on an area of 0.5 km^2; 2005 proof-of-principle of radio detection technique by LOPES@KASCADE; ca. 80 scientist from 11 countries.

HEAT

Three tiltable buildings are situated close to one of the fluorescence buildings of the Pierre Auger Observatory. HEAT uses the same telescopes, but can be operated in two modes: the Down Mode, corresponding to the standard field of view, is used for installation, maintenance and calibration. In the Up Mode the whole telescope is tilted by 30 degree upwards allowing to measure the low energy events developing higher in the atmosphere.

Dr. Andreas Haungs KIT, Pierre Auger Observatory, KASCADE-Grande, IceCube-Gen2

Dr. Julian Rautenberg Bergische Universität Wuppertal, Pierre Auger Observatory and CROME


Cosmic Rays at the Ultrahigh-Energy Frontier

The origin of ultrahigh-energy cosmic rays has been a mystery for the last five decades. The Pierre Auger Observatory keeps accumulating precise data on these enigmatic particles to unveil their origin and nature. The instruments of the observatory are currently being upgraded to enhance the capability of determining the particle type of ultrahigh energy cosmic rays.

The highest-energy cosmic rays are considered to be particles that are accelerated at astrophysical objects in the Universe. These assumptions result in near-isotropic arrival directions of low-energy extragalactic cosmic rays and a flux suppression at ultrahigh energies because of energy losses en route to Earth by interactions with the cosmic microwave background radiation (Greisen-Zatsepin-Kuz'min (GZK) effect). However, the data of the Auger Observatory call for different and more elaborated interpretations. These interpretations involve models about hadronic interactions occurring in the particle cascades initiated by cosmic rays in the Earth's atmosphere at energies far beyond the LHC. Moreover, astrophysical assumptions about the sources of the highest-energy cosmic rays are needed and the propagation of cosmic rays in extragalactic photon fields needs to be taken into account as well as the deflection in Galactic and extragalactic magnetic fields. Due to the uncertainties of both the data and model assumption it is still difficult to draw unambiguous conclusions about the origin of ultrahigh energy cosmic rays. However, current data can be interpreted in favor of the observed flux suppression being caused by the upper-limit of the power of the cosmic ray accelerators.

Energy Spectrum

The energy spectrum of ultrahigh energy cosmic rays is measured in a so-called hybrid approach. Events which are detected by both the Fluorescence Telescopes and the Surface Detector array are used to calibrate the energy scale of the Surface Detector. The large exposure of the Surface Detector allows to measure the key features of the energy spectrum with high statistics. The spectrum is derived for energies above several 10^{17} eV

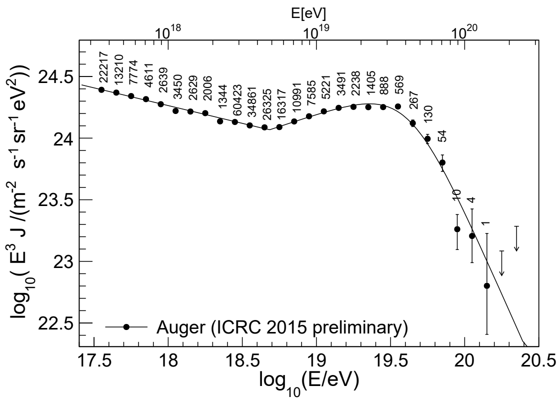
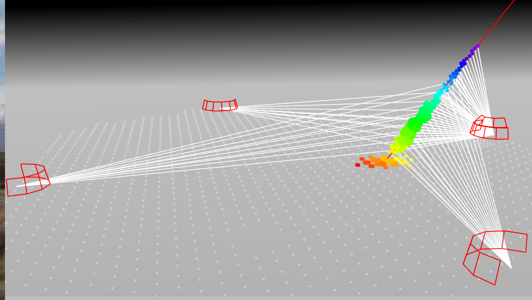


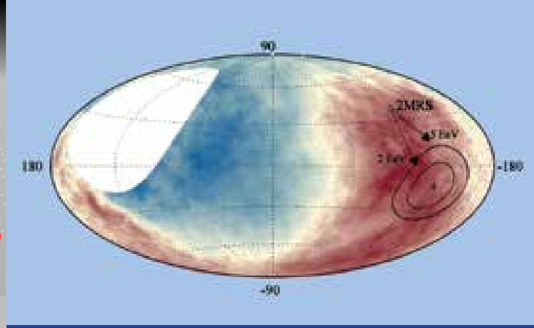
Fig. 1: Combined energy spectrum of cosmic rays fitted with a flux model. The number of events is given above the points.

and can be described by a broken power law with index -3.3 below the feature usually referred to as "the ankle" at around $10^{18.6}$ eV. Above the ankle, the spectrum is described by a power law with index -2.6 followed by a strong flux suppression, above E = $10^{19.5}$ eV (see Fig. 1). This suppression of the cosmic-ray flux has been established unambiguously with high significance by the Pierre Auger Observatory. Under certain assumptions about the distribution of possible sources in the Universe, the spectral shape can be described by both, a pure proton composition with a GZK-based flux suppression or by a mixed composition and the scenario of reaching the maximum acceleration energy at the source.

Composition

Until very recently, precise measurements on the nature of cosmic rays at ultrahigh energies did not exist and it was generally assumed that they are protons. This assumption is currently challenged by the Pierre Auger Observatory which recorded a large number of





particle cascades initiated by cosmic rays when they enter Earth's atmosphere. The interpretation of the fluorescence detector data leads to the conclusion that cosmic rays are indeed mainly protons at energies near the ankle, but that their average mass gets increasingly heavier as they approach the flux-suppression region. Above 10^{19} eV, the data are compatible with a proton fraction of 15% or less. A possible reason for this mysterious vanishing of protons at ultrahigh energy could be that only highly-charged (hence massive) nuclei can be accelerated to these energies in astrophysical sources. Unfortunately, composition measurements at highest energies are difficult due to the low statistics of events measured by the fluorescence telescopes.

Anisotropies

No convincing evidence for a small-scale anisotropy of the arrival direction of ultrahigh energy cosmic rays has been found so far. A tantalizing over-density of cosmic rays within a radius of 20° and in the vicinity of the supergalactic plane has been reported by the Telescope Array Collaboration in the Northern hemisphere. But neither this "hot spot", nor a weaker overdensity in the direction of the Centaurus supercluster of galaxies reported by the Auger Observatory, reach the required significance to exclude that they might just be a statistical fluke. A major breakthrough was however achieved at lower energies, where the Auger Observatory could for the first time detect a deviation from anisotropy at a very high level of confidence ("five sigma"). The cosmic ray sky at energies just below 10^{19} eV was found to exhibit a dipolar large-scale anisotropy with an amplitude of about 7%. The direction of the dipole is a strong evidence for the extragalactic origin of cosmic rays at these energies and it is compatible with the mass overdensity in the local neighborhood of our Galaxy. An illustration of the dipole can be seen on top in the right picture.

AugerPrime

The primary objective of the upgrade of the Auger Observatory is to answer the question about the origin of the flux suppression at the highest energies, i.e. the differentiation between the GZK-effect and the maximum energy of nearby astrophysical sources. Therefore, it will be of central importance to extend the composition measurements into the flux-suppression region and to enable composition-related anisotropy measurements at the highest energies. Moreover, explicit experimental confirmation of a 10-15% flux contribution of light elements at the highest energies will be a decisive ingredient for estimating the physics potential of existing and future cosmic ray, neutrino, and gamma-ray detectors.

To achieve these goals, the 1,660 existing water-Cherenkov detectors will be enhanced with a plastic scintillator and new readout electronics. The scintillator and water-Cherenkov detectors have different sensitivities to the electromagnetic and muonic component of the particle cascades. Using the combined information, the mass of individual primary particles can be estimated. The upgrade of the observatory will enhance its overall performance at the ultrahigh energy frontier until 2025.

The Pierre Auger Observatory

Completed in July 2008, it covers an area of about 3,000 km^2 near Malargüe, Argentina. The observatory consists of 1,660 Surface Detector stations which are water-Cherenkov tanks arranged in a triangular grid of 1.5 km spacing. The array is overlooked by 24 fluorescence telescopes distributed in four stations. Several installations complement the setup which are a 25 km^2 infill area with HEAT (3 High-Elevation Auger Telescopes), AMIGA (50 burried myon detectors), and AERA (160 radio antennas). Several calibration and monitoring installations complete the observatory.

Dr. Michael Unger KIT
Pierre Auger Observatory, NA 61
Prof. Karl-Heinz Kampert Bergische Universität Wuppertal, Lehrstuhl für Astroteilchenphysik

„What is your Main Motivation

Comments and thoughts of members and friends

Exploring what the most energetic particles can tell us about our cosmos is fascinating and needs collaborative and creative efforts.
Markus Risse, U Siegen

From infinitesimal fundamental particles to gigantic astronomical objects, it is the farthest-reaching journey your mind can embark on.
Carmelo Evoli, GSSI L'Aquila

Astroparticle Physics may provide us with novel diagnostics for the study of the small-scale structure of spacetime.
Frans Klinkhamer, KIT Karlsruhe

These mysteries and unknowns, the origin of time and space, dark energy, dark matter, new laws to invent are so tantalizing and challenging for the mind.
Sotiris Loucatos, Irfu CEA-Saclay and APC, Paris

We are studying fascinating phenomena and extreme physical conditions far beyond anything accessible in earth-bound laboratories.
Thomas Lohse, HU Berlin

Most violent environments in the universe? Super Massive Black Holes, Super High Energies, Supernovae, ... Super Cool!
Johannes Knapp
DESY in Zeuthen

Searching for tiny and rare particles in the Earth's atmosphere to explore the Universe with its many facets is really intriguing.
Bianca Keilhauer
KIT Karlsruhe

Always wondered where we came from, where we're going? Can't decide which is cooler, astronomy or particle physics? Astroparticle Physics is the answer!
Michael Klasen, U Münster

Exactly 30 years ago I was mesmerised by 24 neutrinos from SN 1987-A and launched neutrino astronomy in Zeuthen. This was the right choice: The astroparticle saga since then has topped my boldest expectations.
Christian Spiering, DESY in Zeuthen

I once started with astroparticle physics and couldn't stop since then.
Bernhard Siebenborn, KIT Karlsruhe

Leonardo da Vinci already answered this question 500 years ago: „Since in the inventions of nature (cosmic rays) nothing is missing or superfluous".
Karl Mannheim, U Würzburg

for Doing Astroparticle Physics?"

of the Helmholtz Alliance for Astroparticle Physics

To explore the most fundamental reality we need to study physics at the frontiers of knowledge. Astroparticles probe the most extreme energies and distances in the Universe and thus may hold the key to the physicist's dream of a unified description of Nature.
Heinrich Päs, U Dortmund

Having two Standard Models describing the micro- and macro-cosmos, but knowing also that Nature has plenty of fundamental, non-standard physics, what's the most exciting way to go beyond what is standard? Astroparticle physics!
Antonio Masiero
INFN and U Padua

Early on, I was overwhelmed by the pure size of the Universe. To understand the biggest, I first had to learn about the smallest things!
Stefan Schindler, U Mainz

25 years ago and interested in Astrophysics and in Particle Physics, KASCADE crossed my path: how can there be greater motivation to do Astroparticle Physics?
Andreas Haungs
KIT Karlsruhe

From far far far beyond the shining stars of Milky Way humongous creatures send cryptic messages to us with cosmic rays.
Oleg Kalekin, U Erlangen

SN1987A sent neutrinos for my 6th birthday. A school lesson about Pauli made me study physics. Tiny particles show great secrets of our universe. Wow!
Kerstin Fehn, U Erlangen

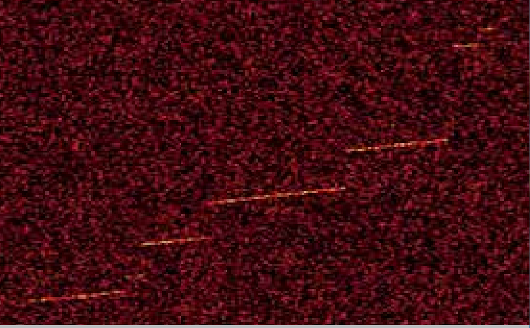
My motivation was to research dark matter, because I find it fascinating that so far we do not know what ~25% of the universe consist of.
Nils Håkansson
U Stockholm, Oscar Klein Center

It's simple: I want to see the cosmic Exa- and perhaps even the Zettatrons in the sky and ultimately even understand how they work.
Karl-Heinz Kampert
Bergische Universität Wuppertal

It is very fascinating that we can use properties of elementary particles to learn about the fate of the Universe as a whole - as well as the other way round!
Thomas Schwetz-Mangold
KIT Karlsruhe

Since I was young I was always intrigued by trying to answer the ultimate question of life, universe and everything ...
Bastian Beskers, U Mainz

The mysteries of physics which contradict our human experience and intuition most, are connected to the smallest particles and to the largest structures. This is why astroparticle physics is so fascinating to me!
Gisela Anton, U Erlangen



i-PROGRESS

HAP conducted an internship PROGram for Young RESearch Scientists[1] to work in one of the HAP-related experiments and to gain international experience at an early stage of their carreer.

This program aimed for supporting junior researchers at their early stage of career to gain international experience in the field of astroparticle physics. Young scientists got a unique opportunity to work in top research groups across Germany and Argentina, France, The Netherlands, Russia, USA as HAP-associated partner countries. Young scientists from abroad could apply for a research visit at a German institution and scientists affiliated in Germany for a research visit at an institution in Argentina, France, The Netherlands, Russia, or USA where at least the host institution for the visit is either a HAP member institution, a HAP as-

Christine Claessens
PhD student
from Johannes Gutenberg University Mainz
to CENPA, University of Washington

In which field are you doing your PhD?

Since January 2016, I am a PhD student at the experimental particle and astroparticle physics department (ETAP) of the Johannes Gutenberg University Mainz. My thesis is focused on data analysis and data acquisition for the Project 8 experiment. The Project 8 collaboration has recently developed the new field of Cyclotron Radiation Emission Spectroscopy and aims to employ it to measure the absolute neutrino mass.

Which project did you follow during your i-PROGRESS visit?

As KATRIN and Project 8 intend to push the precision limit of direct neutrino mass measurements down to the sub-eV region, molecular effects play a non-negligible role. Therefore the Tritium Recoil-Ion Mass Spectrometer (TRIMS) experiment is designed to measure the branching ratio of molecular tritium beta decay to the bound 3HeT+ molecular ion. During my i-Progess visit to the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington I joined the effort of assembling and preparing the modified main apparatus. The main focus of my work was the characterization of the ion detectors. Further tasks involved the installation, commissioning and field mapping of the magnets providing the solenoidal guiding field for the decay electrons. I also contributed to the installation of a ROACH2 board and the slow control applications of the Project8 experiment.

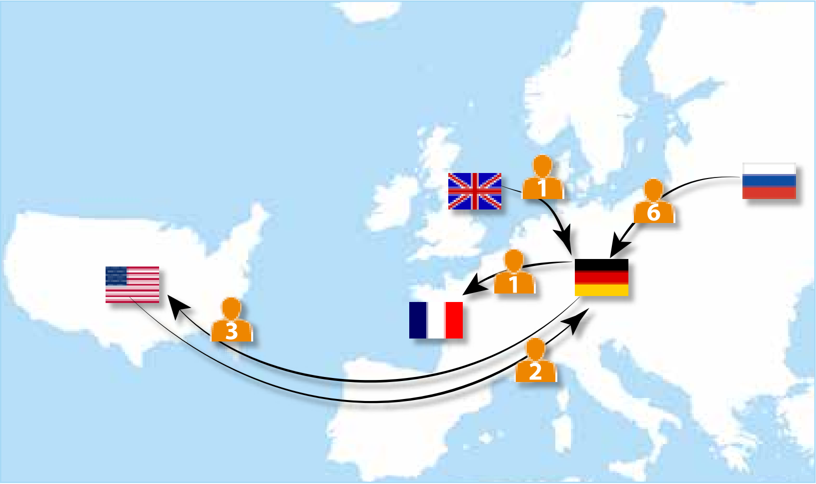
What are your personal benefits from i-PROGRESS?

I benefited substantially from the i-Progress internship program in many ways. Characterizing the detectors and working on the hard- and software side of the data acquisition systems for both TRIMS and Project8 enable me to contribute to the trigger development for Project8 as part of my PhD thesis. Assisting the assembly of the TRIMS main apparatus broadened my hardware knowledge and skills considerably and I enjoyed addressing all upcoming problems and solving them with the combined efforts of the excellent team at CENPA. Furthermore I feel that this has really strengthened my relationship with the other members of the KATRIN and Project8 collaborations at the University of Washington and I am looking forward to our continued cooperation.

sociated partner or an official collaborator of one of the HAP-related experiments. The period of visit were 2 months for a master student and 1 month for a PhD student.

From 2013 to 2016, 13 young scientists participated in this internship program. Four of the participants were Master students while nine were already doing their PhD thesis. This international experience was gathered by five female and eight male scientists with nine students coming from abroad to Germany and four Germans going abroad. Overall, five different countries were involved.

[1] *i–PROGRESS – reads as „I progress“, i.e. "I go forward, I improve"*



Alan Coleman
PhD student
from Penn State University
to Karlsruhe Institute of Technology

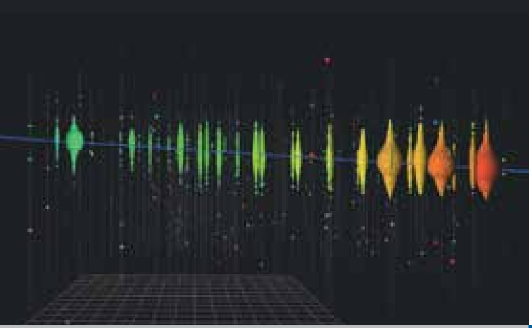
Which project did you follow during your i-PROGRESS visit?

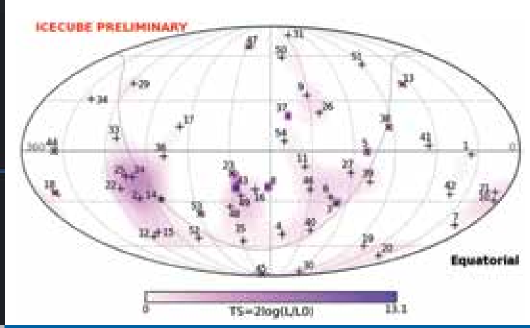
As part of my involvement in the Pierre Auger Observatory, I work with my KIT collaborators. When an ultra-high energy cosmic ray interacts with the air molecules high in the atmosphere it creates a large particle cascade called an air shower. At the energies Pierre Auger observes, the number of particles in showers is so large that fluctuations in the development of individual air showers are small. This concept is called universality. Ways are studied to incorporate universality into our reconstruction algorithm in order to increase the variety of measurements the Auger surface detectors can make. I was able to use the extensive library of air showers that researchers at KIT have not only simulated, but developed the software to do so.

What are your personal benefits from i-PROGRESS?

One of the most useful aspects of this trip was building a connection with my collaborators and being able to have face-to-face conversations with them about their work and mine. So far the work on using universality in Auger has been to extend the measurements of primary masses we observe to higher energies. My thesis work involves extending universality to lower energies instead. While on my trip to KIT I was able to discuss with my collaborators strategies for developing the reconstruction method further.

For me the greatest benefit from my i-PROGRESS internship are the personal connections with my collaborators who otherwise I might not have met. Since arriving back at my home university in the United States, I have continued to work with the KIT researchers daily.





Neutrinos on the Rocks: IceCube

The discovery of astrophysical neutrinos by the IceCube Observatory in 2012 has opened a new window to the non-thermal universe. These elusive messengers allow us to explore the universe at PeV energies and to study and understand the most extreme environments of our cosmos.

The IceCube Neutrino Observatory

The IceCube Observatory (Fig. 1) is located at the Amundsen-Scott South Pole Station. It is run by an international collaboration of nearly 300 scientists. Germany participates in IceCube with DESY and nine university groups, contributing one third of the IceCube authors. KIT and MPP are associated IceCube members.

A total of 5160 optical sensors have been deployed on 86 strings deep in the Antarctic ice, at depths between 1450 m and 2450 m, instrumenting a volume of 1 km^3. The sensors measure the Cherenkov light that is emitted by charged particles produced in neutrino interactions inside or around the detector. Different flavors of neutrinos produce different signals. Most muon neutrino interactions produce a signal pattern that resembles a long track and tell us accurately which directions the neutrinos came from. Other types of neutrino interactions (and some muon neutrinos) produce a spherical light pattern when they interact inside IceCube, allowing an accurate measurement of the incoming neutrino energy.

A densely instrumented region in the bottom center of IceCube (called "DeepCore"), lowers the energy threshold to < 10 GeV and enables neutrino oscillation studies with atmospheric neutrinos. On the surface, IceTop completes the IceCube observatory. It is an air shower array consisting of 162 ice-Cherenkov tanks co-located with the IceCube strings to measure the elemental composition of cosmic rays by combining the signals on the surface and in the ice. IceTop is also used to identify and discard muons from cosmic-ray air showers in neutrino searches.

HAP funding allowed us to develop scintillator-based detectors to improve the surface detectors and mitigate the effects of snow accumulation on the IceTop tanks. It also allowed to deploy a prototype of a Cherenkov camera for air shower detection (IceACT) which is a promising technology for a possible future extension of the surface array.

Cosmic Neutrinos

The properties of the newly discovered flux of cosmic neutrinos were surprising for many in the scientific community. It was widely expected that IceCube would first discover a few individual bright sources of neutrinos, maybe connected to the enigmatic phenomena of gamma-ray bursts (GRBs) or the powerful jets that can form around supermassive black holes in the center of active galaxies. Yet, the observed cosmic neutrino flux seems to arrive from all directions with similar strength, implying that whatever the sources are they must be numerous, but not very powerful neutrino emitters to avoid being resolved individually.

With no sources present the most valuable information we can extract from the cosmic neutrinos is their energy spectrum and flavor composition that both can give us indirect clues about their origin. Within HAP, a study was performed that combined different signal patterns and different datasets in a single analysis, which derived the best constraints on the neutrino energy spectrum and the relative contribution of the different flavors so far. The obtained spectrum has been used widely in the neutrino astrophysics community to judge the viability of different models of the origin and production mechanisms of the cosmic neutrinos.

Several more studies of HAP members allowed to narrow down the origin of the astrophysical neutrinos,

even though no positive evidence for a specific astrophysical source population could be found. Studying the clustering of neutrinos in space and time excluded short, bright neutrino bursts as the origin of the cosmic flux, as would be expected from e.g. GRBs. They cannot contribute more than a few percent. A cross-correlation study between the arrival directions of neutrinos and the locations of active galaxies observed in GeV gamma rays did not find any correlation, implying that also these galaxies can contribute only a small fraction to the observed neutrino flux. A similar cross-correlation study with a catalog of nearby supernovae is still ongoing.
In summary, the quest for understanding the origin of the cosmic neutrinos is still on-going. However, significant constraints on the populations of sources where the cosmic neutrinos can come from could be derived over the last years.

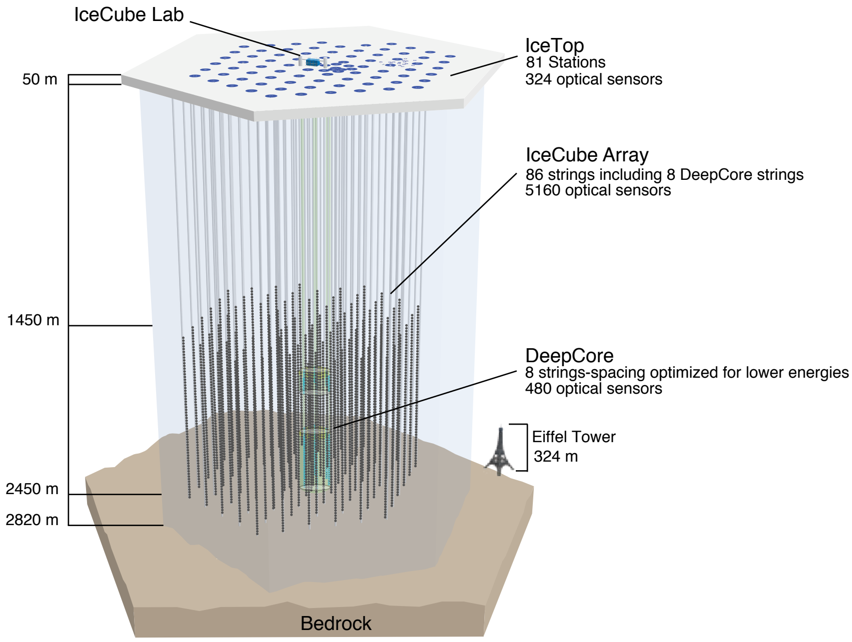


Fig. 1: The IceCube detector with its sub-detectors.

Properties of Neutrinos

IceCube is not only an instrument for astronomy. The large number of neutrinos from the atmosphere that are observed in the array can be used to study fundamental properties of the neutrino itself. In particular the phenomenon of neutrino oscillations, i.e. neutrinos “switching” flavors dependent on their energy and the distance traveled. Some of the atmospheric neutrinos produced above Antarctica have traveled only a few tens of km when they reach IceCube, others arrive from the opposite side of the Earth after a journey of more than 10,000 kilometers. Comparing their numbers tells us how many have oscillated into a different flavor, and enables us to determine the parameters that govern this oscillation, e.g. the mass difference between two types of neutrinos and their mixing angles.
Fig. 2 shows the result of a HAP-funded study that allowed the first precise measurement of neutrino oscillation properties with IceCube. The number of observed neutrinos is shown. A comparison to the expected numbers of neutrinos assuming that no oscillation phenomena exist, indicates the measurement precision that can be achieved with IceCube.

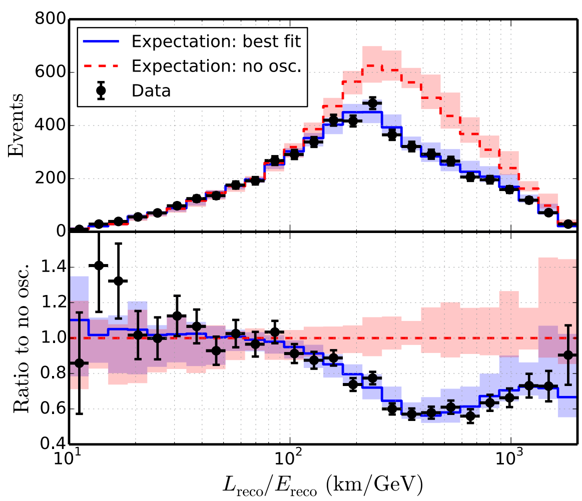


Fig. 2: Number of muon neutrinos detected in IceCube (black) as a function of the ratio between the travelled distance and the neutrino energy. It is compared to the expected number without neutrino flavor oscillations (red) and the expected number with the neutrino oscillation parameters that fit the IceCube data best (blue).

Dr. Markus Ackermann DESY in Zeuthen
IceCube, Fermi
Dr. Timo Karg DESY in Zeuthen
IceCube

Neutrinos in the Mediterranean Sea

For full-sky coverage in the full energy range of interest, neutrino astronomy must encompass observatories at different geographic locations. The deep waters of the Mediterranean Sea offer optimal conditions for a Northern-hemisphere instrument. Building on the success of the ANTARES detector, construction of the future KM3NeT telescope has started.

Neutrino telescopes in the deep sea measure high-energy neutrinos by detecting the faint Cherenkov light induced by charged secondary particles produced in neutrino interactions. They employ photomultipliers serving as photon sensors, installed in glass spheres providing protection against the immense pressure and the chemically aggressive salt water. Even though this concept is shared between ice and water detectors, the technical implementation is significantly different for both media and poses major technological challenges. The first water project – DUMAND close to Hawaii – started as early as 1976, but it took until 2008 to complete construction of the first-ever deep-sea neutrino telescope, ANTARES

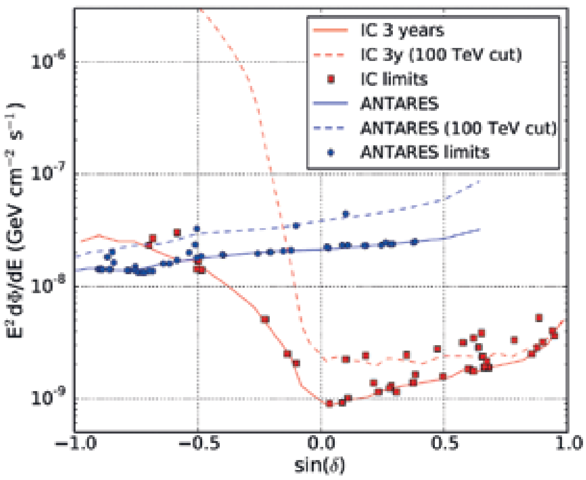


Fig. 1: 90% CL limits for selected sources (squares and dots) and sensitivities using the Neyman method as a function of the declination (lines) reported in the ANTARES 2007-2012 (blue) and the IceCube 3 years (red) point source analyses. An unbroken E^{-2} power-law source spectrum is assumed for the limits and lower sensitivity curves (solid lines). Dashed lines indicate the sensitivity for an E^{-2} spectrum with neutrino energies of $E_\nu \leq 100$ TeV using the Neyman method (Astrophys. J. 823:65, 2016).

- **A**stronomy with a **N**eutrino **T**elescope and **A**byss environmental **RES**earch. An underwater neutrino telescope installed in lake Baikal came into operation much earlier, but did not have to overcome the difficulties imposed by the salt water environment.

During the HAP core-funding period, ANTARES was taking data at full steam, and HAP supported various analyses through the Non-thermal Universe topic. A very wide spectrum of scientific questions have been addressed using ANTARES data, resulting in more than 30 publications since 2011. They cover results on the search for astrophysical point sources of neutrinos, on diffuse neutrino emission from regions like the Fermi Bubbles or the Galactic ridge, on the search for neutrinos from annihilation of dark matter particles, or the search for magnetic monopoles. Regrettably, no neutrino signals could be observed so far. The exclusion limits are, however, complementary to those of IceCube, and some of them constrain parameter spaces of underlying models significantly.

In particular during the past years, ANTARES has assigned high priority to multi-messenger analyses and is part of a global alert network, both generating and receiving alerts. These activities have resulted in a number of publications together with collaborations operating optical telescopes, satellite-borne X-ray instruments, and gravitational wave detectors. A common paper with LIGO/Virgo was presented together with the first detection of gravitational waves in 2015 and has received a lot of attention. Furthermore, a common ANTARES and IceCube publication on a search for point sources in the combined data samples has appeared in 2016. Fig. 1, taken from this paper, shows the sensitivities of ANTARES and IceCube to neutrino fluxes from point



Fig. 2: A KM3NeT DOM consists of a spherical glass vessel with a wall thickness sufficient to withstand the enormous pressure at the bottom of the sea - up to 350 times the normal atmospheric pressure. In this glass vessel 31 photomultiplier tubes have been arranged to look in all directions for the faint light emitted by particles passing by.

sources with a "generic" neutrino energy spectrum proportional to E^{-2}, with and without an assumed cut-off at 100 TeV. It becomes very clear that even a relatively small detector like ANTARES provides highly important complementary information to a large one like IceCube if situated on the other hemisphere.

In future, the Mediterranean neutrino telescope KM3NeT is to provide similar sensitivity as IceCube and will thus open the era of full-sky neutrino astronomy. KM3NeT will comprise two installations – **A**stronomy **R**esearch with **C**osmics in the **A**byss (ARCA) for high-energy cosmic neutrinos and **O**scillation **R**esearch with **C**osmics in the **A**byss (ORCA), a densely instrumented detector for neutrino physics with atmospheric neutrinos in the few GeV regime. Both ARCA and ORCA will use the exact same technology and will have common management, data repositories, etc. During the HAP core-funding period, the design of KM3NeT has been finalised and the construction of the detector has started. In particular, HAP has contributed significantly to technical work on the digital optical modules (DOMs), and on a DOM assembly line in Erlangen. Currently the first two ARCA strings (18 DOMs each) are taking data, and 29 further strings are expected to be installed before the end of 2018 ("Phase-1", fully funded). Subsequently, ARCA (230 strings) and ORCA (115 strings) will be completed in KM3NeT 2.0.

A particularly important technical development for KM3NeT is the DOM, housing 31 3-inch PMTs instead of one large one (see Fig. 2). This design maximises the photocathode area per DOM and minimises the risk due to cable penetrations, provides enhanced photo-counting capability, and adds directional sensitivity. A similar design is meanwhile also under consideration for the future IceCube-Gen2 project.

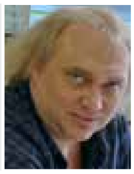
A big advantage of KM3NeT will be the superb angular resolution, both for track-like (median <0.1° at high energies) and for cascade events (median <2° beyond 100 TeV). It is expected that these resolutions will greatly help in investigating the origin and nature of the diffuse flux of cosmic neutrinos reported by IceCube.

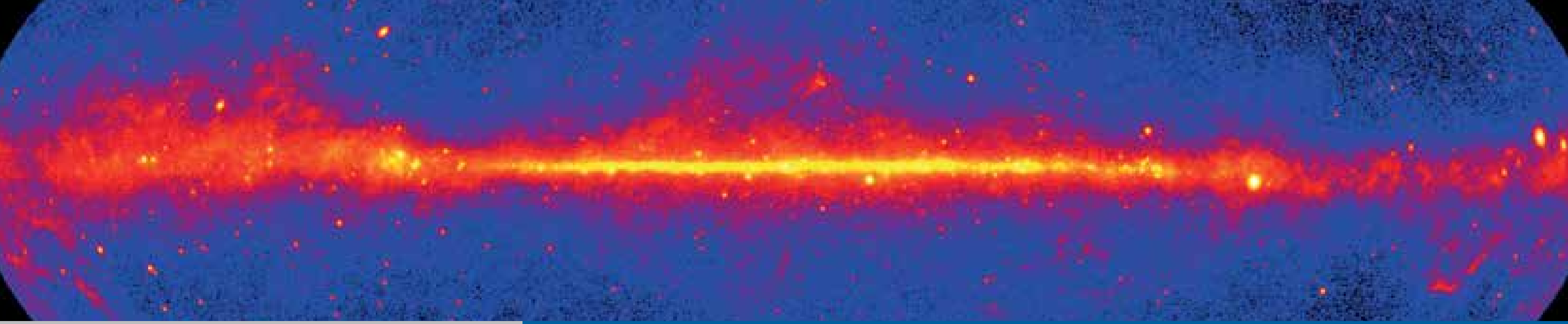
In addition to neutrino detection, ANTARES and KM3NeT also provide the unique opportunity to perform long-term, real-time measurements for deep-sea research, in fields such as marine biology, oceanography, or environmental sciences. Various studies are pursued in ANTARES, and a series of publications demonstrates the importance of this interdisciplinary cooperation.

GNN

The **G**lobal **N**eutrino **N**etwork (GNN) aims for a closer collaboration and a coherent strategy among the neutrino telescope projects. At present, it comprises the ANTARES, Baikal/GVD, IceCube and KM3NeT collaborations. GNN aims to foster cooperation between these collaborations and to exploit synergistic effects. In a yearly meeting organised by GNN, the collaborations exchange news on physics results, analysis methods and hardware developments.

Prof. Uli Katz
Lehrstuhl für Astroteilchenphysik,
FAU Erlangen-Nürnberg
ECAP - Erlangen Centre for Astroparticle Physics





The Fermi Large Area Telescope

The Fermi Gamma-ray Space Telescope is a multi-agency space mission with the Large Area Tele-scope (LAT) as main instrument on-board. Gamma-ray measurements are complemented by Cherenkov telescopes towards higher frequencies. Within the framework of HAP, analysis of LAT data focused on the variable gamma-ray sky and the extragalactic gamma-ray background.

The Variable Gamma-Ray Sky

With the Fermi All-sky Variability analysis (FAVA), a tool has been developed for routinely scans of the gamma-ray sky for gamma-ray eruptions. Every week a list of flaring gamma-ray sources is determined and published by NASA, http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA. HAP supported the development of FAVA. These flares were used to build the first catalog of flaring gamma-ray sources. In total 518 sources were found. Their positions in the sky are shown in Fig. 1. The kind of sources are very different in nature. They range from super massive black holes in the center of distance galaxies, to Nova explosions in our Galaxy and variable pulsars.

One flaring source of particular interest has been the Crab nebula. This is one of the most studied sources in astronomy. It is the remnant of an historical Supernova observed in 1054 AD. Using FAVA, it was shown that this source showed strong eruptions in gamma-ray (Bühler & Blandford, RPPh 77 6, 2014). This was highly unexpected since before it was expected that the source has a constant emission over time. In fact, it was therefore often used to cross calibrate instruments at other frequency bands. Understanding this puzzling flares has been an important subject of research over the past years. It was realised, that standard acceleration of particles in the source are not fast and efficient enough to explain these events. More likely, the eruptions are related to magnetic reconnection events, similar to the ones observed during solar eruption.

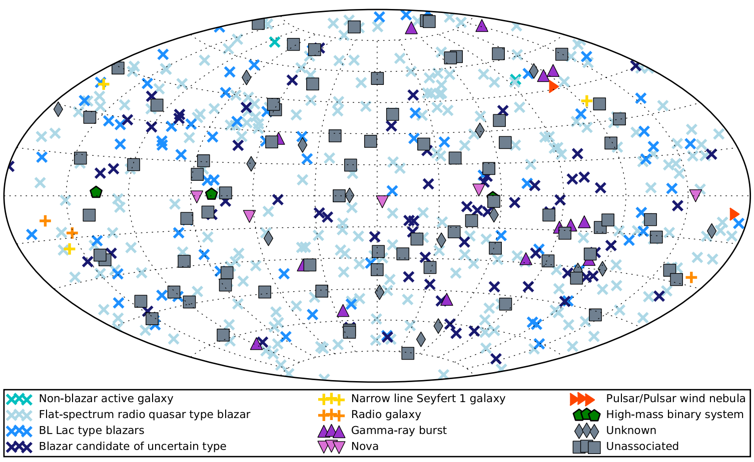
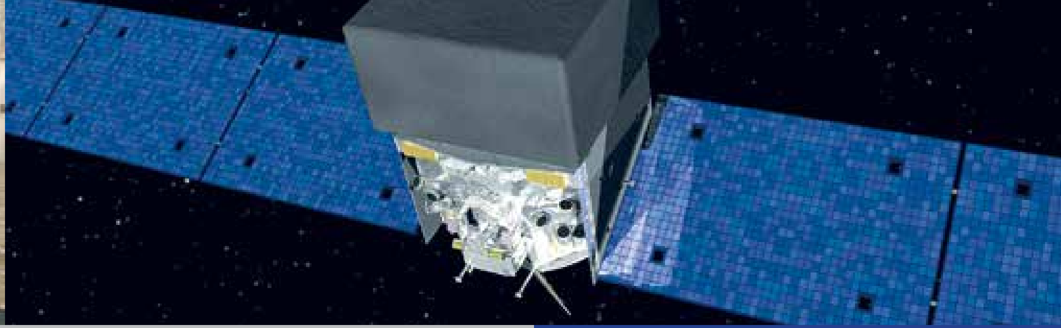


Fig. 1: Sky map of the catalog of flaring gamma-ray sources, differen-tiated by source class (galactic coordinates, Aitoff projection).

The Extragalactic Gamma-Ray Background

Gamma rays of MeV and GeV energies can reach Earth from almost anywhere and anytime in the universe, as far back as the age of the very first stars and galaxies. Even the faintest and most far away sources contribute to the gamma-ray glow we see looking out into the universe. This glow is called the Extragalactic Gamma-ray Background (EGB). Most, if not all of it, originates from sources very much like the ones that we can readily observe on the gamma-ray sky. While the objects with the strongest gamma-ray emission show up as individual sources, far more of these sources are too distant or too faint to iden-



tify them as sources. All we can observe is a diffuse isotropic glow, very much like we see the Milky Way only as a diffuse band when we watch the night sky with our bare eyes.

Still the EGB is of fundamental importance. Since no photon is lost on its way to Earth from the time of the early universe, it gives a strong and fundamental upper bound on the density and luminosity of all sources that produce gamma rays. Even more important it constrains as well gamma-ray production in processes that are not related to astronomical sources. Such processes could be the interactions of cosmic rays with the cosmic microwave background and other radiation fields. Gamma rays could also arise from new physics like the annihilation of dark matter into photons or the evaporation of primordial low-mass black holes. Some of the strongest constraints on such beyond-the-standard-model physics came from comparing the expected gamma-ray production in these models to the observed level of the EGB.

HAP funding helped in improving the measurement of the EGB as well as in the investigations of how its origin is related to the origin of the cosmic neutrino flux (for further reading see also “Neutrinos on the Rocks: IceCube” in this brochure). Fig. 2 shows the current best measurement of the EGB from Fermi LAT observation together with estimates of the contributions of different astrophysical source populations. Above energies of a few GeV blazars dominate the gamma-ray sky. Blazars are galaxies with supermassive black holes at their center that convert gravitational energy from in-falling matter into powerful jets of relativistic particles. The emission is even more amplified by the fact that the jets are pointing towards Earth. Other cosmic populations or even processes involving new physics can only contribute a small fraction of the total EGB.

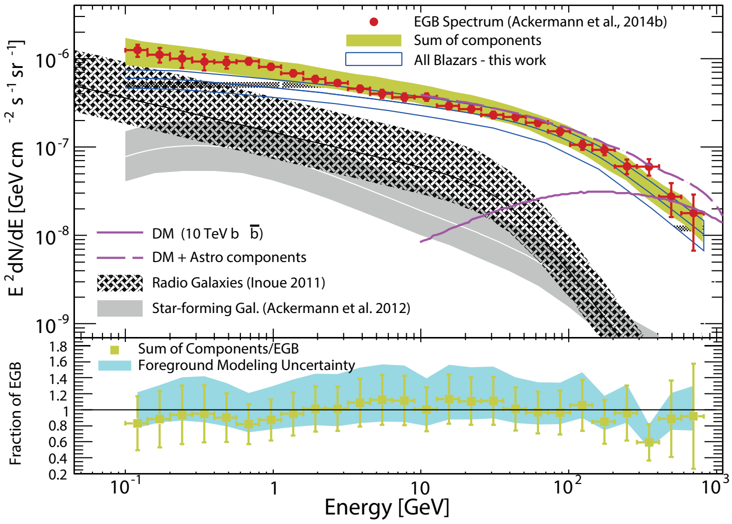
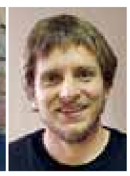


Fig. 2: Spectrum of the EGB with estimates of the contributions of different astrophysical source populations. The purple line shows a hypothetical contribution from the annihilation of dark matter that would exceed the observed level of the EGB. Adopted from Astrophys. J. 800, L27, 2015.

Fermi Gamma-ray Space Telescope

Launched on June 11, 2008, the Fermi Gamma-ray Space Telescope observes the cosmos. Mapping the entire sky every three hours, Fermi provides an important window into the most extreme phenomena of the universe, from gamma-ray bursts and black-hole jets to pulsars, supernova remnants and the origin of cosmic rays. The Large Area Telescope (LAT) is the principal scientific instrument on the Fermi Gamma Ray Space Telescope spacecraft. The LAT is an imaging high-energy gamma-ray telescope covering the energy range from about 20 MeV to more than 300 GeV.

Dr. Markus Ackermann DESY in Zeuthen
IceCube, Fermi
Dr. Rolf Bühler DESY in Zeuthen
CTA, Fermi





The H.E.S.S. Experiment

The H.E.S.S. (High Energy Stereoscopic System) telescopes are located in the Southern Hemisphere, in the highland of Namibia. Unlike other Cherenkov telescopes, they can therefore observe the inner Milky Way and the Magellanic Clouds in the Teraelectronvolt (TeV) gamma-ray band under optimal conditions.

The inner Milky Way is the host of many cosmic particle accelerators. Most of them are remnants of supernova explosions, like neutron stars (pulsars), pulsar wind nebulae or shell-type supernova remnants. H.E.S.S. has performed a 10-year survey of the entire Galactic plane it can observe, revealing 78 TeV emitters that were not known before. The most frequent sources are pulsar wind nebulae. DESY scientists have made major contributions to the understanding of this class, contributing a population study (Fig. 1) and modeling code for the interpretation of their cosmic plasma clouds. The past five years have brought major new insights from H.E.S.S., and DESY has coordinated a major camera upgrade campaign that will ensure a smooth operation of H.E.S.S. in its final years until the Cherenkov Telescope Array (CTA) will take over the lead of the field.

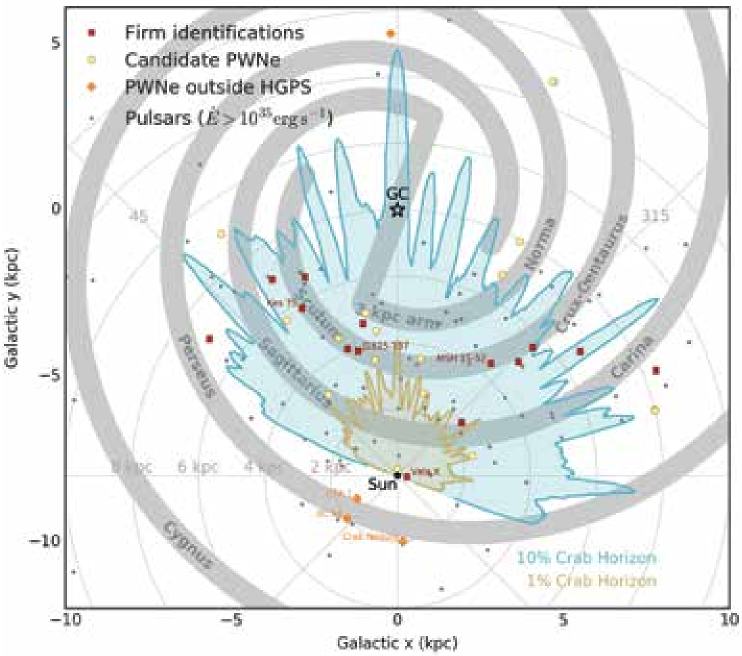


Fig. 1: Firmly identified pulsar wind nebulae and candidates found in the spiral arms of the Milky Way.

Cosmic Pevatron

The possibly most powerful accelerator was only discovered in 2016, in an indirect way: An analysis of diffuse gamma-ray emission in the inner 200 parsecs around the central black hole of the Milky Way revealed a characteristic radial profile and a very hard emission spectrum. Allowed for the conclusion that a very powerful variable accelerator in the centre of the Milky Way injects particles of up to 10^{15} eV (PeV) energies, which over a long time scale diffuse outwards, producing gamma-ray emission on their way. This cosmic accelerator, possibly the black hole itself, might thus be the first cosmic PeVatron ever identified.

Large Magellanic Cloud

Another interesting astrophysical environment in the Southern Sky is the Large Magellanic Cloud (LMC), which is a nearby satellite of the Milky Way. At a distance of 163.000 light years, it is one of the few galaxies that can be resolved and surveyed with present-day Cherenkov

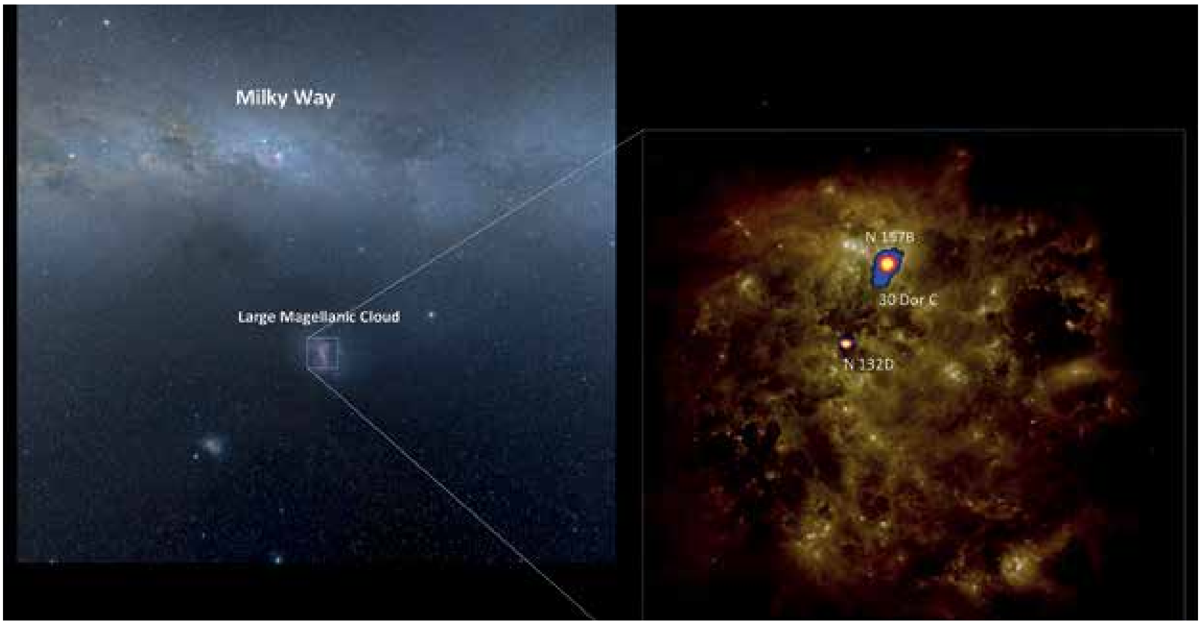


Fig. 2: Optical image of the Milky Way and an infrared zoom into the Large Magellanic Cloud with superimposed H.E.S.S. sky maps.

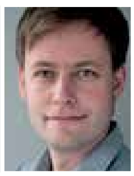
telescopes. After 210 hours of observation, the first H.E.S.S. results have been published in 2015 in the journal Science: Three TeV gamma-ray sources were found (Fig. 2), including the most luminous pulsar wind nebula ever found (N 157B), and a so-called "superbubble" (30 Dor C), which is a class of object that was not seen in gamma-rays before.

Camera Upgrade

A big hardware project, conducted by DESY physicists, engineers and technicians, was started in 2012 and aimed for the modernisation of the four cameras of the 12-meter H.E.S.S. I telescopes. The cameras had been installed in 2003 and had approached the end of their lifetime, with increasing failure rates and decreasing data quality. For the design of the refurbished cameras, modern technology was used wherever possible: For the readout chips that digitise the signals of the photo sensors, NECTAr chips (**N**ew **E**lectronics for the **C**herenkov **T**elescope **Ar**ray) were used, which will also be used in cameras for the CTA mid-size telescopes. The readout uses a fast Ethernet switch.

In 2015, the first DESY-built camera was installed, and in 2016, the rest of the array was upgraded. The project finished in time and on budget, and the first TeV source was detected in spring 2017. As a result, 4 out of 12 presently operating cameras of Cherenkov telescopes were built at DESY (with support of HAP), proving that the CTA technologies used are working for TeV astronomy and that DESY is a capable partner for the design and production of sophisticated components for Cherenkov telescopes.

Dr. Stefan Klepser
DESY in Zeuthen
H.E.S.S. group leader at DESY



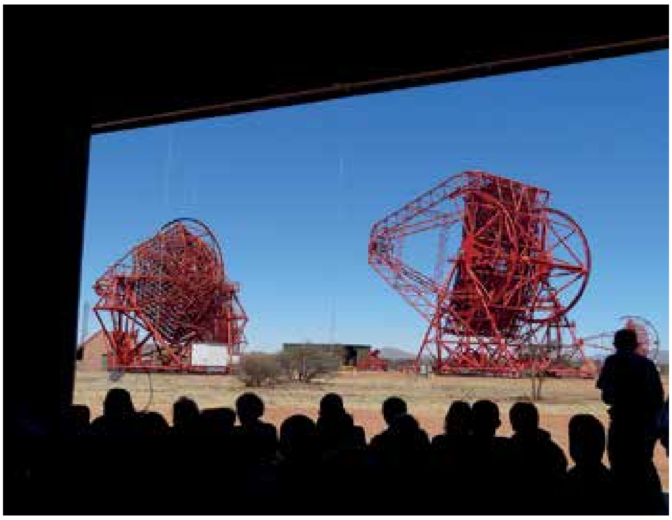
Journey to H.E.S.S.

In September 2012, ten years after the inauguration of its first telescope, the H.E.S.S. collaboration made another major step towards exploring the high-energy Universe with the inauguration of the second phase of its telescope array. *Journey to H.E.S.S.* is a travel diary about the celebrations of the H.E.S.S. II telescope in Namibia.

H.E.S.S. is a system of Imaging Atmospheric Cherenkov Telescopes that investigates cosmic gamma-rays in the energy range from tens of GeV to tens of TeV. Together with the four smaller (12-metre) telescopes already in operation since 2004, the H.E.S.S. II telescope adds a 28-metre mirror to the array and is dedicated to observing the most violent and extreme phenomena of the Universe in very high-energy gamma-rays.

The new H.E.S.S. II telescope was officially dedicated on September 27-30, 2012. The festivities began with a scientific symposium, followed the next day by the official inauguration on the H.E.S.S. site. Finally, the celebrations ended during the weekend with an open house.

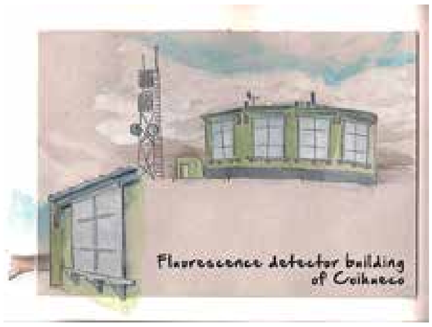
Journey to H.E.S.S. is a collection that mixes photography, graphic design, video and new media to show the H.E.S.S. telescopes and the science of high-energy gamma-ray in a different and entertaining way. This blog was written by Astrid Chantelauze, HAP science outreach manager.



journeytohess.tumblr.com

Journey to Auger

In November 2015, the Pierre Auger Observatory celebrated 15 years of achievements and signed a new International Agreement to run for another ten years with an upgraded detector design, so-called AugerPrime. *Journey to Auger* is a travel diary about the celebrations of Auger-Prime in Malargüe, Argentina.

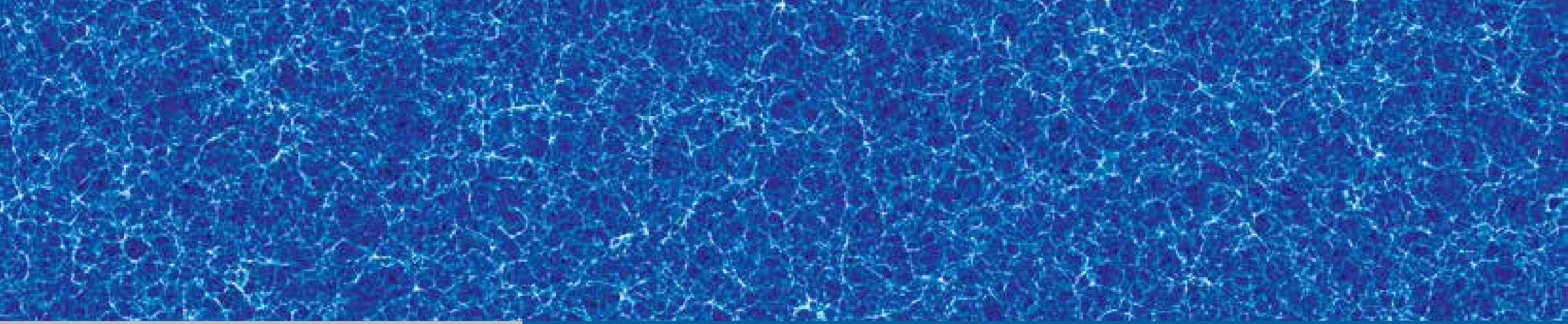


The Pierre Auger Observatory is the largest running detector field for exploring cosmic rays at the highest energies. The AugerPrime upgrade most visible feature enhances the 1,660 existing surface detector stations with new scintillation detectors.

The AugerPrime symposium was held on November 15-16, 2015. The festivities began with presentations of the Observatory and visits of the Central Campus and "in the field" of one of the fluorescence telescope buildings, surface detector stations and an AugerPrime prototype station. The next day the signing ceremony of a new International Agreement took place for continued operation of the Pierre Auger Observatory until 2025, followed by the annual Malargüe Parade.

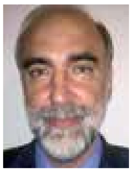
Journey to Auger aims to show the Observatory and the science of high-energy cosmic-rays in a different and entertaining way. This blog was co-written by Astrid Chantelauze and Marie-Noëlle Rolland, a freelance graphic designer.

journeytoauger.tumblr.com



German Science, Astroparticle Physics and HAP

German science has played a central role in shaping the world as we know it. Nowadays, Germany is the economic engine of Europe, but it can also be the catalyst for Europe to regain the world scientific leadership it had for centuries. The astroparticle physics in which HAP stands out can be a prototype of that future that awaits us.



Prof. Carlos Muñoz Theoretical Physics,
Universidad Autónoma de Madrid and
Instituto de Física Teórica IFT UAM-CSIC
Member of the HAP Advisory Board

When we teach our students at university about twentieth-century physics, it is inescapable to explain the two great scientific revolutions that changed our way of understanding the world, relativity and quantum physics, and the scientists who made them, Einstein, Planck, Heisenberg, Schrödinger, Pauli, Born ... The truth is that when I talk about these giants of science and their theories, I never associate them with any nationality, for me they are universal, citizens of the world, but ... if I stop for a while to think about it, I realise that many of them were German scientists. Germany, from the middle of the eighteenth century until the first decades of the twentieth century, through its science and culture, has shaped the world. Kepler, Humboldt, Helmholtz, Hertz, Röntgen and many other scientists contributed to this feat. Suffice it to recall that until the 1940s, Germany had generated more Nobel Prizes in science than any other nation.

There is a correlation between the scientific achievements of a nation and its economic development. Which of them is the cause and which effect is debatable, but what is clear is that both are united. Nowadays, Germany is the economic engine of the European Union and therefore has a solid basis to also contribute to Europe regaining the scientific leadership worldwide that it had for centuries. A German boost in that direction is fundamental. Maybe it is in physics where we are better prepared to take that leap. What better example than we can get that CERN, the European organization leading the world in particle physics. Its discoveries will continue to be studied in Universities forever.

Closely related to particle physics, astroparticle physics is a new emerging and thriving field at the frontier of science that attacks fundamental problems that in the future could lead to new scientific revolutions, dark matter, neutrinos, gamma rays, cosmic rays, dark energy, gravitational waves. A field in which Europe plays a fundamental role and to which HAP has contributed during the last years developing knowledge, technologies, training young scientists, and creating synergies not only between the German groups but also of these with the international collaborations that are preparing the ground for the next generation of discoveries. With these initiatives, Germany and therefore Europe are back on track.

As Coordinator of the Spanish project for research in dark matter, MultiDark, it has been an honor to collaborate with HAP and to serve as a member of its International Advisory Board. HAP has opened a new window in the field of astroparticle physics in Europe.

Astroparticles in Europe, from Adolescence to Maturity

Astroparticle Physics (APP), which started with the detection of cosmic rays at the beginning of the last century, has evolved into a science pointing to fundamental problems of physics, especially since the discovery of the oscillating nature of neutrinos and of the acceleration of the universe, in the 90's.

Dr. Sotiris Loucatos
Deputy director of APC – AstroParticule et Cosmologie
Associated partner of HAP, and Irfu, CEA-Saclay

APP is rapidly evolving at the intersection of astronomy, particle physics and cosmology. Experimentally, it combines the advanced instrumentation of physicists with the finest imaging of the cosmos by astronomers. Theoretically, it connects the Big Bang model of cosmologists to the standard model of particle physicists. It aims to gain insight into long-standing enigmas such as the Extreme Universe, the Dark Universe, the nature of neutrinos, the Early Universe. These mysteries and unknowns, the origin of time and space, dark energy, dark matter or new laws to invent are so tantalizing and challenging for the mind.

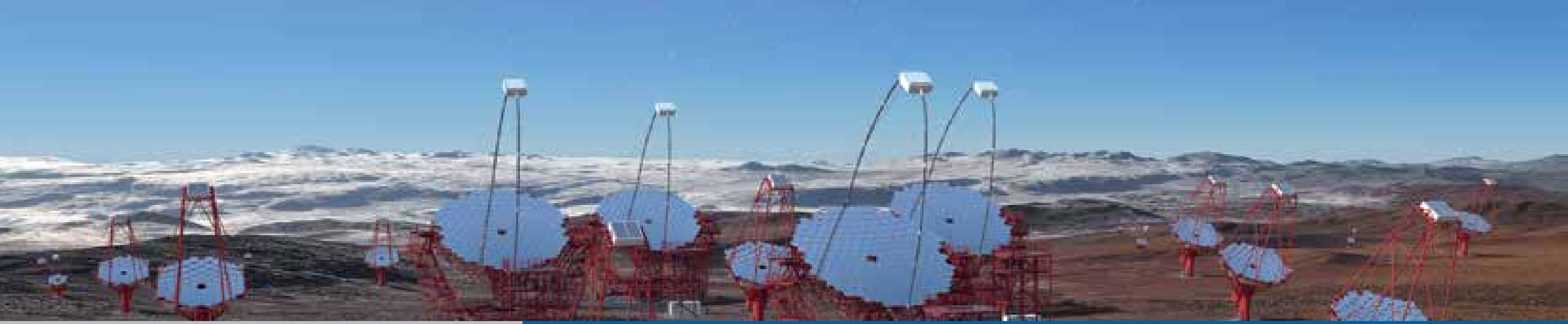
APP, spread out to the smallest installations and labs, allows scientific and technological ingenuity to diffuse to remote regions. Physicists from different countries meeting in sometimes surprising sites, follow the tradition of the international community of scientists, based on the value of people, defying nationalist fears and "alternative facts", dangerously reappearing with the current crises. Instrumental developments have been fabulous and AP, like astronomy and cosmology, is now also orbiting in space.

The smaller scale instruments can be installed in various labs. The multiple competitions are necessary for the vitality and reliability of science and have been a long-standing feature. But it has not to be taken to the extreme, so, public financing and management of science requires national, European and global refereeing and planning.

Germany and France, with Italy, are the three European countries with the biggest resources, both human and financial, in APP. In Germany the institutions active in AP research are led by the Helmholtz Association of German Research Centers, the Max Planck Society, and universities. HAP is a major link of AP institutes. In France research of our discipline is carried by CNRS (institutes In2p3 and Insu), CEA (Irfu) and universities. The association of APC to HAP has given the opportunity of a closer collaboration between French and German laboratories with postdoc mobility and a deeper mutual understanding.

Coordination across European countries has grown thanks to ASPERA and APPEC. Orientations in APP have been worked out in cooperation with national governments and funding agencies, the European Commission, partners outside Europe and those working in the intimately connected research fields of particle physics, astronomy and cosmology, as well as the institutions of these latter fields (CERN, ESO and ESA).

With the discovery of gravitational waves and the observation of neutrinos of cosmic origin we have entered a new era. For years before discovery, LIGO and Virgo have been scrutinizing silence. Strolling inside the magnificent installations of the Gran Sasso lab sometimes I wonder if silence is filled with ghost particles that will be captured by the ingenious DM detectors or are we fooled by yet unknown laws? We are like children before our descendants, because we know so much less…



The Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) will be the next-generation gamma-ray observatory providing an order-of-magnitude increase in sensitivity compared to currently operating instruments. German institutions, including DESY, two Max-Planck institutes, and seven universities are among the main contributors to the design, construction, and future operation of CTA.

CTA will allow observation of the Universe in gamma rays with energies between 20 GeV and 300 TeV. The collection area of over a million square meters on sites in the northern and southern hemisphere will open a new window to high-energy phenomena in the cosmos and give access, for the first time, to almost all of the night sky. CTA will consist of 99 imaging Cherenkov telescopes at the Paranal site in Chile and 19 telescopes on La Palma. These arrays will increase the number of detected gamma rays dramatically, while providing, at the same time, a hugely improved angular resolution. The tremendously improved flux sensitivity (Fig. 1) will allow a sensitive survey of a large portion of the sky and to image, with arcmin resolution, extended objects like supernova remnants or pulsar wind nebulae. The sensitivity of CTA will facilitate the detection of an unprecedented number of γ-ray emitting objects with exceptionally high spatial, spectral and temporal resolution. The remarkable boost of the photon detection area will provide access to the shortest time-scale phenomena. For example, CTA will be five orders of magnitude more sensitive to hour-long gamma-ray flares at 30 GeV than NASA's Fermi-LAT instrument.

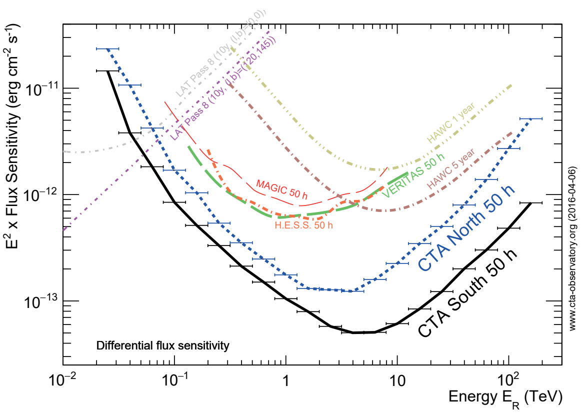


Fig. 1: Differential energy flux sensitivity of CTA for the Paranal (Chile) and La Palma (Spain) sites in comparison to gamma-ray satellite and ground-based instruments.

CTA will be the first ground-based gamma-ray observatory open to guest observers from the world-wide astronomical community. It is developed and built by an international collaboration with institutes from all over the world. The headquarters of CTA is located in Bologna (Italy) and the Data Science Management Center will be hosted by DESY in Zeuthen.

The Instrument

Each CTA array will consist of four very large (23 m diameter) central telescopes providing excellent efficiency below 100 GeV, embedded in an array of 15 and 25, respectively, medium-size telescopes giving high sensitivity and precision between 100 GeV and 10 TeV. At the southern site, these telescopes will be surrounded by an array of 70 small dishes to catch the bright but rare showers above around 10 TeV.

The medium-size telescopes with mirrors of 12 m diameter are the core of the observatory. They are mainly designed and developed by CTA groups in Germany (including several HAP members). A complete mechanical prototype has been built by DESY (Fig. 2) and is used to verify the design and to establish a cost-efficient production process with industrial partners. A fully digital camera and readout design for the medium size telescope is developed and prototyped by a consortium consisting of MPIK and German universities. A similar effort is lead by the MPI Munich for the construction of the large-size telescope; a first prototype of these telescopes is built on the La Palma site.

Construction for CTA is planned to begin in 2018, first scientific data is expected in 2020.

The Science

CTA will address a wide range of major questions in astrophysics, cosmology and particle physics. The CTA science drivers can be grouped into three major topics: understanding the origin and role of relativistic cosmic particles, probing extreme environments such as those around neutron stars and black holes, and exploring frontiers such as the nature of dark matter or the search for axion-like particles.

Relativistic particles play a major role in a wide range of astrophysical systems, from supernova explosions to star-forming galaxies and active galactic nuclei. Cosmic rays are accelerated to energies of up to 10^{20} eV in unknown environments. In our own galaxy, the energy density of cosmic rays, gas pressure and the magnetic field are very similar, yet the connection between these components, which is of great importance for the evolution of galaxies and galaxy clusters, is not very well understood. CTA will address these issues by providing a census of particle accelerators in the Universe and by high-precision measurements of bright nearby sources, such as young supernova remnants or the radio Galaxy M87.

The unprecedented sensitivity of CTA will open up a large discovery space in the area of fundamental physics, paving the way for potential major discoveries in this field. CTA will reach the thermal relic cross-section for self-annihilating dark matter for a wide range of masses, including those inaccessible to the LHC. CTA will also be sensitive to energy-dependent variations of the speed of light, as expected from quantum gravity effects, by measuring short and intense flares from distant galaxies for a wide range of photon energies. Axion-like particles make the Universe more transparent to high-energy photons. The large number of extragalactic gamma-ray sources that will be seen by CTA should allow these effects to be either measured or refuted with great precision.

Fig. 2: Mechanical prototype of a CTA mid-size telescope in Berlin-Adlershof.

γ-rays from Cosmic-Ray Accelerators

CTA will detect hundreds of supernova remnants and pulsar-wind nebulae in our Galaxy, providing an almost complete census of these powerful nearby particle accelerators. CTA aims for resolving the detailed properties of cosmic-ray accelerators, measure the propagation of the accelerated particles and their impact onto the interstellar medium. Our knowledge about cosmic rays will increase and fundamental laws of physics in environments not accessible to laboratory measurements can be tested.

The Empty Universe?

Most of the Universe consists of seemingly empty regions separated by filaments of galaxies. These large voids are filled with light, elementary particles and magnetic fields. The density of the respective fields is under debate and of great importance to understand the evolution of our Universe. CTA will be able to determine the properties of the voids by measuring γ-ray spectra of many distant active galactic nuclei and their halo of electromagnetic emission with unprecedented precision.

Dr. Gernot Maier
DESY in Zeuthen
Coordinator of the CTA Analysis and Simulations working group

Particle Physics with Neutrino Telescopes

Neutrino telescopes detect an unprecedented amount of neutrinos from cosmic ray interactions in the atmosphere. Even though the large sensor spacing does not allow precision measurements on individual events, the huge statistics makes them a powerful tool to study neutrino oscillation phenomena.

Neutrino Oscillations

Neutrino oscillations, i.e. the ability of neutrinos to change their flavor during propagation through quantum mechanical interference, directly implies that neutrinos have mass. This constitutes clear evidence of new physics beyond the standard model, in which neutrinos are massless by construction. The discovery of neutrino oscillations by the Super-Kamiokande and SNO collaborations was consequently rewarded with the Nobel Prize. Great progress has been made in the mean time and by now both the mass differences and mixing angles that determine the oscillation patterns are known with fair precision. Curiously though, the parameters that describe the mixing of the atmospheric neutrinos where the oscillations effects are strongest currently have the largest uncertainty. To determine them in beam experiments requires very long baselines between neutrinos source and experiment as well as very large detectors and an intense muon source, both of which are not easily realized. On the other hand, the constant bombardment of the earth's atmosphere by cosmic rays provides neutrinos from all around the globe over a wide range of energies and baselines of interest for oscillation studies. Harvesting this ubiquitous natural flux of atmospheric neutrinos, neutrino telescopes such as IceCube's low-energy extension DeepCore have now caught up and provide measurements that are competitive with the beam experiments.

ORCA and PINGU

HAP members from both the KM3NeT and IceCube collaboration are now aiming to fully exploit the potential of the huge detection volumes that can be realized in water or ice. ORCA is an array of 115 strings of 18 optical modules each and part of the KM3NeT project currently constructed in the Mediterranean. The proposed PINGU detector consists of 24 strings of 96 optical modules to be deployed in the Antarctic ice in the frame of the IceCube-Gen2 observatory. Both reach an effective mass of a few megatons in the GeV-range where the oscillation effect for atmospheric neutrinos is strongest. Though challenged by the low number of photons that will be detected from each neutrino interaction at these energies and the limited directional and energy resolution this implies, the hundreds of thousands of events that will be accumulated by both arrays will provide unprecedented precision on the atmospheric mixing parameters (see Fig. 1).

Moreover, these high-statistics measurements will allow to address some of the remaining open issues in oscil-

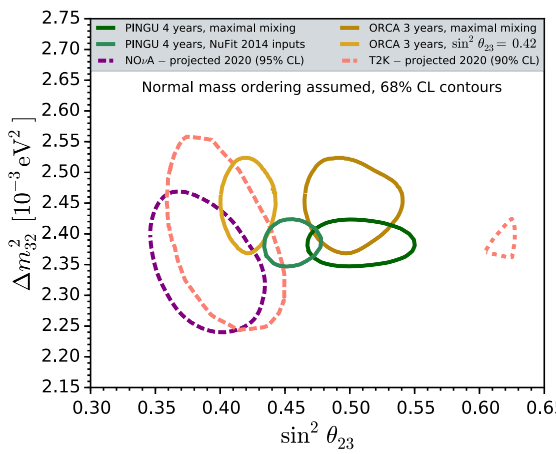
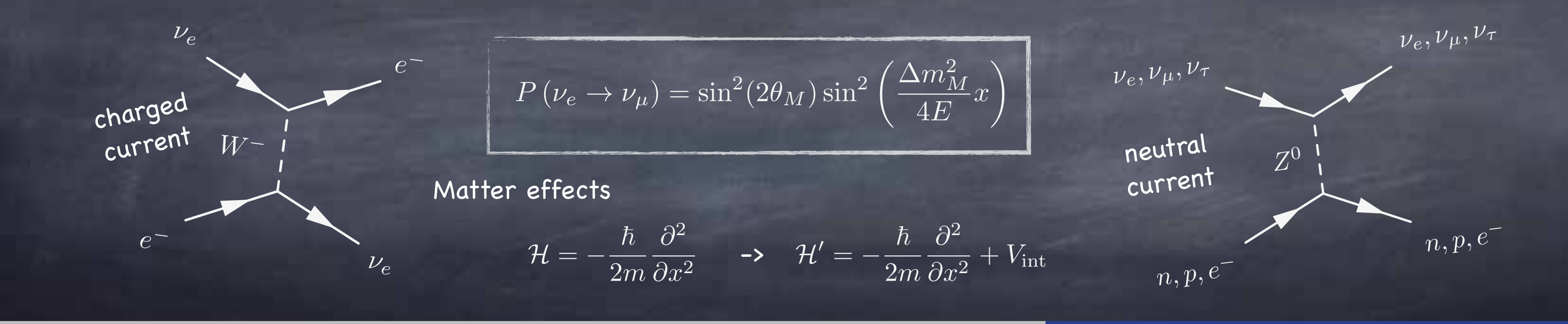


Fig. 1: Projected constraints on the atmospheric neutrino parameters from currently operating beam experiments (T2K, NOνA) and for three or four years of operation of the planned PINGU and ORCA arrays.



lations physics, such as wether the mixing angle for the atmospheric states is really at the value of $\sin^2\theta_{23} = 0.5$ that provides a maximal mixing effect and why the mixing is so much stronger than in the quark sector.

Another question that is fundamental to understand where neutrino masses come from is the order in which the three mass eigenstates are arranged. This neutrino mass hierarchy problem is challenging to address, as neutrino oscillation phenomena in vacuum to first degree only depend on the difference of the masses, not on their ordering. The symmetry of the oscillation pattern with the order of states is however broken for neutrinos traveling through a region of high density – such as the earth core – where some of them can interact with electrons while others will not. These matter effects leave a distinct imprint in the oscillation pattern – either for neutrinos or for anti-neutrinos, depending on the order (see Fig. 2). It is inherently challenging to pick up these modifications for neutrino telescopes, which are generally not able to distinguish between anti-particle and particle interactions. Yet again it is the large number of detected events in combination with a higher interaction probability for neutrinos than anti-neutrinos in the detector that leads to a measurable effect. Both ORCA and PINGU are optimized in their design for this measurement and are in a leading position to solve this question within a few years.

Sterile Neutrinos

Already in 1957 Goldhaber established in his renowned experiment that the neutrinos are left-handed – meaning their spin axis is aligned with their direction of flight. This paradigm has stood unchallenged for a long time, but can only be fully true for massless neutrinos. The fact that neutrinos have mass therefore implies, that also right-handed neutrinos should exist – a daunting hypothesis as the weak force that is behind all neutrino interactions couples to left-handed particles only. While the interactions of ordinary neutrinos are already extremely weak, right-handed neutrino states can not interact with matter at all and are consequently labeled as sterile. Yet, these sterile neutrinos could still be observed as they partake in the phenomenon of neutrino oscillations.

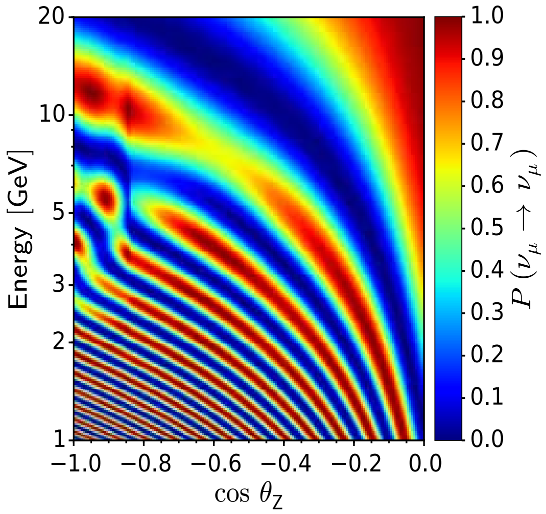


Fig. 2: Probability for a muon neutrino generated in the atmosphere to be observed as a muon neutrino as a function of its energy and zenith angle. The distinct feature at the top left appears either for neutrinos or anti-neutrinos, depending on the ordering of the mass eigenstates.

A number of anomalous observations from reactor and beam oscillations experiments that can not be explained under the standard three-neutrino paradigm have hence been ascribed to the existence of a potential fourth sterile neutrino with a mass as large as 1eV/c². This value, which is at least a factor of ten above the masses allowed for the three known active neutrino states, implies that they will generate oscillation effects in the atmospheric flux at TeV energies. A fortunate coincidence, as these high-energy events are not only copiously detected by IceCube: additionally, for neutrinos crossing the dense earth core the mixing of neutrino flavors is enhanced by the same matter effects that yield sensitivity to the neutrino mass ordering. HAP Members in Aachen have thus set stringent limits on the mass range at which such a fourth flavor can exist – severely challenging the sterile neutrino hypothesis.

Prof. Sebastian Böser
JGU Mainz
Experimentelle Astroteilchenphysik im PRISMA-Exzellenzcluster

Blazar Monitoring Using SiPM Photosensors

The First G-APD Cherenkov Telescope (FACT) pioneered the use of SiPM photosensors in ground-based γ-astronomy achieving unprecedented time coverage. Monitoring blazars at TeV energies profited from maximizing the duty cycle of the instrument and minimizing the observational gaps. Frequent alerts prompting multi-wavelength follow-up observations have been issued.

Blazars are powerful extragalactic gamma-ray sources. High-resolution radio images reveal that their emission originates from active galactic nuclei driving out relativistic plasma jets at small angles to the line-of-sight. It is commonly believed that these jets are powered by the accretion of matter onto super-massive black holes and their subsequent spin-down. Jets thus represent a direct probe of the plasma emerging from the ergosphere of spinning black holes.

The observed gamma-ray flux varies on time scales from minutes to years with large amplitudes. The variability suggests that the high-energy emission originates from the very compact base of the jet. To understand the physics of blazars, astronomers need to manage the challenging task of sampling light curves of blazars on time scales from minutes to years measuring their emission from radio waves to gamma rays.

So far, monitoring the gamma-ray flux from blazars with Cherenkov telescope arrays such as H.E.S.S. and MAGIC (many HAP partners in each collaboration) was hampered by the low data-taking efficiency of classical high-voltage photomultiplier tube cameras. As an alternative, Geiger-mode avalanche photodiodes (G-APDs) arranged in so-called Silicon-photomultiplier (SiPM) arrays, promise higher data taking efficiency and lower operation costs.

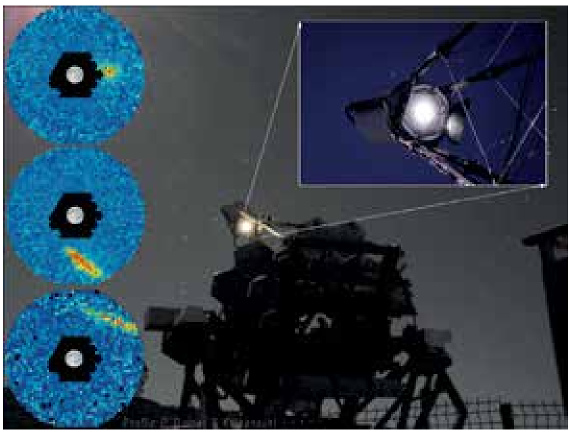
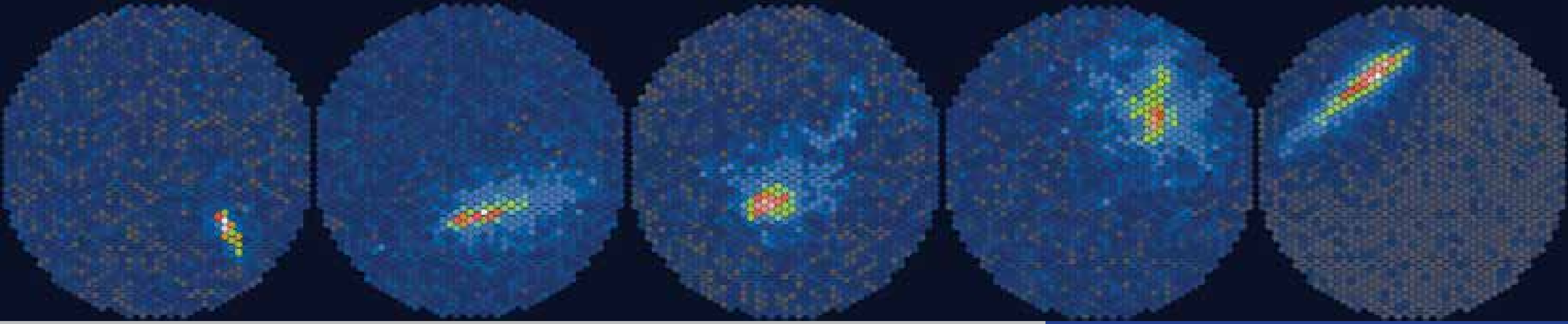


Fig. 1: Even when pointing to the full moon, FACT records cosmic ray showers, illustrating the robustness of SiPM.

SiPM for Continuous Monitoring

The First G-APD Cherenkov Telescope was designed and constructed as a proof-of-principle of this novel technology under operating conditions by a German-Swiss collaboration involving the HAP partners TU Dortmund and U Würzburg. During more than five years of operation, the SiPM photosensors have shown stable and excellent performance (Biland et al. JINST 9 (2014) P10012). Since summer 2012, the telescope is operated remotely. The operations were automatised maximizing the data taking efficiency to 95% between start and end of astronomical twilight for good weather. Another benefit of SiPMs is that the operation can be extended to very bright moon light without the need of filters or lowering the voltage (Fig. 1). This not only increases the duty cycle of the instrument, but also minimises the gaps around full moon providing unprecedented long-term light curves of TeV blazars. The Alliance was an optimal incubator for the transfer of knowledge from FACT to other projects. SiPMs are now the prime choice of photosensors for CTA-SST cameras (FAU Erlangen) and are under investigation for their use in large pixel clusters for CTA-MST and LST (MPI München, TU Dortmund, U Würzburg) as well as for fluorescence telescopes augmenting the Pierre Auger Observatory extended air shower array (RWTH Aachen).



Decoding Blazars by Variability

While snapshots of blazar spectral energy distributions (SEDs) can be explained with a variety of theoretical models, time-resolved SEDs are the key to distinguish between them. Such theoretical models have been developed e.g. by HAP members at U Hamburg, U Potsdam, and U Würzburg. For leptonic models, a correlation between the low and high energy emission is expected. The variability patterns for hadronic models can be more complex. Moreover, hadronic models predict correlated neutrino emission. Therefore, contemporaneous multi-wavelength and multi-messenger studies are important. One of the driving players in this field is IceCube with HAP partners at DESY in Zeuthen, TU Dortmund, RWTH Aachen, and FAU Erlangen.

Time-domain studies of blazars also help to localise the origin of the high-energy emission. Causality constrains the size of an incoherent emission region to be smaller than the distance traveled by the light during a flare. The infered sizes are much smaller than the angular resolution of gamma-ray instruments. Minute-scale variations reflect source regions as small as the event horizon of super-massive black holes.

With the quick-look analysis of FACT, monitoring data become publicly available in real time (www.fact-project.org/monitoring) enabling rapid alerts to other instruments for follow-up studies across the electromagnetic spectrum. In the last three years, 44 alerts and six astronomer's telegrams have been issued. The blazar 1ES 1959+650, which showed low activity before, exhibited several strong outbursts in summer 2016 (Fig. 2). Currently, the statistical analysis of the light curves and multi-frequency campaigns are subject to in-depth studies by the FACT collaboration and associated collaborators presented in the HAP-workshop "Monitoring the Non-Thermal Universe" in Cochem, December 2016.

To study typical variability time scales of blazars, the ultimate goal is 24/7 monitoring with a global network (DWARF project). The M@TE (Monitoring at TeV Energies) project is an Imaging Air Cherenkov Telescope (IACT) to be installed in Mexico. Combining data of FACT and M@TE will provide continuous observations of up to 12 hours. Furthermore, this monitoring can trigger highly sensitive observations with the Cherenkov Telescope Array (CTA).

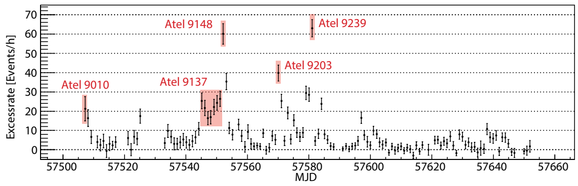


Fig. 2: 1ES 1959+650 gamma-ray flux measured by FACT in summer 2016. This represents the most dense light curve ever measured by an IACT. Astronomer's telegrams are marked in red.

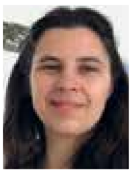
FACT

The First G-APD Cherenkov Telescope, located at the site of MAGIC on Palma, is an IACT pioneering the usage of Silicon based Photo Sensors (SiPMs) in astroparticle physics. Operational since October 2011, the major goal is unbiased long-term monitoring of bright TeV blazars. With remote and automatic operation and observing even during bright moon phases, the data taking efficiency has been maximised recording 2375 hours of physics data in 2016.

MAGIC

The two Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) telescopes are located in the Observatorio del Roque de los Muchachos, being also the Northern CTA site on La Palma. With mirror diameters of 17 meters, an energy threshold of 50 GeV is reached for stereo observations. A sensitivity of 0.67% C.U. (Crab Units) allows for an excellent timing resolution in variability studies.

Dr. Daniela Dorner
U Würzburg
2015 Gustav-Hertz-Preis; 2016 Guest professorship at FAU Erlangen-Nürnberg



FUNK – Search for Hidden-Photon Dark Matter

In case dark matter consists of hidden-sector photons which kinetically mix with regular photons, a tiny oscillating electric-field component is accompanying the dark matter. At the surface of a conducting material this can induce an emission of photons with the corresponding photon frequency matching the mass of the hidden photons.

There is a number of convincing astrophysical and cosmological evidences that a large fraction of the energy density in the universe must be composed of invisible non-baryonic matter, so-called dark matter. The most explored options for explaining dark matter are extensions of the Standard Model for elementary particle physics predicting axions and weakly-interacting massive particles. In recent years attention has been turned also to weakly-interacting slim particles (WISPs), as e.g. axion-like particles or hidden photons. WISPs could be non-thermally produced in the early universe and survive as cold dark matter until today. Although many detection methods have been proposed for the search of dark matter, only a few active efforts exist in the low-mass particle sector. While the viable parameter space for axions is rather constrained by cosmological observations, this is not so much the case for the hidden-photon option, the final and definitive answer should be given by the dedicated experiments.

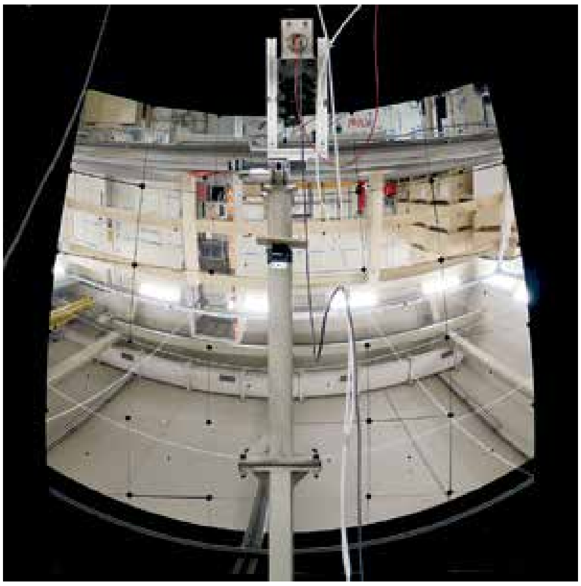


Fig. 1: FUNK with the mirror (in the back) and the low-noise photomultiplier in the center of the curvature (top).

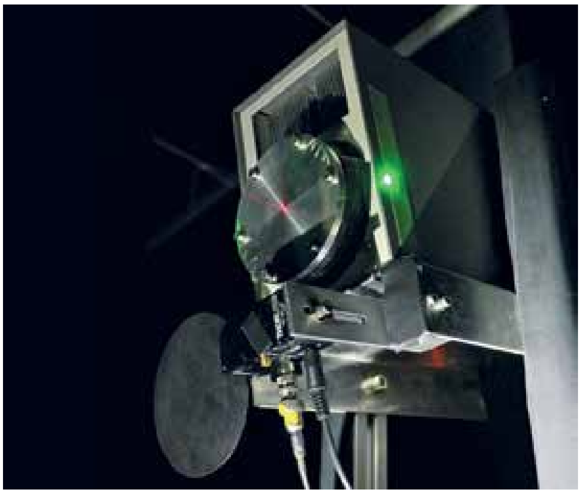


Fig. 2: The low-noise photomultiplier (in its cooling enclosure) used for the detection in the UV-extended visible range of photon wavelengths. The cross-section of the red and green laser beams marks the spherical center of the mirror.

In our case we consider hidden photons as candidates for the dark matter, which emerge from an extension of the Standard Model through additional light U(1) gauge bosons that kinetically mix with the Standard Model photons. Large regions of the hidden-photon parameter space, spanned by its mass and mixing strength with regular photons, are compatible with the observed dark matter signatures and are already searched for with many experimental methods such as haloscopes, helioscopes, and light-shining-through-a-wall methods like ALPS at DESY. Direct search experiments for WISPy dark matter are usually very time consuming as they need to be tuned to the assumed WISP mass.



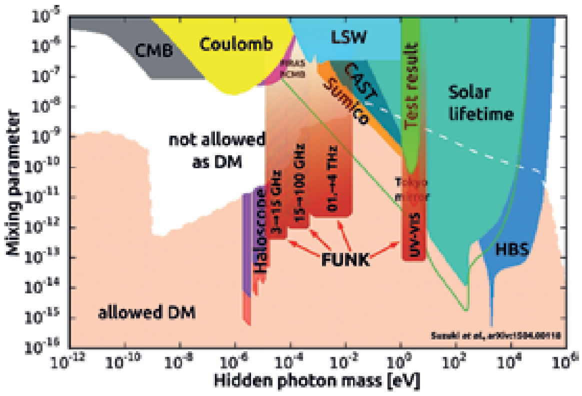
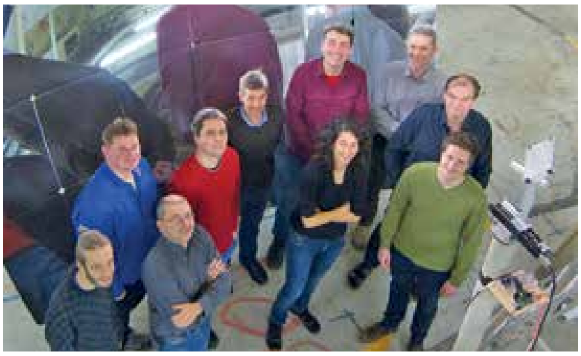


Fig. 3: Expected sensitivity of FUNK in various photon-energy ranges (red shaded areas). The allowed parameter region for dark matter composed of hidden photons is indicated. In addition, several limits from other studies or experiments are given, e.g. precision tests of Coulomb's law, "Light Shining through Walls" experiments, the CAST experiment, and solar hidden photon search with the Tokyo Axion Helioscope are marked as "Coulomb", "LSW", "CAST" and "Tokyo", respectively. Constraints from the solar lifetime calculations with different assumptions are shown as a green area and line.

The experiment FUNK - **F**inding **U**(1)s of a **N**ovel **K**ind – has been setup as a dedicated broadband observation of possible candidates for hidden photons with the so-called dish-antenna method. At the surface of a conductor the dark matter, accompanied by a tiny oscillating electric component, gets with low probability converted to faint electromagnetic waves. These waves can be geometrically enhanced and focused by a spherically shaped mirror. Since the photons are emitted almost perpendicularly to the conducting surface, the hidden-photon-induced light emerging from any part of the mirror is effectively collected in the center of the sphere while the unavoidable photon background is due to its random direction not subject to such enhancement. In the center of our mirror with an area of more than 14 m^2 various detectors can thus be suitably placed (Fig. 1). The dark-matter nature of the signal can be verified by exploiting the daily and seasonal variations of the relative motion of our detector with respect to the ambient dark matter. The relative velocity is expected to be a few 100 km/s and results in a tiny change in the direction of the emitted photon with respect to the mirror surface, which is for example easily detectable with a CCD. Once dark matter is detected, such measurements would allow determination of details of the local dark matter halo structure.

Currently high-sensitivity measurements are performed in the UV-extended visible range of the photon wavelengths using a cooled low-noise photomultiplier ET9107BQ (Fig. 2). Soon various standard and novel photon sensors and wave receivers will be deployed, covering the 3 -15 MHz, 15 - 100 MHz, and 0.1 - 4 THz spectrum range, see Fig. 3. As dark-matter hidden photons would move at non-relativistic speeds, the FUNK search frequency is given by hidden photon mass.

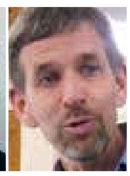


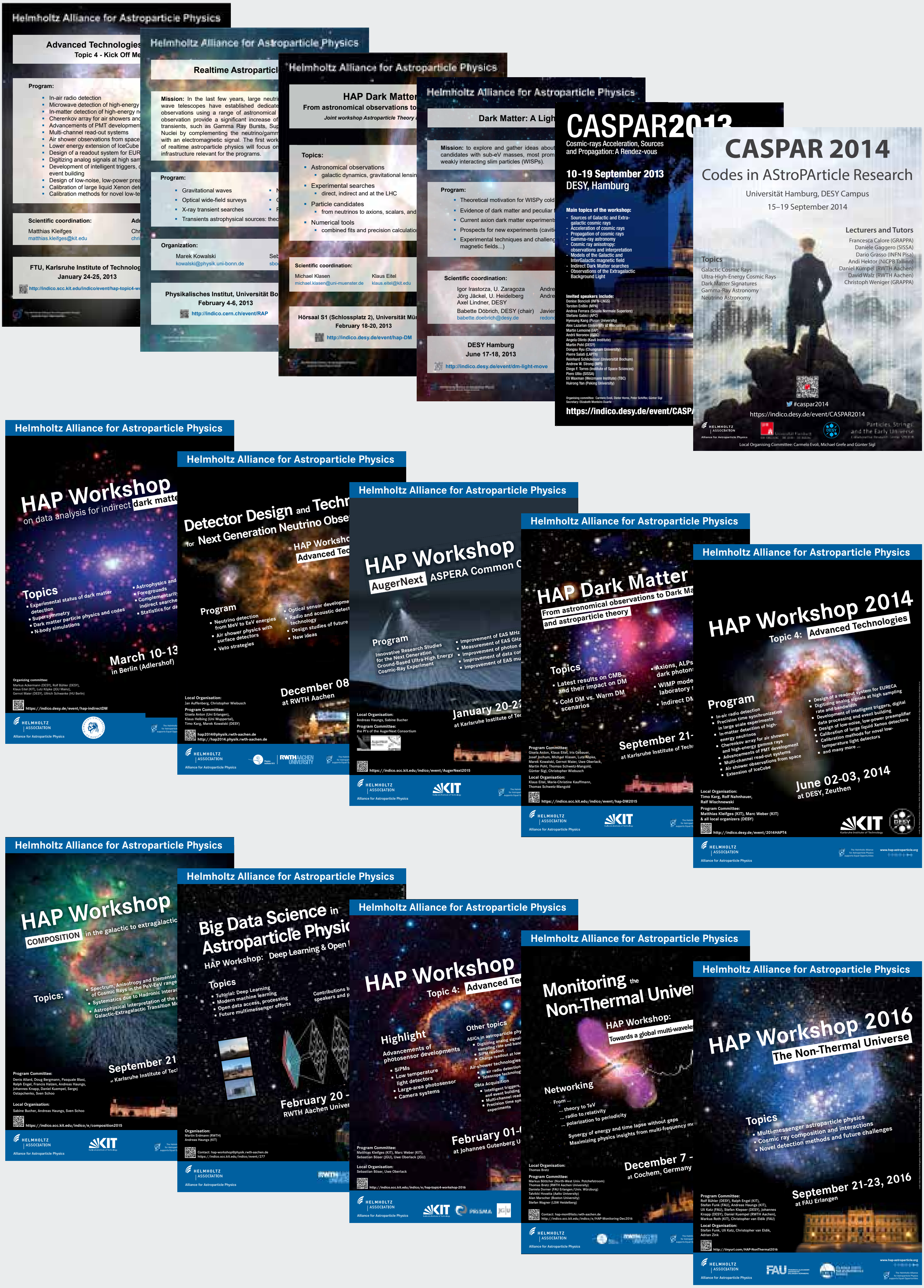
Some of the members of the FUNK experiment posing in front of the mirror. The device with a frost glass on a motorised stage, used for focusing of individual mirror segments, can be seen on the right side.

FUNK

Search for dark matter in the hidden-photon sector using a large spherical mirror with an area of more than 14 m^2, probing for dark matter candidates with masses in the eV and sub-eV energy range. FUNK is located at the KIT and re-uses mirror segments developed for the Auger Observatory. Searches in the eV mass region will be conducted in 2017/18, the radio regime will be probed around 2020.

Dr. Darko Veberic KIT
Pierre Auger Observatory, NA61-SHINE, FUNK
Dr. Axel Lindner DESY in Hamburg
ALPS, SHIPS, FUNK



Helmholtz Alliance for Astroparticle Physics
Advanced Technologies
Topic 4 - Kick Off Me
Program:
In-air radio detection
Microwave detection of high-energy
Cherenkov array for air showers and
Multi-channel read-out systems
Air shower observations from space
Lower energy extension of IceCube
Scientific coordination:
Matthias Kleifges
matthias.kleifges@kit.edu
FTU, Karlsruhe Institute of Technolog
January 24-25, 2013
Helmholtz Alliance for Astroparticle Physics
Realtime Astroparticl
Program:
Gravitational waves
Optical wide-field surveys
X-ray transient searches
Organization:
Marek Kowalski
kowalski@physik.uni-bonn.de
Physikalisches Institut, Universität Bo
February 4-6, 2013
http://indico.cern.ch/event/RAP
Helmholtz Alliance for Astroparticle Physics
HAP Dark Matter
From astronomical observations to
Joint workshop Astroparticle Theory
Topics:
Astronomical observations
Experimental searches
Particle candidates
Numerical tools
Scientific coordination:
Michael Klasen
Klaus Eitel
Hörsaal S1 (Schlossplatz 2), Universität Mün
February 18-20, 2013
http://indico.desy.de/event/hap-DM
Helmholtz Alliance for Astroparticle Physics
Dark Matter: A Ligh
Program:
Theoretical motivation for WISPy cold
Evidence of dark matter and peculiar
Current axion dark matter experiment
Prospects for new experiments
Scientific coordination:
Igor Irastorza, U. Zaragoza
Jörg Jäckel, U. Heidelberg
Axel Lindner, DESY
Babette Döbrich, DESY (chair)
DESY Hamburg
June 17-18, 2013
http://indico.desy.de/event/dm-light-move
CASPAR2013
Cosmic-rays Acceleration, Sources and Propagation: A Rendez-vous
10-19 September 2013
DESY, Hamburg
Main topics of the workshop:
Invited speakers include:
https://indico.desy.de/event/CASP
CASPAR 2014
Codes in AStroPArticle Research
Universität Hamburg, DESY Campus
15–19 September 2014
Lecturers and Tutors
Topics
Galactic Cosmic Rays
Ultra-High-Energy Cosmic Rays
Dark Matter Signatures
Gamma-Ray Astronomy
Neutrino Astronomy
#caspar2014
https://indico.desy.de/event/CASPAR2014
Helmholtz Alliance for Astroparticle Physics
HAP Workshop
on data analysis for indirect dark matte
Topics
March 10-13
in Berlin (Adlershof)
Helmholtz Alliance for Astroparticle Physics
Detector Design and Techn
for Next Generation Neutrino Obse
HAP Worksho
Advanced Tec
Program
December 08
at RWTH Aachen
Helmholtz Alliance for Astroparticle Physics
HAP Workshop
AugerNext
ASPERA Common C
Program
January 20-2
at Karlsruhe Institute of Tec
Helmholtz Alliance for Astroparticle Physics
HAP Dark Matter
From astronomical observations to Dark Ma
and astroparticle theory
Topics
September 21-
at Karlsruhe Institute of Techn
Helmholtz Alliance for Astroparticle Physics
HAP Workshop 2014
Topic 4: Advanced Technologies
Program
June 02-03, 2014
at DESY, Zeuthen
Helmholtz Alliance for Astroparticle Physics
HAP Workshop
COMPOSITION in the galactic to extragalactic
Topics:
September 21
at Karlsruhe Institute of Tec
Helmholtz Alliance for Astroparticle Physics
Big Data Science in
Astroparticle Physic
HAP Workshop: Deep Learning & Open
Topics
February 20 -
RWTH Aachen Univer
Helmholtz Alliance for Astroparticle Physics
HAP Workshop
Topic 4: Advanced Te
Highlight
Other topics
February 01-
at Johannes Gutenberg U
Helmholtz Alliance for Astroparticle Physics
Monitoring the
Non-Thermal Unive
HAP Workshop:
Towards a global multi-wavele
Networking
December 7 -
at Cochem, Germany
Helmholtz Alliance for Astroparticle Physics
HAP Workshop 2016
The Non-Thermal Universe
Topics
Multi-messenger astroparticle physics
Cosmic ray composition and interactions
Novel detection methods and future challenges
September 21-23, 2016
at FAU Erlangen


HAP Workshops

HAP was formed to intensify the ties between scientists. Even though modern media ease communication, face-to-face meetings are inevitable for fruitful discussions and the development of cooperations as well as for young scientists to feel at home in the community. Workshops of different types were organised and supported by HAP – here are some exemplary summaries.

Dark Matter Workshops

Theorists and experimentalists within HAP have discussed concepts, ideas and experimental results on dark matter (DM) in two well recognised workshops, first at the University of Münster in 2013, then at the Karlsruhe Institute of Technology in 2015. Astronomical observations, the CMB and its impact on DM, modelling structure formation, Cold DM versus Warm DM scenarios, WIMP models and (laboratory) searches, axions, ALPs and dark photons, and indirect DM searches were the covered topics. The about 100 participants of each workshop included senior German DM scientists, many postdocs and students, as well as experts from neighbouring countries such as Belgium, Denmark, France, the Netherlands, Spain, Sweden, Switzerland and the UK.

Dark Matter: A Light Move

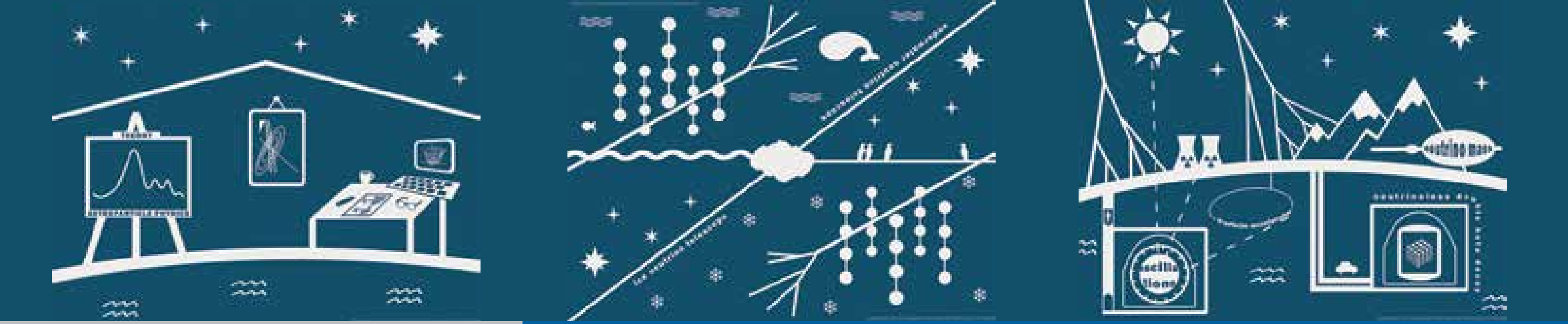
This workshop in June 2013 aimed to explore and gather ideas about searching directly for Dark Matter candidates with sub-eV masses, most prominently the axion and other weakly interacting light particles (WISPs). Particle physicists, astroparticle physics experts, cosmologists, radio astronomers and engineers from different disciplines joined to discuss the prospects of finding WISPy Dark Matter with established or new and unconventional ideas. At the meeting short presentations alternated with long discussion times resulting in an intense workshop: the participants even closed their laptops and stopped reading mails to engage themselves strongly.
As a direct outcome of the workshop the FUNK experiment at KIT was established.

CASPAR Workshops

Astroparticle physics often deals with extreme environments and processes. To model those, many publicly available software packages are used – some were further developed within HAP – such as CRPropa. To train in particular young scientists, two CASPAR workshops were held in September 2013 and 2014 in Hamburg. CASPAR stands for **C**osmic-rays **A**cceleration **S**ources and **P**ropagation – **A** **R**endezvous and **C**odes in **AS**tro**PA**rticle **R**esearch. A further article about these high-energy particles in the Universe can be found in this brochure.
Lectures on CR physics and indirect signatures of DM were given by experts, whereas afternoons were devoted to intense discussions. The 2014 workshop was a „hands on coding“ workshop. About 20 students from Germany and Europe received expert instructions how to install codes such as CRPropa, DRAGON and DarkSUSY and how to run simple example problems.

Splinter Meetings

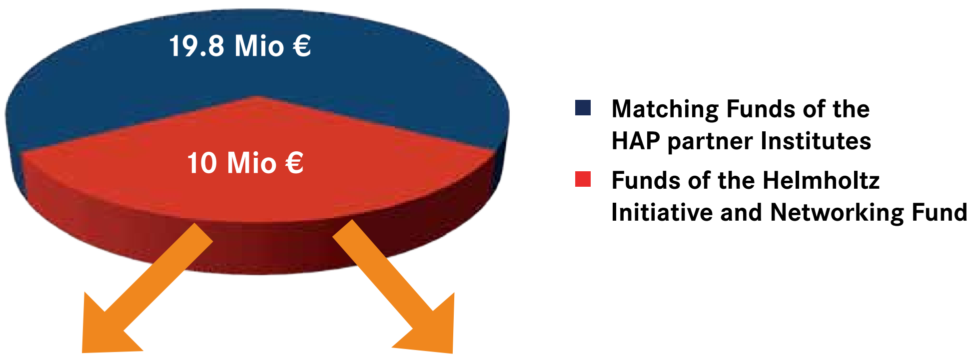
Under the umbrella of the Helmholtz Alliance for Astroparticle Physics five splinter meetings have been organised between 2012 and 2016 as part of the Annual Assembly of the German Astronomical Society. The sessions included a variety of topics ranging from Dark Matter to multi-messenger and high-energy astroparticle physics driven by keynote speakers from the alliance. The splinter meetings fostered the interdisciplinary collaboration, helped to establish new networks between the astronomical and astroparticle physics community and became an inherent part of the Annual Assembly of the German Astronomical Society.



Facts and Figures about HAP

The Helmholtz Alliance for Astroparticle Physics received financial support from the Helmholtz Initiative and Networking Fund (German: Impuls- und Vernetzungsfond, IVF) during its core-funding period from July 1, 2011 to December 31, 2016. These funds were matched by other funding from all partners of HAP.

Funding



10% for Backbone activities

90% for HAP partner institutes

Personnel

85% of all funds were used for personnel.
The IVF-funds allowed HAP to fund almost 100 young scientists, about 70% PhD students and 30% postdoctoral researchers.

The exact counting in terms of Full Time Equivalent (FTE), with one PhD student counting as 0.5 FTE, results in:

IVF-Funds:

87 FTE PhD students
52 FTE postdoctoral researchers
139 FTE in total

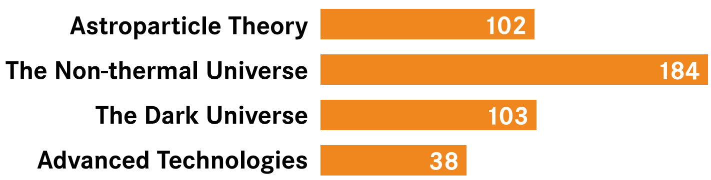
Matching Funds by partners:

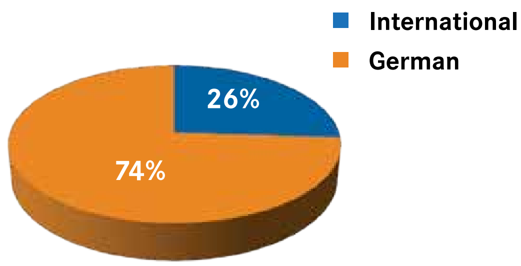
72 FTE PhD students
115 FTE postdoctoral and senior researchers
27 FTE scientific support personnel
214 FTE in total

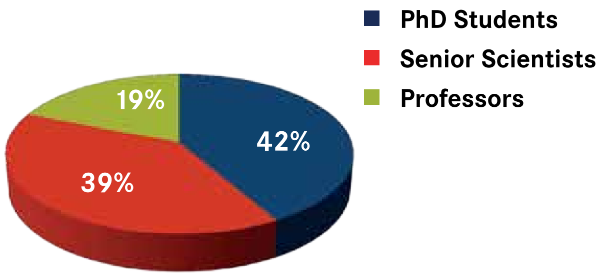
HAP Members

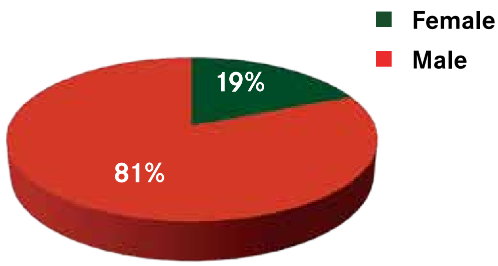
We gathered information about our members in a database assigning its participants directly to the HAP mailing list. Overall 335 scientists from 7 countries signed up for HAP. People could mark their favorite topics (multiple selections possible) and list all their experiments working on, independent of HAP. Between mid 2011 and end 2016, about 700 physics articles were published by HAP members in the context of the Alliance in scientific journals.

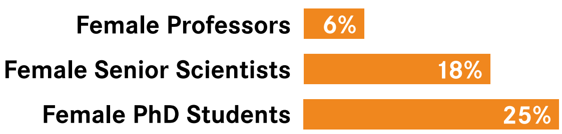
Members assigned for HAP Topics:









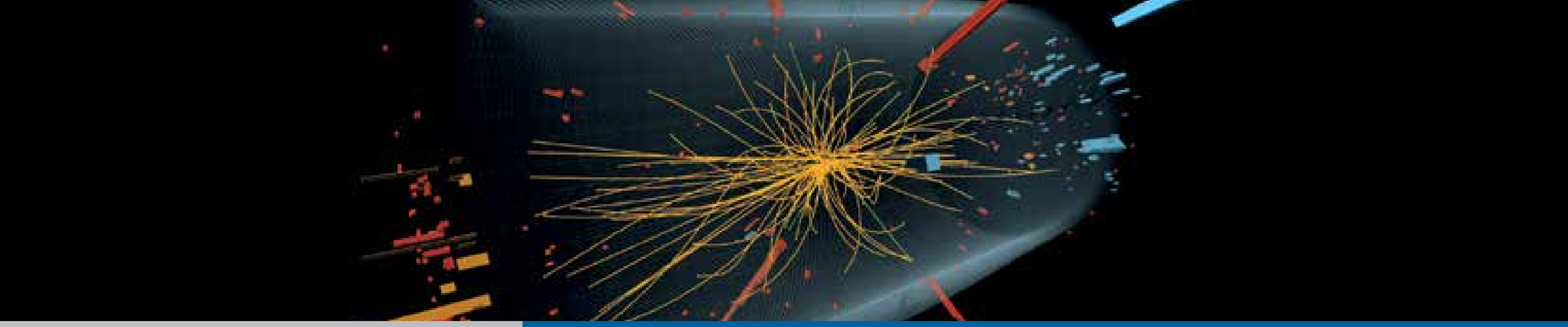


Experiments of HAP Members

AMADEUS, ANTARES, ATLAS, Borexino, CMS, COBRA, COMPTEL, CRESST, CROME, CTA, DARWIN, Double Chooz, EDELWEISS, EURECA, FACT, Fermi-LAT, GERDA, GNO, H.E.S.S., HiSCORE, IceCube, JEM-EUSO, JUNO, KASCADE-Grande, KATRIN, KM3NeT, LENA, LOPES, LXeGRIT, MAGIC, MICA, OPERA, Pierre Auger Observatory, SNO+, SOX, Tunka-Rex, VERITAS, XENON

New Groups in HAP

Since 2011, five new groups at HAP partner institutions with funding-support from HAP have joined the Alliance, one in 2012, two in 2013 and two in 2015. Furthermore, four new associated HAP partners, without funding-support from HAP, joined the Alliance. In 2013 two Russian groups from the SINP from Moscow and the "Troitsk nu-mass" group of the INR joined and in 2015 the two Dutch groups NIKHEF and Grappa.



Particle Physics at the Highest Energies

Cosmic particles can have energies of up to 10^{20} eV, more than one million times higher than those reached at the most advanced man-made accelerators. They are messengers of the most extreme processes in the universe and, at the same time, provide us with a window to particle physics phenomena that cannot be studied in the laboratory.

In 1963, J. Linsley reported the observation of a particle cascade that had to be the result of a cosmic particle entering the Earth's atmosphere with an energy of about 10^{20} eV. This surprising observation was the starting point of a race for collecting more particles of such extreme energies. Today we know that these particles are very rare and even with the most advanced and biggest detector for cosmic rays, the Pierre Auger Observatory, only a handful of these particles have been measured.

Due to the very low flux, the observation of high-energy cosmic rays has to rely on detecting the gigantic cascades of secondary particles, called extensive air showers, they produce when interacting with nuclei in the Earth's atmosphere. Even though this is an indirect way of detecting the highest-energy particles in the cosmos, the existence of these particles is firmly established now and they are used to study various physics phenomena.

Sources

One of the key questions is that of the possible sources that produce such energetic particles. Already in 1984 M. Hillas showed that 10^{20} eV is a seemingly magic limit. On general grounds, it is expected that none of the known astrophysical accelerators (including active galactic nuclei, gamma ray bursts, or neutron stars) can accelerate protons to such a high energy. This question is subject to an ongoing debate, in which also nuclei are considered as they can be accelerated to higher energies because of their higher charge. With indications of astrophysical sources "running out of steam," alternative source scenarios have been proposed. In contrast to the previously described "bottom-up" scenario, decay processes of super-heavy objects – as predicted in some extensions to the Standard Model of particle physics – can provide ultra-high-energy particles in a "top-down" process (Fig. 1). These super-heavy objects could be, for example, topological defects, strings, necklaces, particles of super-heavy dark matter, or even particles from mirror universes.

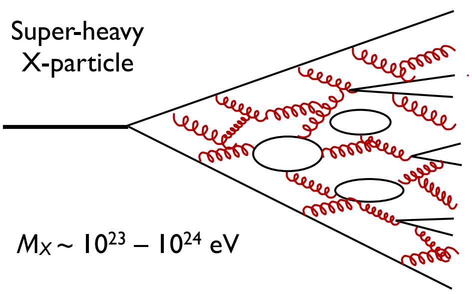


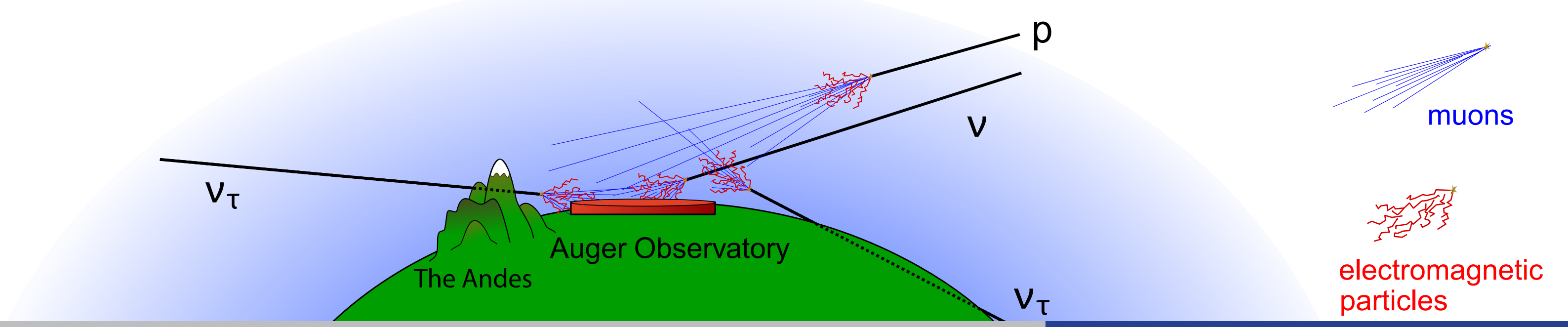
Fig. 1: Decay of a super-heavy particle that is a relic of the early Universe. Proceeding through a cascade of quarks and gluons a large number of pions and baryons is produced. The baryons are then ultra-high-energy cosmic rays

Photons and Neutrinos

Photons and neutrinos of the highest energies are the decisive messengers to distinguish top-down and bottom-up source scenarios. Any top-down decay process will always produce an abundant amount of charged and neutral pions, which decay to photons and neutrinos. Until now, all searches for particle showers initiated by ultra-high-energy photons and neutrinos ended up empty-handed, ruling out exotic physics scenarios as dominant source processes for cosmic rays. The detection principle for ultra-high energy neutrinos at the Auger Observatory is shown in the top banner at the right side.

Structure of space-time

Another physics application is the search for space-time fluctuations and violation of the fundamental principle of Lorentz invariance at extreme energies. The higher



the energy at which cosmic protons are observed the stronger are the constraints on a possible violation of Lorentz invariance. The shape of the end of the cosmic ray flux at the highest energies, if related to the Greisen-Zatsepin-Kuz'min (GZK) effect, and features of extensive air showers are also sensitive to modifications of Lorentz invariance.

Cosmic rays meet LHC

In general, extensive air showers at ultra-high energy offer a trove of information on particle physics processes. For example, the depth of the first interaction in the atmosphere is a direct measure of the interaction cross section and can be compared to measurements made at particle colliders such as the LHC (Fig. 2). Air shower data reach to much higher energies, confirming the extrapolation of low-energy data without the need for new physics assumptions such as extra spatial dimensions. On the other hand, more muons are found in air showers than expected – a discrepancy that is not yet understood.

Gigantic particle cascades

To derive all this information from the gigantic particle cascades (Fig. 3), detailed simulations of the numerous interaction and decay processes are needed. With more than 10^{11} secondary particles in these cascades, the full simulation of individual showers at 10^{20} eV requires advanced supercomputers. Various

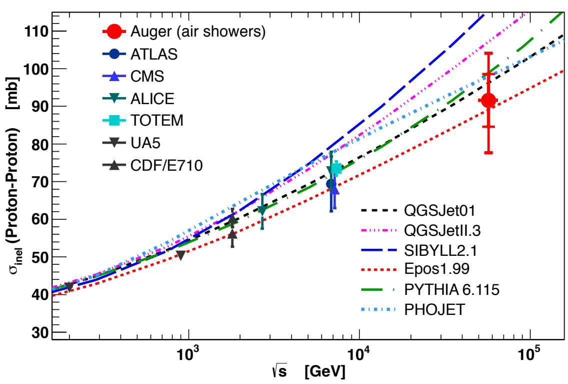


Fig. 2: Inelastic proton-proton cross section measured at colliders and with the Pierre Auger Observatory. The curves show different model predictions.

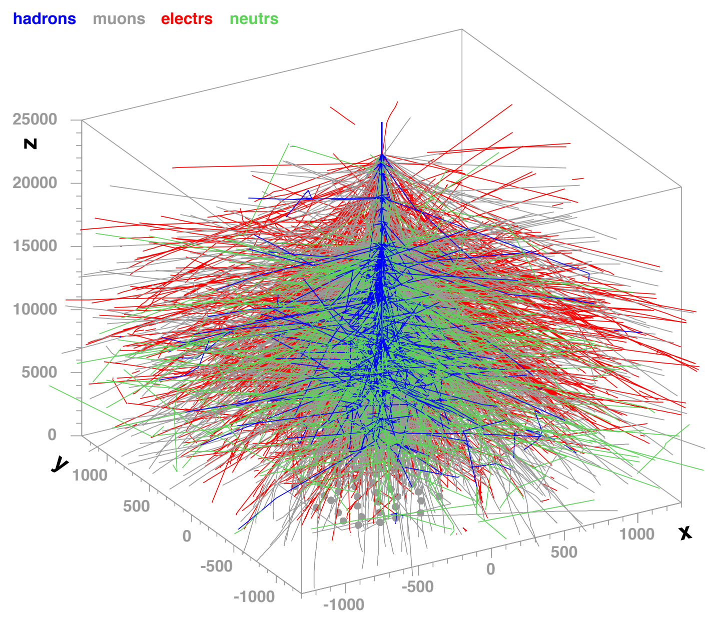


Fig. 3: Tracks of the particles in an air shower simulated with CORSIKA. To be able to plot the tracks, the shower of an iron nucleus of 10^{13}eV is shown.

methods for simplifying and speeding up the simulation process have been developed and are available in CORSIKA, a program package for Monte Carlo simulation of air showers.

CORSIKA

Initially developed for the KASCADE air shower array, CORSIKA has become the world-wide standard tool for all air shower experiments. It allows the simulation of particle cascades in full detail and includes interfaces to different Monte Carlo event generators for simulating hadronic interactions with the highest possible quality. Some of these generators are also regularly used for interpreting particle physics data of fixed-target and collider experiments. Linked with the CoREAS package, CORSIKA can also be used to calculate the radio signal of air showers.

Dr. Ralph Engel KIT, Pierre Auger Observatory, IceCube-Gen2, NA61, FUNK
Prof. Markus Risse U Siegen, Experimentelle Teilchenphysik, Pierre Auger Oberatory


High-Energy Particles in the Universe

For more than 100 years scientists have pondered the origin of highly relativistic cosmic rays from the cosmos. A crucial ingredient is to understand how they interact and propagate in the cosmic soup of photons and magnetised plasmas. To this end a new numerical tool, CRPropa 3, was developed within HAP and is now widely used to interpret observations.

The highest energy particles occurring in our Universe reach macroscopic energies of up to about 50 Joules, or a few times 10^{20} electron volts which is the energy an elementary charge would gain by transversing a voltage of a few times 10^{20} volts. These enormous energies are presumably concentrated in one elementary particle such as an atomic nucleus or a proton. The first such event was detected in 1963 by the Volcano Ranch Observatory which triggered construction of further experiments with larger exposure such as the Fly's Eye, the Telescope Array and the Pierre Auger Observatory (more details in a separate article in this brochure).

Nobody has a very clear understanding yet of how such particles are accelerated and in which kind of astrophysical sources they originate. The search for their origin is complicated by the fact that during propagation from the source to the observers the trajectories of such particles can be deflected significantly by galactic and extragalactic magnetic fields and energy can be lost due to inelastic interactions with low energy photons. An illustration is given in Fig. 1 where a trajectory of a 10^{20} eV oxygen nuclei is shown.
Connecting the source characteristics with the observations thus requires detailed modelling of ultra-high

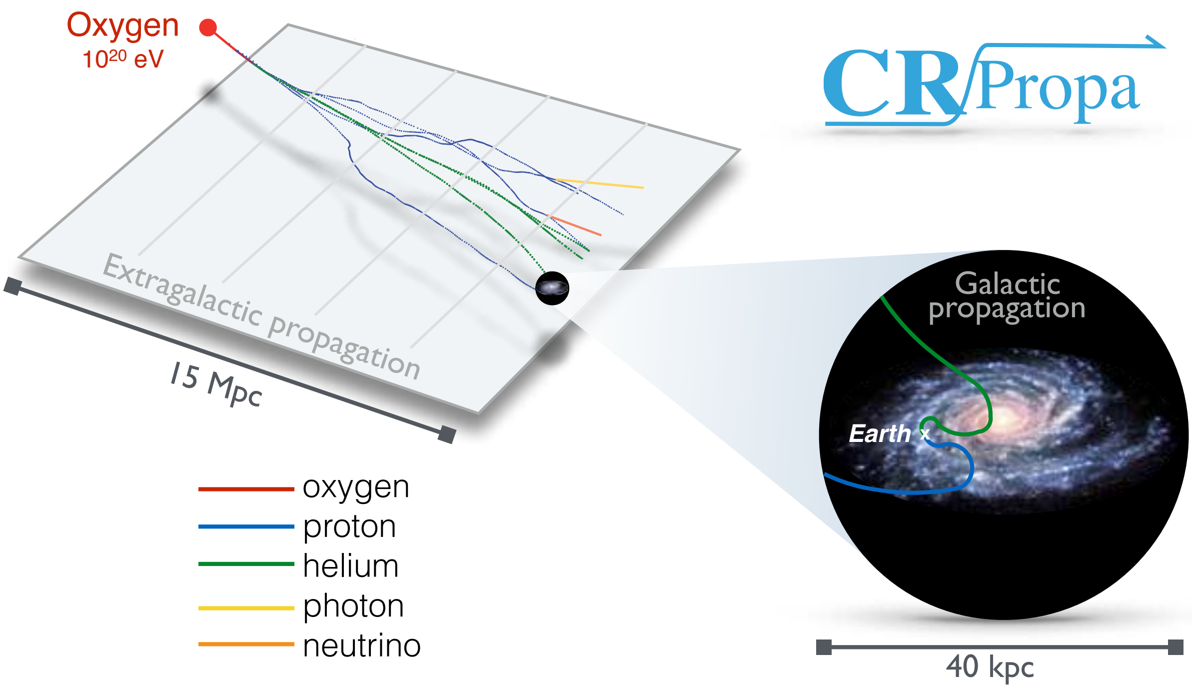
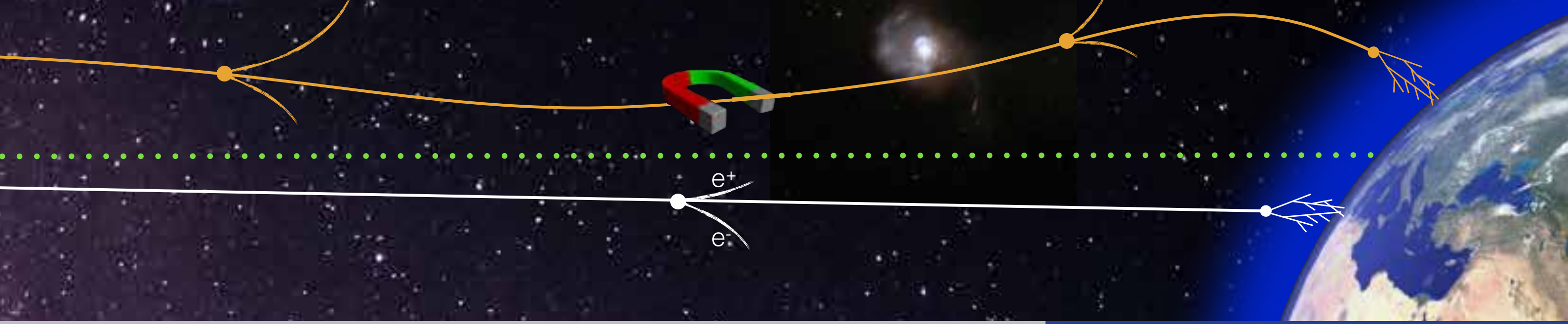


Fig. 1: Basic use case of the CRPropa 3 framework. In this example an oxygen nuclei with energy 10^{20} eV is injected at a distance of about 15 Mpc. Subsequent particles are indicated.



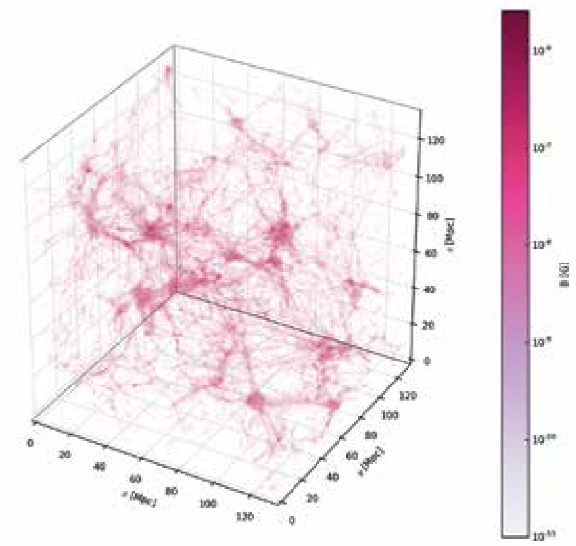


Fig. 2: Illustration of a three-dimensional structured extragalactic magnetic field model

energy cosmic ray propagation which generally has to be done numerically. This motivated the development of the CRPropa software tool. CRPropa is a public and user friendly numerical program built to simulate the energy spectrum, mass composition and arrival direction distribution for various source arrangements and injection characteristics while accounting for interactions with background photons and deflections of the intervening cosmic magnetic fields.

The latest version, CRPropa 3, has been developed in close cooperation between RWTH Aachen University and the Universities of Hamburg and Wuppertal within the Helmholtz Alliance for Astroparticle Physics. CRPropa's precursors were developed in the 1990s and 2000s in Chicago and Paris. However, the architecture and the code implementation have been completely reworked in order to profit from modern programming design and computing techniques. Its modular structure allows different components of a given astrophysical scenario to be combined and assembled. Users can also extend scenarios by including their own physics modules. Compared to previous versions, CRPropa 3 also contains new features. Most notably are models for the cosmological evolution of the infrared and radio backgrounds, corrections for the effects of cosmological expansion when simulating deflections in cosmic magnetic fields, the evaluation of deflections in the galactic field, updates to the implemented photodisintegration processes, and a "four-dimensional mode" which allows the simulation of time dependent scenarios by registering particle detections within a chosen time window. An illustration of a structured extragalactic magnetic field and the corresponding arrival directions for injected iron nuclei is shown in Fig. 2 and Fig. 3. In addition, the development and propagation of electromagnetic cascades can now be simulated numerically down to TeV energies using a Monte Carlo approach. This enables detailed predictions of astrophysical scenarios in a wide energy range and opens the window for sophisticated multi-messenger analyses.

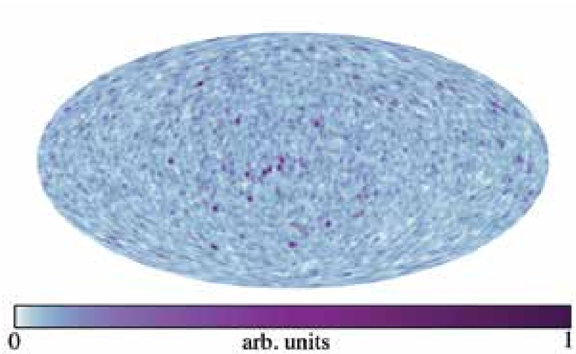
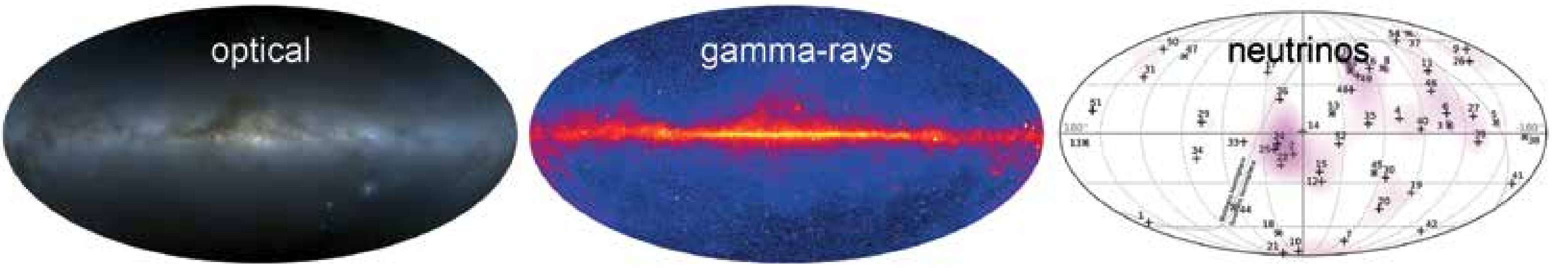


Fig. 3: Sky map of cosmic ray arrival directions propagated through a structured extragalactic and galactic magnetic field.

Given the variety of possible applications CRPropa 3 has the potential to become the new state-of-the-art tool for propagating extragalactic and galactic cosmic rays. The program is publicly available and can be downloaded at https://github.com/CRPropa/CRPropa3 .

Prof. Günter Sigl U Hamburg, II. Institut für Theoretische Physik, Pierre Auger Observatory
Dr. Daniel Kümpel RWTH Aachen University, Bergische Universität Wuppertal, Pierre Auger Observatory



Multi-Messenger Astronomy

The most violent sources in the Universe shine bright in many wavelengths. Every time we observe the Universe in a new wavelength (i.e. with light of a different energy), we open a new window to the Universe, enabling us to study different physical processes taking place in a source and its environment.

While our eye is sensitive to only a tiny fraction of the light spectrum – to optical light – modern telescopes allow us to study light at low energies (e.g. radio emission) or high energies (e.g. X-rays and gamma-rays). However, the photons (i.e. light) are only one of several messengers reaching us from the high-energy Universe. Novel messengers, such as cosmic rays, neutrinos and gravitational waves, may open even more windows to the Universe and provide us with a deeper understanding of the highest-energy processes.
Although cosmic rays bombard us from all directions at high rates, they do not reveal the direction of their sources, because they are charged particles, which get deflected in intergalactic magnetic fields (Fig. 1). High-energy neutrinos are produced alongside the high-energy cosmic rays in the most violent sources in the Universe and might be the key to solve the 100-year old question of the origin of high-energy cosmic rays. However, neutrinos are hard to detect and only a small number of astrophysical events were identified – not enough to pinpoint their sources (yet). Combining data from neutrinos, cosmic rays and photons is the most promising way to identify neutrino and cosmic-ray sources. The multi-messenger approach was a central topic at the HAP workshop "The non-thermal Universe" in September 2016 in Erlangen.

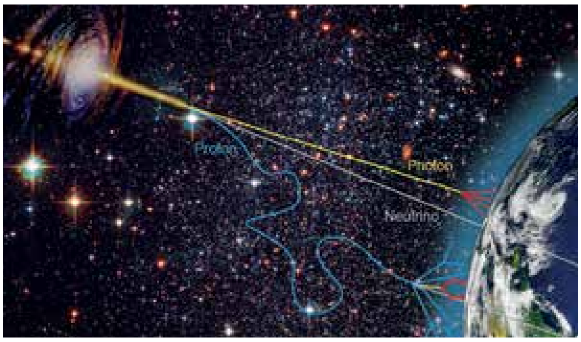
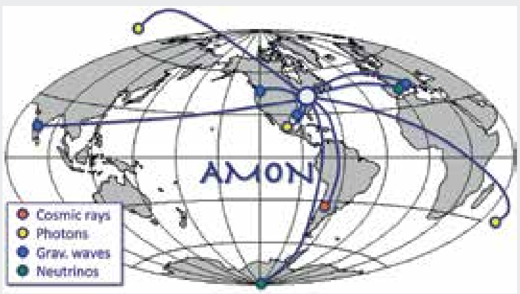


Fig. 1: Particles from outer Space travelling towards the Earth.

AMON

Multi-messenger astronomy depicts a new tool to explore the most violent phenomena in the universe. Different messengers such as neutrinos, photons and gravitational waves reach detectors on the ground and satellites in space.
The Astrophysical Multimessenger Observatory Network (AMON) will combine signals from various observatories aiming to find coincident signals in real time to identify transient astrophysical sources and their electromagnetic counterparts and provide alerts to follow-up observatories.



Collaborating instruments are the neutrino observatories IceCube and ANTARES, the Pierre Auger Cosmic Ray Observatory, the gamma-ray instruments HAWC, VERITAS, FACT and Fermi, the robotic optical telescopes MASTER, PTF and LCO, the X-ray satellite Swift as well as the gravitational wave detector Advanced LIGO.

Tracking Down Neutrino Sources

Using information from gamma-ray telescopes enabled a targeted search for neutrinos from gamma-ray blazars (AGNs with jets pointing at us) and gamma-ray bursts (GRBs) to probe whether they are neutrino and thus cosmic-ray sources. No significant excess of neutrinos from blazar or GRB directions has been found.
Surveys in other wavelength (e.g. very-high energy gamma-rays at TeV energies or optical wavelength) suffer from limited sky coverage and might miss fading or variable sources. To overcome this caveat, a real-time search for electromagnetic counterparts to high-energy neutrino events was developed.

Real-Time Searches

The real-time search uses the most interesting neutrino events to notify other telescopes, which will then immediately observe the corresponding region in the sky aiming for the detection of a variable or fading counterpart, for illustration see Fig. 2. This way we make sure not to miss a rapidly fading source or a high state of a variable source. High-energy neutrino events are followed up by optical, X-ray, gamma-ray and radio telescopes. The HAP alliance helped to establish the leading role of the IceCube group at DESY in optical, X-ray and gamma-ray follow-up of high-energy neutrinos.
A common platform to combine interesting events from different messengers is provided by the *Astrophysical Multi-Messenger Observatory Network (AMON).* Events from neutrino, cosmic-ray, gravitational-wave and gamma-ray observatories are collected and correlated in real time. If interesting correlations are found, a network of follow-up observatories is notified. The IceCube team at DESY installed a stream of neutrinos, which is fed into AMON within tens of seconds after the neutrino arrival time. The HAP workshop "Monitoring the non-thermal Universe" in December 2016 in Cochem, which was followed by an AMON workshop, brought the international community a step closer towards a global multi-messenger network.

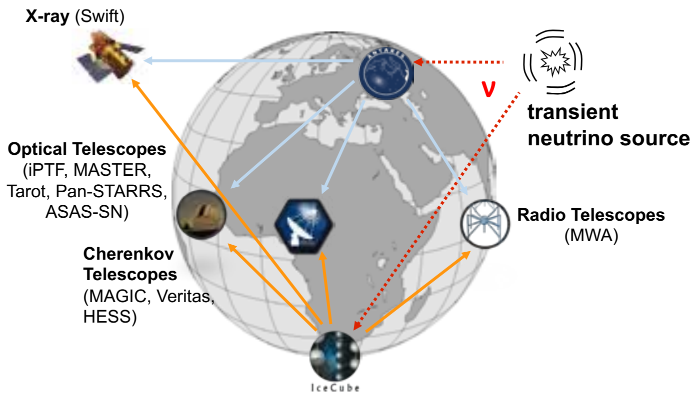
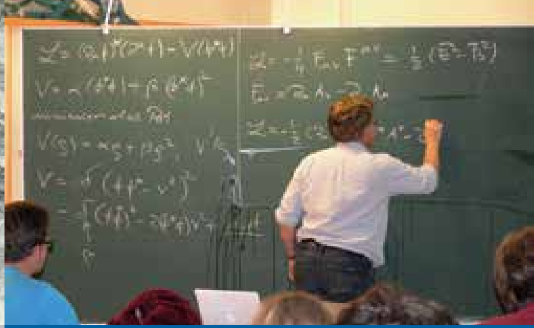


Fig. 2: Notification scheme of IceCube and ANTARES for interesting neutrino events.

Gravitational Waves

Entirely new messengers are gravitational waves (GW), ripples in spacetime caused e.g. by the merger of two black holes. Predicted by Einstein's general relativity theory, searches for GW have been on-going for decades and have finally been successful in September 2015 with the detection of a merger of two black holes with ~30 solar masses. A second event was detected in December 2015.
A large follow-up observation program was triggered by the GW alerts. Unfortunately the localization of state-of-the-art GW detectors is very poor, providing only banana-shaped regions in the sky covering several hundreds of square degrees. The poor localization complicates the search for a counterpart in other wavelengths and requires multiple pointings of wide-field-of-view telescopes. No obvious counterpart was found. Future GW events might include mergers of neutron stars, which are more likely to produce high-energy emission, including gamma rays and neutrinos. An additional GW detector is foreseen to take data in 2017.

Dr. Anna Franckowiak
DESY in Zeuthen
Leader of the Helmholtz Young Investigator Group
VH-NG-1202


Support for Schools for Young Scientists

Young scientists can be the driving forces in science. With their projects and fresh ideas, they can inspire the scientific landscape significantly. To open the full variety of astroparticle physics to them, early stage training like schools is a useful tool. Therefore, HAP supports two well-known schools and encourages its members to participate in such events.

School for Astroparticle Phyiscs

The School for Astroparticle Physics (www.astroteilchenschule.nat.fau.de) takes place every year in October in the small village of Obertruch-Bärnfels in the Franconian Switzerland. For nine days PhD students and lecturers come together at this really remote place to explore the mysteries of astroparticle physics. The school comprises lectures in the morning and exercises in the afternoon as well as presentations by the participants on their own research work. The school covers actual topics from astroparticle physics, being complemented by lectures on many facets of particle physics, astrophysics and cosmology given by international, eminently respectable experts.

The focus of the school varies from year to year so that over time many different topics and projects have been addressed. It is the special mixture of people and topics which stimulate the lively discussions that take place not only in the lecture room but also during breaks and after dinner.

The „Gasthof Drei Linden" is hosting the school since 2004. Participants and lecturers as well enjoy the friendly atmosphere of the hotel, the excellent meals and the beautiful countryside. During the afternoon breaks, they go out for playing soccer, for hiking or relaxing. After the nine days the whole group has grown together and many participants regret that the school came to its end.

Prof. Gisela Anton
Lehrstuhl für Teilchen- und Astroteilchenphysik
FAU Erlangen-Nürnberg
ECAP - Erlangen Centre for Astroparticle Physics

ISAPP

Astroparticle Physics is an interdisciplinary field at the interface of particle physics, nuclear physics, cosmology and astrophysics. Since 2002 a network of European Institutions has been created, named ISAPP (International Schools in AstroParticle Physics), with the purpose of implementing the early stage

ISAPP Schools 2011 - 2017

2011 **Varenna, I:** The Neutrino Physics and Astrophysics
Heidelberg, D: The Dark Side of the Universe

2012 **Paris, F:** Multi-Messenger Approach in High Energy Astrophysics
La Palma, E: CMB and High Energy Physics

2013 **Canfranc, E:** Neutrino Physics and Astrophysics
Stockholm, S: Dark Matter Composition and Detection

2014 **Belgirate, I:** Multi-Wavelenght and Multi-Messenger Investigation of Visible and Dark Universe
LNGS, Assergi, I: Hands-On Experimental Underground Physics at LNGS

2015 **Paris, F:** School on Cosmology

2016 **GSSI, L'Aquila, I**: Summer Institute on Particle Physics to Understand and Image the Earth
Milano, I: Physics and Astrophysics of Cosmic Rays in Space

2017 **Arenzano, I:** Neutrino Physics, Astrophysics and Cosmology
Texel, NL: The Dark and the Visible Side of the Universe

training in the field of Astroparticle Physics both by jointly organizing yearly International Schools on Astroparticle Physics and by promoting the mobility of students and young researchers within the Doctorate Schools.
The ISAPP network is based on a firm agreement. The participating Institutions are asked to facilitate, whenever possible, jointly supervised doctoral theses as well as the participation of ISAPP members in examination Committees. The network is managed by an International Scientific Committee composed of one representative for each Institution. The Committee elects a Coordinator, in charge for two years. The network presently includes 36 Institutions from 11 different European Countries. Other Institutions negotiating their joining are welcome.

Every year ISAPP organises a 15 days or two times 10 days of intense school activity, held either in two different sites or in two consecutive events in the same site. The schools are conceived as didactic courses of lectures at the level of a doctorate school. The schools are opened to doctorate students and young researchers from any Institutions, even if not members of the network.
The ISAPP schools are organised by turn in the various countries of the network. The physics subjects cover Neutrino Physics and Astrophysics, dark datter, Dark Energy, Cosmic Microwave Background, Large Scale Structure, Cosmic Rays, Early Universe, Gravitational Waves. Since 2002, 27 ISAPP Schools have been organised. Since 2012 until 2016, the ISAPP Schools have been sponsored by HAP.

Prof. Gianluigi Fogli
Full professor of Theoretical Physics at
U of Bari
Coordinator of ISAPP 2011 - 2016

How do you evaluate the interplay of more national networks like HAP and international cooperations like ISAPP?

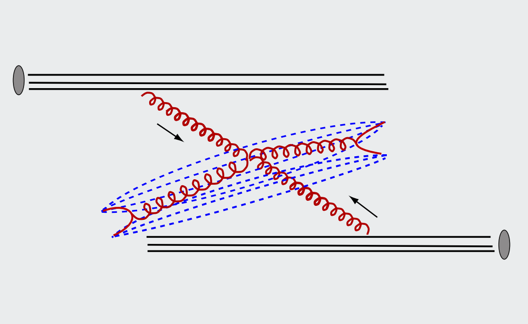
Fogli: I am strongly in favour of the cooperation between different institutions of different countries. In the past I have been coordinator of ENTAPP, the "European Network of Theoretical Astroparticle Physics", the first initiative, in my knowledge, of collecting the theoretical activity of Astroparticle Physics in Europe. ENTAPP was part of the I3 (Integrated Infrastructure Initiative) named ILIAS, i.e. "Integrated large Infrastructure for Astroparticle Science", initiative proposed and approved within the 6° PQ of the EU. Until the end of 2016 I was Coordinator of ISAPP, which can be considered a consequence of that experience.

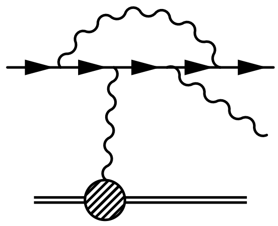
Which benefits of ISAPP do you see for the networking of Astroparticle Physics within Europe?

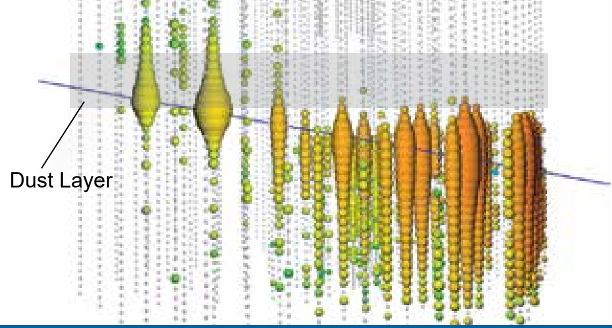
Fogli: The benefits are very relevant. Students of different countries, coming often with different basic preparation, have the possibility of following courses of high level, in general with teachers well known in their fields, in a climate of positive competition. This is fundamental for their formation. Personally, I still remember the first school I have followed, in 1965, in Bad Kreuznach, with Van Hove, Perkins and Winter within the teachers. It is the first step forward long-term understanding and friendship between the students. And for the teachers, too.

Which benefits do you see in general of an international networking within Astroparticle physics?

Fogli: Since Astroparticle Physics is typically a interdisciplinary field at the interface of particle physics, nuclear physics, cosmology and astrophysics, the international networking become fundamental. Each researcher comes from a different school, with different experiences. Accordingly, he gives a different contribution to the Astroparticle community, by favouring the common reseach activity.







Support for PhD Students and Postdoctoral Researchers

HAP emphasised from its beginning the support of young scientists as one of the main goals, especially when supporting new ideas or projects extending the main research lines in the partner institutes. Here, we report on four examples out of more than 80.

Ultra-High Energy Cosmic Rays

Dr. Ralph Engel, PI, KIT

The work on a multi-purpose hadronic event generator such as Sibyll is at the heart of HAP due to its multidisciplinary character. Thanks to the support by the Helmholtz Alliance it was possible to extend the Sibyll model from its direct application in air shower physics to predictions for atmospheric lepton fluxes. Many different groups working in a multitude of different experiments profit from this development.

Dr. Felix Riehn,
PhD student, received PhD in Dec. 2015

High energy processes in the Universe are studied through the detection of messenger particles, like photons, neutrinos and protons or nuclei. Everything from the production at the source, the propagation through space, and the arrival at Earth is influenced by the interactions of these particles with matter. My work within HAP was focused on the modelling of hadron interactions at all energies. A new version of the Sibyll model was developed and tuned to describe the largest possible set of laboratory measurements and to predict interactions up to 10^{20} eV in the lab system. Sibyll is mainly used for the simulation of air showers but will be applicable for any hadron interaction, be it at the source or in the interstellar medium. With the inclusion of a detailed model for charmed hadron production, Sibyll is the first dedicated model that allows the prediction of inclusive atmospheric lepton fluxes.

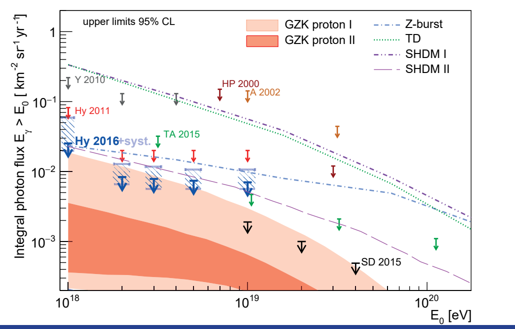
Astroparticle Theory

Prof. Wolfgang Rhode, PI, U Dortmund

The study of particle fluxes in Astroparticle Physics implies the precise knowledge of the interaction probabilities of all involved particles. This goal requires an interdisciplinary cooperation of particle physics and astroparticle physics. The Helmholtz Alliance has opened the possibility for successful cooperations crossing not only physical borders. The results are relevant for IceCube and all similar underground experiments.

Alexander Sandrock
PhD student

The cross sections of muon energy loss processes have been calculated with sufficient accuracy for the purposes of detectors at accelerators. However, for underground neutrino detectors in astroparticle physics, the energy loss has to be known more accurately because it directly enters the determination of the neutrino spectra. HAP made it possible for us to study the calculation of energy loss cross sections of muons in detail and to cooperate with leading scientists of the field in Moscow to calculate new cross sections and to reduce the systematic uncertainties. We calculated radiative corrections to the bremsstrahlung energy loss using a modified Weizsäcker-Williams method to take into account for the extended charge density of the nucleus and its screening by atomic electrons. We showed that the energy loss increases by several percent through this correction.



Double Beta Decay

Prof. Kai Zuber, PI, U Dresden

The search of lepton number violation in form of neutrino-less double beta decay is of eminent importance for showing the Majorana character of the neutrino. This might explain why there is more matter than antimatter in the Universe. HAP allowed to perform an analysis of a world-wide leading experiment but also to study this decay mode in dark matter detectors and also to estimate the contributions of solar neutrino background for future double beta decay experiments.

Thomas Wester

PhD student

I worked on data analysis and Monte Carlo simulations for double beta decay and dark matter research. The focus was on alternative decay modes that lead to emission of gamma/x-rays, like double beta decays into excited states of the daughter nucleus or double beta+ decays and double electron capture. The research was embedded in the GERDA experiment using double beta decay modes of Ge-76. As GERDA uses a large liquid argon cryostat, it allows studying background related to liquid argon and search for the double electron capture of Ar-36. Sensitivity studies using proposed designs like the DARWIN project will test the feasibility of double beta decay searches of Xe and Ar isotopes. More realistic Monte Carlo simulations considering additional double beta decay modes and further background (e.g. from solar neutrinos) are being developed.

Ultra-High Energy Photons

Prof. Markus Risse, PI, U Siegen

The search for ultra-high energy photons is a win-win situation: upper bounds constrain theories on the origin of cosmic rays, while finally detecting them opens a new window to the Universe. HAP funding allowed us to conduct this search and achieve the world's best limits. It also meant a win-win situation for the persons involved: we could hire excellent talents, who in turn grew to researchers with own profiles.

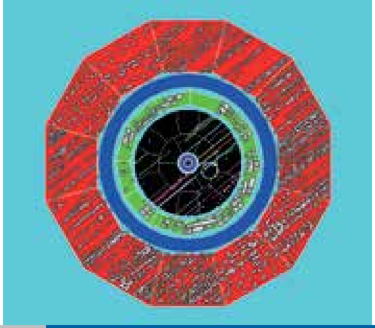
Dr. Mariangela Settimo

PostDoc

My research activity is focused on the study of ultra high-energy cosmic rays. At Siegen, I was primarily involved in the search for ultra-high energy photons with the Pierre Auger Observatory. These photons are expected to be extremely rare. No photons have been identified so far but they are privileged messengers of the sources and the propagation of the most energetic particles in the Universe. As result of my activity, I have derived the most stringent limits currently available at energies above 10^{18} eV and I developed a Monte Carlo code (EleCa) for the propagation of high-energy photons in the extragalactic space. I was coordinator of the analysis task for the search of ultra-high energy photons within the Auger Collaboration and member of the multi-messenger working group in collaboration with IceCube and Telescope Array colleagues.

Statistics

About 85% of the HAP funding was dedicated to personnel. These were mostly doctoral researchers doing their PhD project and about 30% postdoctoral researchers. The average support period with HAP funding was 24 months at one of the HAP institutes. Female scientists represented more than 20% of this group. By the end of 2016, almost 60% of the HAP-supported researchers were still working at the same or at another HAP institute, about 20% were still in science, but at other institutions or areas, and 10% left science to work in industry or schools.



HAP Senior Fellows

One of the principle purposes of the Helmholtz Alliance for Astroparticle Physics is to build and strengthen the network of scientists in the field of Astroparticle Physics. Within HAP, this network is understood to overcome regional distances but also distances between young potentials, well-settled researchers and active, but already officially retired scientists.

The HAP has awarded the honour of "Senior Fellow of the Helmholtz Alliance for Astroparticle Physics" to ten distinguished scientists in this field. The award comes along with an one-off financial incentive and the opportunity for receiving reimbursements for science travels and equipment. This support shall help the senior scientists to remain active in the field of Astroparticle Physics and to participate in workshops and conferences. The community benefits from their experience and broad overview.

Prof. Claus Grupen
HAP Senior Fellow since 2015
Member of MARS, PLUTO, ALEPH, MUTRON, KASCADE/KASCADE-Grande.

What are the important developments in Astroparticle Physics within the last 5 to 10 years and how do you evaluate the cooperations of the national and international players in the field?

The selection of the most important developments in my mind are the recent detection of gravitational waves, the precision measurements of the cosmological blackbody radiation especially by the Planck satellite and the successful search for exoplanets using refined astronomical techniques. The detection of gravitational waves was a really joint and international affair. Without the elaborate technique of squeezed light developed by the Albert-Einstein-Institute in Hannover the required sensitivity would not have been reached to see the minute ribbles of space-time. The same is true for the measurements of the Planck satellite as well as the exoplanet search. Such big projects require – not only financially – the intellectual input which you only find on an international basis.

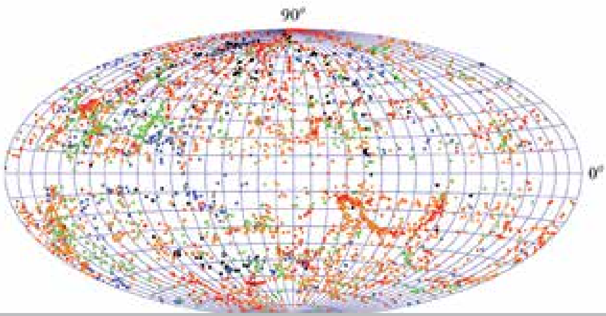
Which HAP-developments are most favorable and worth for intense support in coming years in your opinion?

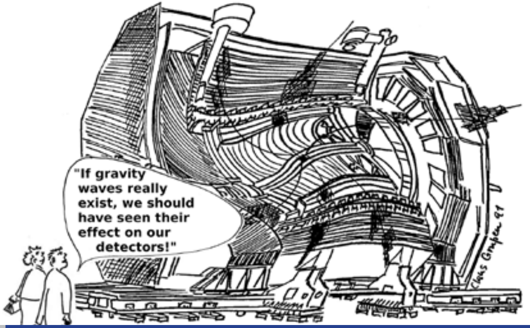
I find the different approaches in the observation of interesting astrophysical objects using multi-messenger probes based on new technologies very attractive. It would be nice to see the objects emitting gravitational waves also in other spectral domains. The observation of the afterglow of colliding black holes should be very revealing, but it is also a challenge. For the coming years activities and encouragements for young scientists should rank at high priority.

How could you use the HAP Senior Fellow Award personally?

After having received the HAP Senior Fellow Award I benefitted from the possibility to participate in meetings and workshops, like the ones organized in the framework of the Non-Thermal Universe.

I also took advantage of efficient and productive discussions on astroparticle physics problems as member of the KASCADE-Grande experiment and I appreciated the familiar and cooperative atmosphere in this experiment.





HAP Awardees:

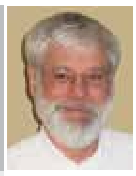
2011 **Prof. Dr. P. L. Biermann** (MPI für Radioastronomie in Bonn)
Dr. H. O. Klages (KIT, Karlsruhe)
Prof. Dr. E. Otten (U Mainz)

2013 **Prof. Dr. F. von Feilitzsch** (TU München)
Dr. G. Schatz (KIT, Karlsruhe)
Prof. Dr. H. J. Völk (MPIK, Heidelberg)

2014 **Dr. C. Spiering** (DESY, Zeuthen)
The second nominee, **Prof. Dr. E. Lorenz** (MPP, München) sadly passed away before receiving the award.

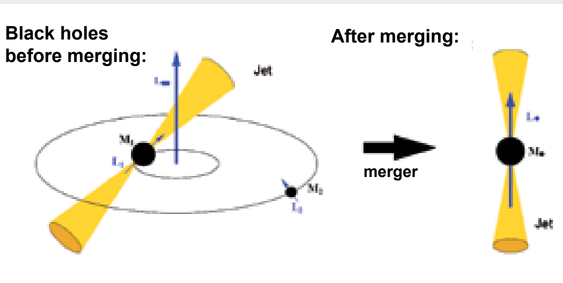
2015 **Prof. Dr. C. Grupen** (U Siegen)
Prof. Dr. H. Meyer (BU Wuppertal)

Prof. Peter L. Biermann
HAP Senior Fellow since 2011
Member of LOPES, JEM-EUSO, and the Auger Collaboration



What are the important developments in Astroparticle Physics within the last 5 to 10 years and how do you evaluate the cooperations of the national and international players in the field?

The main results have been i) the discovery of the inhomogeneity of arrival direction distributions of the AUGER and TA Ultra-High-Energy Cosmic Ray (UHECR) events, ii) the detection of a High Energy neutrino background and its tentative identification with a sub-class of flat spectrum radio sources (Kun Dissertation U. Szeged), those with a flat spectrum extending to near THz, and often with TeV gamma photon emission, and iii) the detection of gravitational waves. Considering the tentative identifications of the High-Energy neutrino events (Kun Dissertation U. Szeged) suggests that the main injection of UHECR particles occurs following a merger of Super-Massive Black Holes (SMBHs), with an ensuing spin-flip (Dissertation Zier, U. Bonn) and so reorientation of the dominant jet. The detection of 100 Mpc scale arc-like distributions of SMBHs (Caramete Dissertation U. Bonn) suggests that their formation was quite early in the universe, possibly near redshift 100, see sky map on the top with SMBHs, $\geq 3 \cdot 10^7$ $M_\odot$, and colors from black (small) to red (large) redshift.



What are the differences in the field of Astroparticle Physics today in comparison to your own early career?

When I was young, the field did not even exist, and many of my former students and postdocs have made their contribution.

How could you use the HAP Senior Fellow Award personally?

It allowed me to accept invitations to visit conferences and a school in London to give lectures.

Key Technologies for Dark Matter Search

Signals from dark matter particles scattering on normal matter are expected to be extremely rare, with tiny energy deposits. A key requisite for any direct search experiment is thus an excellent suppression of spurious background combined with a highly efficient detector technology. HAP fostered a fruitful exchange to ever improve detector technologies as illustrated here.

Ultra-Pure Xenon for XENON1T

The experiment XENON1T uses 3.5 t of liquid xenon as a target searching for dark matter particles in the halo of our galaxy. The sought-after signal of a dark matter particle interacting with the detector is a tiny recoil of a xenon nucleus giving rise to a few photons and a few electrons in the detector. Unfortunately, radioactive decays can mimic such a signal. Therefore, the detector materials are carefully screened and selected for ultra-low radioactivity. Additionally the self-shielding property of liquid xenon, an absorber for gamma radiation nearly as good as lead, reduces the background from non-dark matter events in the inner part of the detector. Still one kind of background can not be avoided by these methods: radioactive isotopes in the liquid xenon itself. Xenon collected from the atmosphere by liquefying air always contains spurious amounts of the noble gas krypton including a tiny fraction of the radioactive isotope Kr-85.

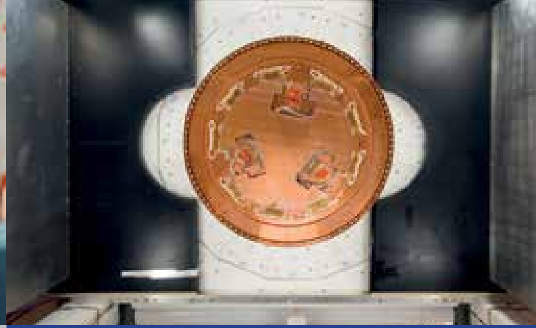
To avoid background events from Kr-85 decaying in the detector, the xenon has to be purified from krypton. Commercially available xenon gas contains krypton levels of 1 ppm to 10 ppb (1 ppm = 1 part per million, 1 ppb = 1 part per billion), which is far too much for such a very sensitive dark matter detector like XENON1T. A dedicated cryogenic distillation column to remove krypton from xenon by at least another factor of 10,000 has been designed and built at University of Münster. For this challenging task the advice by a cryogenic distillation expert from Tritium Laboratory Karlsruhe at KIT was crucial. This cooperation in the design of the apparatus was enabled and funded by HAP. After transporting the cryogenic distillation column to the Italian underground laboratory LNGS at Gran Sasso and installing it at the XENON1T experiment the scientists eagerly awaited its performance. Sending a probe of distilled xenon to MPIK in Heidelberg, the RMGS group there could only measure an upper limit of 48 ppq (1 ppq = 1 part per quadrillion) of krypton in xenon, a new world record. Since November 2016 the XENON1T detector is running in search for dark matter containing in its inner part the purest xenon ever.

First tests with this apparatus have proven that the method of cryogenic distillation could even be applied to remove radon out of xenon, the other noble gas with radioactive isotopes contaminating xenon.

Cryogenic distillation column with top condenser, package tube in the middle part, and input condenser and reboiler in the bottom, total height 5.5m.

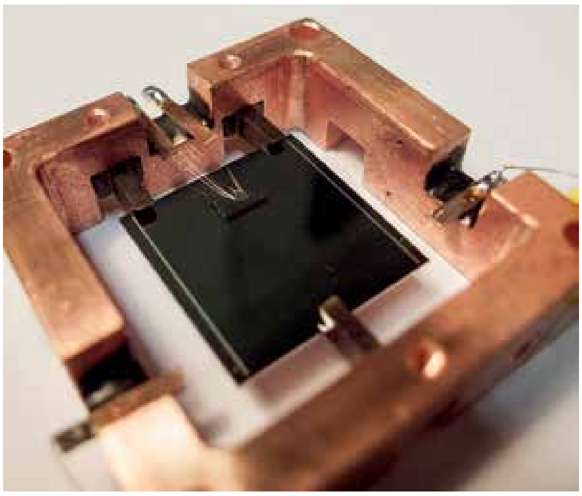
Prof. Christian Weinheimer
U Münster,
Institut für Kernphysik
KATRIN, XENON1T





Improved Light Sensors for CRESST

The CRESST experiment is located at Laboratori Nazionali del Gran Sasso, Italy and it is currently the most sensitive experiment searching for light dark matter particles (masses smaller than < 2 GeV/c^2). The experiment uses cryogenic detectors operated at milli-Kelvin temperatures to search for very low-energetic recoils induced by dark matter scattering off the nuclei in scintillating calcium tungstate ($CaWO_4$) target crystals. These detectors measure the recoil energy very precisely using so-called transition edge sensors (TES), very sensitive superconducting thermometers. The amount of scintillation light produced in the $CaWO_4$ crystals depends on the kind of interacting particle, i.e., whether the event was induced by electrons and gamma-radiation, alpha-particles, or nuclear recoils. The scintillation light for each event is measured with a separate cryogenic light detector and this allows to efficiently suppress events induced by natural radioactivity within the detectors and ambient radioactivity from the laboratory. The cryogenic light detectors consist of silicon or silicon-on-sapphire disk that absorbs the scintillation photons and their energy is measured using a TES. For future phases of the experiment it is very important to further improve the sensitivity of the light detectors and a promising way to achieve this is the so-called Neganov-Trofimov-Luke effect (NTLE). The NTLE amplifies the primary signal by drifting the charge carriers created by the absorption of photons in an electric field applied to the semiconductor absorber. In this field, the charges gain additional energy, resulting in an improved sensitivity. With the support of HAP, the fabrication techniques used to produce NTLE detectors were improved and new energy calibration methods have been studied. In addition, new applications for these detectors in the search for the neutrinoless double beta decay have been investigated.



Light sensor in its copper frame, electrically connected to allow signal amplification through the NTLE effect

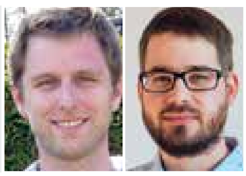
XENON1T

The experiment XENON1T is the largest and most sensitive dual phase liquid noble gas detector searching for dark matter particles. It has been installed in the Italian Laboratori Nazionali del Gran Sasso (LNGS) in the Abruzzi mountains near Rome by an international collaboration of 22 institutions from 10 countries. In Germany the Max-Planck-Institute for Nuclear Physics at Heidelberg as well as the Universities of Freiburg, Mainz and Münster are members of XENON1T.

CRESST

The CRESST experiment, located also at LNGS, is searching for dark matter particles scattering off the nuclei in scintillating calcium tungstate crystals ($CaWO_4$). The crystals are operated as cryogenic detectors at milli-Kelvin temperatures and the emitted light is detected in a separate cryogenic light detector, enabling the identification of different kinds of particle interactions. Its ability to detect even very low energetic nuclear recoils makes CRESST currently the most sensitive experiment for dark matter particles with masses smaller than ~ 2GeV/c^2.

Dr. Jean-Côme Lanfranchi TU München
Physik-Department E15, CRESST
Dr. Michael Willers TU München
Physik-Department E15, CRESST



New Technologies for Cosmic-Ray Detection

Within the Alliance a special focus was given to new technologies which seem to be applicable and of interest for the community. Innovative and synergetic R&D strategies for new detection techniques were developed and supported in order to extend the acceptance, energy range, and sensitivity of existing or future facilities dedicated to astroparticle physics.

The rapidly evolving field of astroparticle physics experiences sometimes changes in the detection strategies to solve the big questions of physics. This is also driven by fast progress in industrial developments (e.g. for photo-sensors or data communication systems) and requires a high flexibility for the instrumentation of new facilities. Fortunately, the flexibility of the Alliance allowed us to raise various new synergies with experts from different institutes, communities, collaborations and countries for specific R&D studies. By this, HAP provides a real added value, in particular for smaller projects with emerging future to newly evolving ideas. Some of these projects would even not have been started. As example, concerted studies of methods by radio and acoustic detection will be described. Though these are very different approaches applied to various facilities, there are common features like the emission mechanisms, the sensor technologies or the signal processing.

Radio or acoustic pulses provide an alternative way for the detection of high-energy cosmic particles that occasionally hit the Earth or its atmosphere. By these collisions of cosmic particles, cascades of millions of secondary particles are created that can be measured not only by particle detectors, but also by their emission of electromagnetic or acoustic waves. The radio emission is created by two mechanisms: firstly, due to the deflection of the charged particles in the Earth's magnetic field; secondly, due to the rapid evolution of a temporary charge excess in the front of the cascade that propagates almost with the speed of light. In addition, the heat deposit of the cascade in dense media produces a measurable acoustic wave.

The sensor technology is currently driven by commercial products, e.g. receivers of satellite TV dishes for the GHz radio detection or Piezo elements for the underwater microphones. The technological challenge for applications in astroparticle physics lies in the readout electronics and signal processing. Due to the ultra-short nature of the radio signals of few nanoseconds, dedicated solutions have been developed within HAP. A special pre-processing is directly implemented in the firmware of the readout electronics, and analysis software has been developed.

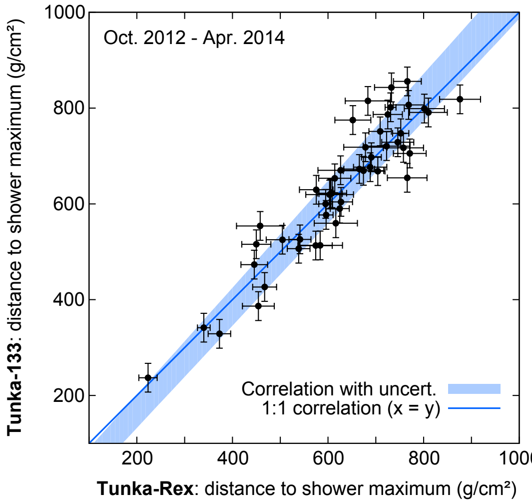
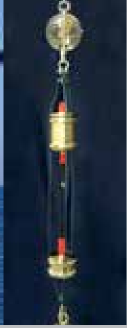


Fig. 1: Correlation of the distance to X_{max} (atmospheric depth between the shower maximum and the shower core) between radio and Cherenkov light measurements at Tunka (JCAP01(2016)052).

Dr. Julian Rautenberg Bergische Universität Wuppertal, Auger Observatory und CROME
Dr. Frank Schröder KIT
Auger Observatory, Tunka-Rex





AERA

The Auger Engineering Radio Array is the largest antenna array for high-energy cosmic rays in the world consisting of more than 150 autonomous radio-detector stations covering 17 km^2. AERA is located at the Pierre Auger Observatory in Argentina and has provided the proof-of-principle that the radio technique can be applied to large arrays by using solar power, wireless communication, and sophisticated electronics for the local data-acquisition in each station. In combination with the currently deployed upgrade of the observatory, AugerPrime, AERA can provide unprecedented precision data of the most energetic cosmic rays of the Milky Way, and pave the way for radio arrays on even larger scales that are required for the detection of extragalactic cosmic particles of highest energies.

Tunka-Rex

Tunka-Rex is the MHz radio extension of TAIGA, the Tunka Advanced Instrument for cosmic rays and Gamma Astronomy in Siberia close to Lake Baikal. Tunka-Rex started in 2012 at the existing air-shower detector Tunka-133 based on the established Cherenkov-light technique. Meanwhile Tunka-Rex consists of 63 antenna distributed over 3 km^2. By comparison to Tunka-133 it has provided a direct experimental demonstration that radio measurements are a cost-effective way to enhance the precision of existing cosmic-ray observatories. In Fig. 1, the compatibility of Tunka-Rwex data with those of Tunka-133 is displayed, exemplarily for the X_{max} reconstruction.

CROME

A setup of various antennas sensitive to the GHz frequency range were installed at the KASCADE-Grande array at KIT. CROME - Cosmic Ray Observation via Microwave Emission - aimed for searching for microwave emission from particle cascades in the Earth's atmosphere and to verify the existence of the molecular bremsstrahlung in this process. About 30 high-energy events have been detected unambiguously in the 3 to 4 GHz band with CROME. The analysis strongly indicates that the observed signal is due to a Cherenkov-compressed geomagnetic radiation as observed in the MHz band. However, an isotropic, non-polarised radiation as expected from the molecular bremsstrahlung process is disfavoured as dominant emission model. CROME tested microwave radiation as a new channel, but an application of microwaves as a substitute for fluorescence light detection seems very unlikely.

SPATS and AMADEUS

At the highest energies, cosmic rays interact with the cosmic microwave background creating neutrinos of EeV energies. In case of a neutrino interaction in a dense medium such as water or ice, this energy is deposited quasi-instantaneously. Though only a few micro-Kelvin, the sudden heating of the medium makes it expand, resulting in a sound wave that can be detected over large distances. Together with comparatively cheap sensors, this opens the opportunity for instrumenting multi-km^3 volumes to detect the very low fluxes of highest-energy neutrinos. Acoustic sensors have been deployed by HAP institutions both at the South Pole (SPATS - South Pole Acoustic Test Setup) and in the Mediterranean Sea (AMADEUS - Antares Modules for Acoustic DEtection Under the Sea). These projects demonstrated the principle feasibility of acoustic detection in both ice and water and identified the specific issues to be addressed for future setups. Synergetic effects with acoustic positioning systems, marine biology and environmental studies are additional arguments in favor of further investigating acoustic neutrino detection with the future KM3Net and IceCube-Gen2 neutrino arrays.

Dr. Andreas Haungs KIT, Pierre Auger Observatory, KASCADE-Grande, IceCube-Gen2
PD Dr. Robert Lahmann FAU Erlangen-Nürnberg ECAP - Erlangen Centre for Astroparticle Physics


Novel Light-Sensors for Astroparticles

Photosensors play a pivotal role in measuring the rare interactions of of neutrinos, gamma and cosmic rays. For decades photo-multiplier tubes (PMTs) have been used to detect these often very weak signals. For the next generation experiments, design optimizations, novel ways of collecting the light as well as the advent of silicon photomultipliers (SiPMs) have led to substantial improvements.

Photosensors for VLVνTs

With the discovery of a high-energetic flux of neutrinos from outside the solar system, a next generation of Very Large Volume Neutrino Telescopes (VLVνTs) is on its way to reveal their sources. The volume of several cubic kilometers needed to observe the very rare events can only be sparsely instrumented with sensors. Therefore a very high light-collection efficiency is the key aspect of the new generation of photosensors developed for the IceCube-Gen2 project at the South Pole and the KM3Net detector being built in the Mediterranean. At the same time the detectors need to be protected from the high ambient pressure and read out with the limited power available at the remote detector sites.

Within both collaborations, HAP scientists are spearheading the development and design of the photosensors, but are also closely working together to achieve the best result. As a prime example, the mDOM (multi-PMT Digital Optical Module) concept (Fig. 1, left) was initially developed for KM3Net, but has now also been adapted for IceCube-Gen2. Using many small PMTs instead of a single large one, the photo-sensitive area is more than doubled with a great improvement in uniformity. Modern electronics allow to continuously read out the signals from all PMTs simultaneously at an affordable power consumption, greatly simplifying the triggering approach.

In a more novel approach the WOM (Wavelength-shifting Optical Module) concept (Fig. 1, right) employs new techniques to improve the light collection efficiency. Inside a cylindrical quartz housing well adapted to the geometry of the holes drilled in the antarctic ice, the most abundant UV photons are captured by a wavelength shifting paint that is applied to a transparent tube. A large fraction of the re-emitted light is guided towards the ends of the tube by total internal reflection where it is detected. In this way a detection efficiency for Cherenkov light similar to the mDOM can be achieved using two rather small PMTs, which simultaneously reduces the sensor noise.


Fig. 1: left nDOM, right WOM.

SiPMs for Cherenkov Telescopes

A key to the understanding of the emission and acceleration processes in cosmic-ray sources are measurements of their gamma-ray flux. Once the emitted TeV photons reach the Earth's atmosphere, they are measured with telescopes that record the faint and ultra-short light flash of Cherenkov light emitted by the extensive air showers. Exposed to environmental conditions, the stability and robustness of the applied light sensors is of major importance for the measurements.

To improve on these aspects, HAP scientists have constructed and installed the First G-APD Cherenkov Telescope (FACT) on the Canary Island of La Palma. Its novel camera design replaces classical photo-multiplier tubes for photon detection by semi-conductor based photo sensors (SiPM) in conjunction with light concentrators to increase the sensitive area of each sensor. The telescope is now in operation for more than five years with a very high duty cycle thanks to the increased dynamic range allowing the telescope to operate also in astronomical twilight conditions.
Based on SiPM technology, HAP scientists also developed a small low-cost multi-purpose camera. Installed behind a 50 cm diameter Fresnel lens. Its current applications range from the original idea of the detection of fluorescence light of air showers to the use for educational purpose in laboratory courses. Deployed at the High Altitude Water-Cherenkov Observatory (HAWC) in Mexico, an array of these telescopes will improve HAWC's energy resolution. An even larger array could be used as an additional cosmic ray detector component of the IceCube neutrino Observatory, IceAct. A single prototype telescope has been installed at South Pole in 2015 and operated successfully during two polar nights recording events in coincidence with IceCube.

Space Light Sensors

A promising alternative approach for the detection of cosmic rays is the observation of the fluorescence emission from space. HAP is participating in several prototype experiments for EUSO (**E**xtreme **U**niverse **S**pace **O**bservatory) in particular by developing and calibrating the photosensors. HAP supported the development of a calibration stand for single-photon sensitive sensors SPOCK, the **S**ingle **P**h**O**ton **C**alibration stand at **K**IT. The calibration stand is also used for first tests, to verify that SiPM can in future replace the heavy and expensive Multianode PMT's presently in use for the EUSO test experiments. An early prototype of a SiPM based fluorescence camera for space is designed to operate as add-on to EUSO-balloon flights (see Fig. 2).

Fig. 2: Instrument for the EUSO-SPB (Super Pressure Balloon by NASA) during flight preparation, where right of the Multianode-PMT camera the SiPM based add-on camera can be seen.

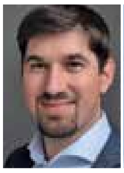
Topical workshop “Detector design and Technology”

In a workshop dedicated to the design and technology for VLVνTs, 78 participants from the KM3Net and IceCube collaborations and representatives from companies met in Dezember 2013 in Aachen. In 27 presentations and many lively discussions a large number of ideas was discussed, while establishing many new contacts between supplying companies, young students and experienced researchers.

Topical workshop “Advanced Technologies”

“Advancements in Photosensor developments” was chosen as the Highlight Topic for the HAP workshop held in Mainz in February 2015, flanked by a broader program on detection and readout technologies and electronics design. From the 21 students, a large number also later participated in the week-long FPGA school organised with HAP support in Mainz in October 2016.

Prof. Sebastian Böser JGU Mainz, Experimentelle Astroteilchenphysik im PRISMA-Exzellenzcluster
Prof. Thomas Bretz RWTH Aachen University Pierre Auger Observatory, FACT



The Digitisation of Astroparticle Physics

Keywords of future science are Big Data, open access, or the digitisation of the society. HAP and astroparticle physics as global community and modern research field try to follow the developments in this area for both, improving the scientific results and contributing to a science-open and science-friendly well-educated society ready for the future.

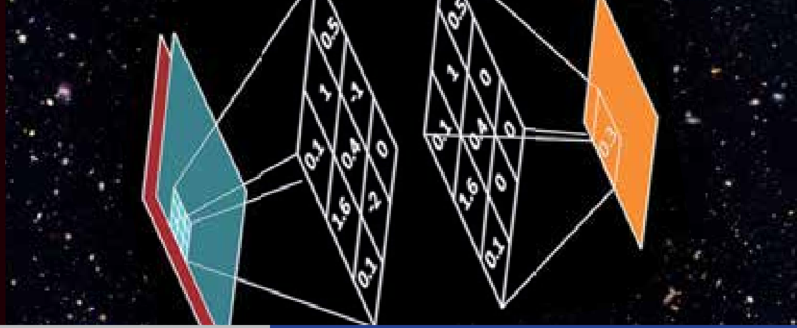
Astroparticle physics is an increasing research field with more and more large-scale facilities distributed over the entire globe – mostly in rough and remote environments like the South Pole, deep underground laboratories, the Argentinean Pampa, high altitude mountains or even in Space. The increasing amount of data provided by these experiments require a sophisticated handling. Methods of Big Data need to be applied, manifested in the high-energy particle physics community by the Grid technology and its data transfer, data storage and data preservation methods. In addition, sophisticated computing resources are indispensable to analyse the data and perform the Monte-Carlo simulations necessary to interpret the data. This includes high performance computing clusters as well as computing on graphical processor units (GPU). These activities are often performed at the individual experiments; however, it is foreseeable that future progress in answering the big questions in astroparticle physics will require a combination of data of many experimental devices, i.e. following the ansatz of multi-messenger astroparticle physics. This approach needs further application of the Big Data idea: a common virtual or real existing hardware platform for scientists have to be provided to combine the data, to perform enhanced simulations, to develop sophisticated analysis methods and to model the theory explaining the measurements. Improving scientific quality is not the only reason for following the path of global digitisation, but it is also a societal duty of science to provide the scientific data in a suitable way to the broader public - according the motto ‘public data for public money’. Here we report about two examples where, within HAP, we tried to be at the forefront of modern science for a better acceptance of basic research, a better education in using Big Data, and an enhanced contribution to the entire society.

KCDC

The aim of the project KCDC (**K**ASCADE **C**osmic-ray **D**ata **C**entre) is the installation and establishment of a public data centre for high-energy astroparticle physics based on the data of the KASCADE experiment. KASCADE, with its later extension KASCADE-Grande, was a detector array for measuring high-energy cosmic rays via the detection of extensive air showers. KASCADE recorded data during more than 20 years on site of the KIT and collected within its lifetime more than 1.7 billion air-shower events to be available at KCDC for public usage.

The web portal as interface between the data archive, the data centre's software and the user is one of the most important parts of KCDC. It provides the door

The KCDC entry website at https://kcdc.ikp.kit.edu
Twitter: #KCDC_KIT



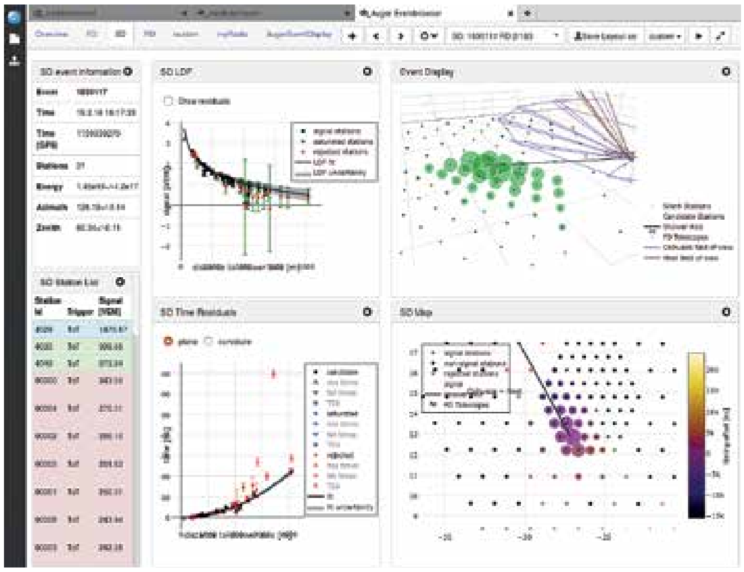
to the open data publication, where the baseline concept follows the 'Berlin Declaration on Open Data and Open Access', which explicitly requests the use of web technologies and free, unlimited access for everyone. We declared both, the scientific and the non-scientific audience as focus of possible users. This requires extensive documentation of the experiment, data, and software on a level understandable and handy for all. In addition, public outreach is important, where we follow with analysis examples ready for masterclasses at schools or young researchers as well as a twitter account providing latest news.

VISPA

A convenient way of accessing scientific data and resources to analyze data is a web browser. Here the VISPA project (**VIS**ual **P**hysics **A**nalysis) offers a development environment for physics data analyses with access to general tools such as a code editor, a file browser, a terminal, and computing resources to perform requested calculations. For the users accessing the VISPA platform from all over the world, no software installations are required such that they can start analyzing data immediately.

The basic part of the VISPA project is a general toolbox for accessing software and computing resources via the web offering also experiment specific data analyses. For example, data of the Pierre Auger Observatory can be visualised through an interactive event display. Furthermore, the arrival directions of the cosmic rays can be analyzed. Users of the platform can investigate their individual science questions by modifying the example analysis codes according to their needs.

Recently, the VISPA platform has been extended to incorporate also analysis techniques of Deep Learning which is nowadays commonly used for speech and handwriting recognition and many other purposes. Applications of deep learning methods in basic research are expected to improve exploitation of measured data. Therefore, within University courses and special workshops, all levels of data analyses are being taught



Visualisation of air shower events at the VISPA website at https://vispa.physik.rwth-aachen.de

such that handling and interpretation of the data from astroparticle physics experiments remain at the forefront of research.

Workshop "Big Data Science in Astroparticle Physics"

A dedicated workshop took place in Aachen in February 2017 with 100 participants. The focus of the workshop was on applications of deep learning techniques. On the first day a tutorial afternoon for participants interested in starting with deep learning was offered. The second day was devoted to machine learning application and to open data. The morning of the third day was devoted to open software, analysis preservation, and discussions on the perspectives of big data science specific to astroparticle physics. The feedback by the participants was overwhelmingly positive and a large request for further workshops with similar topics was expressed.

Dr. Donghwa Kang KIT
KASCADE-Grande, KCDC, IceCube-Gen2
Prof. Martin Erdmann, RWTH Aachen University
Phys. Inst. 3A, Pierre Auger Observatory, CMS

Outreach Activities

Supporting scientists in their public interactions, reporting about astroparticle physics and creating dedicated contents, outreach activities have been an important field for the Alliance. With HAP-funded activities and event support by the HAP outreach manager, as well as activities by HAP members through their own institute outreach, HAP has been very engaged in outreach activities.

Online Activities

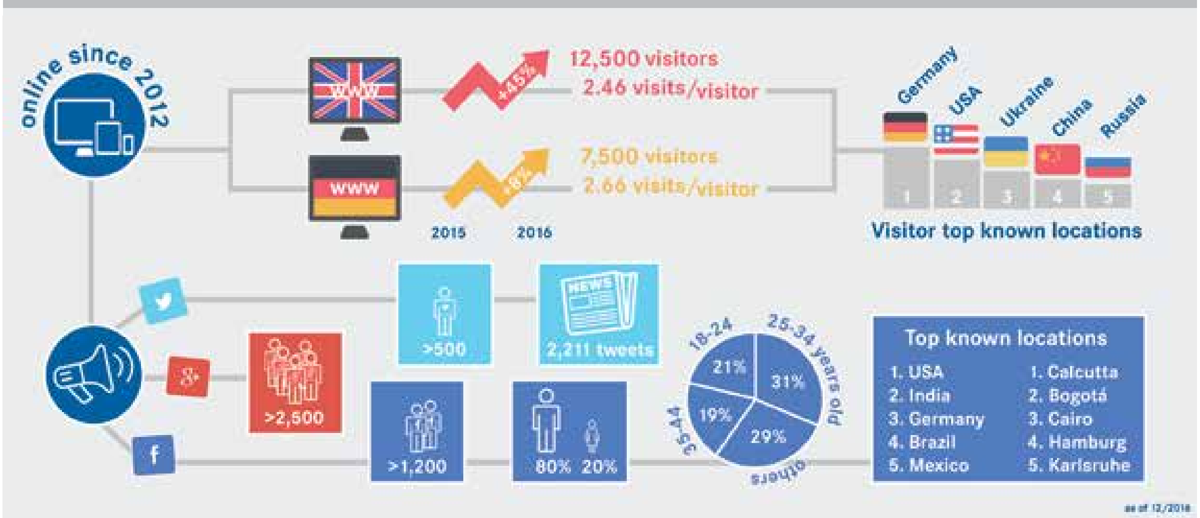
The HAP strategy on online outreach was to have a regularly updated website and to be active on social media. Online since 2012, the HAP website is available in English and in German. For both languages, it is organised in three sections: an introduction about astroparticle physics, then a part relating to latest news – 1 to 2 published per month – and made-in-HAP media, finally a section about the HAP community: conferences, publications, job offers and details about HAP partners, members and experiments.

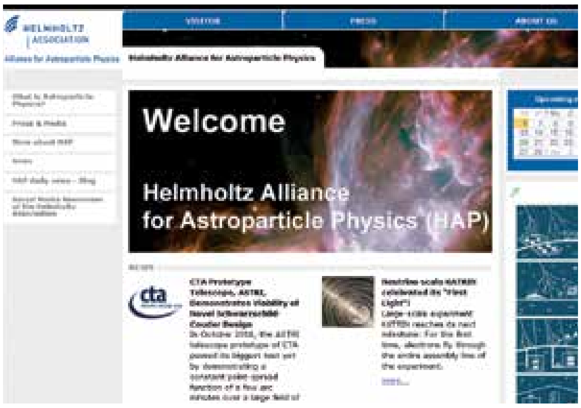
In parallel, from the beginning of its online outreach, HAP was active on the general social media Facebook, Google+ and Twitter. On these three and on the 1st HAP Tumblr. called *HAP Daily News* was shared the latest news from the HAP website as well as more general news about the field and also astrophysics and particle physics. Further Tumblr. blogs were made: *Journey to H.E.S.S.* and *Journey to Auger*, two live-blogging experiences, which are in excerpts in this brochure.

HAP was also online on the business-related social media LinkedIn, both as a page and a group for discussion. Finally, focusing on media, 13 theme-based picture boards were managed on Pinterest, and 6 video playlists on YouTube. On both, a dedicated board/ playlist called *made in HAP* displays media exclusively created by HAP.

Since 2013, what was published on the HAP social media was also sent weekly as a newsletter. Open to everyone, the newsletter had >350 subscribers mostly from Germany and was read with a mean open rate of 35% and a click rate of 10%, doing 1.5 times better than the average industry open rate.

Insights and Analytics





The HAP website at www.hap-astroparticle.org

Public Events & Material

During the HAP core-funding period, HAP supported and reported on astroparticle physics inter/national highlights and outreach events. The HAP outreach manager could participate in inaugurations, like the H.E.S.S. II telescope array in Namibia in 2012, the CTA prototype telescope in Berlin-Adlershof in 2013 or the AugerPrime Symposium in Malargüe in 2016, and in "anniversaries" like the first CERN TweetUp for the AMS 1-year in space anniversary in 2012 or the "100 years of the discovery of cosmic rays" event in Bad Saarow also in 2012.

Outreach events dedicated to the broader public or students with HAP engagement were for example the 4th Science Fair of the Pierre Auger Observatory in Malargüe, Argentina, in 2012, the *Highlights der Physik* 2013 - *Vom Urknall zum Weltall* in Wuppertal in 2013 or the *EFFEKTE – Wissenschaftsfestival* in Karlsruhe in 2013 and 2015.

HAP members participate in several outreach event in Germany covering physics or more focused on astroparticle physics, such as the series *Lange Nacht der Wissenschaften* or the *Girls' Day*, local science festivals, *Science Days* in or for schools and universities and institutes' open days. Outreach activities were also presented at some scientific conferences.

HAP also supported activites to enthuse young students already at high-school level about astroparticle physics. The most prominent example is the *Netzwerk Teilchenwelt*, a German initiative that aims to promote particle and astroparticle physics in schools, more details in a separate article. It also jointly organizes the International Cosmic Day, a yearly one-day workshop happening simultaneously worldwide.

Materials have been created to support the outreach activities. For example, for the science festival *EFFEKTE* in 2015, HAP created posters, small hands-on experiments and a new concept of talk, called *Wissenschaft-Live*, which connected the general public via video conference to scientists live from their experiment site.

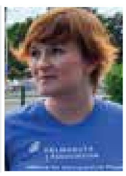
Another example and printed collectible is the booklet *Neue Fenster zum Kosmos*, made together with the *Komitee für Astroteilchenphysik*. This booklet relates the latest discoveries in astroparticle physics and was published with the 2012 June edition of *Spektrum der Wissenschaft*.

Materials have also been created to enhance the feeling of being part of a community. A specific initiative was the presence of *Herr Häkelschwein* – a small pink wool pig, an internet meme picked up by the outreach organisation of the Helmholtz Association – which was photographed at some events and HAP-related experiments.

Further examples of creating dedicated contents are a cloud of words relevant to astroparticle physics, the *Astrosong*, a cover song about astroparticle physics and the set of blue *poPAHrt* pictures, a collection representing the main topics and experiments of the Alliance, see a montage in the banner above. These contents are/were available as T-shirts, roll-ups or stickers, and of course online.

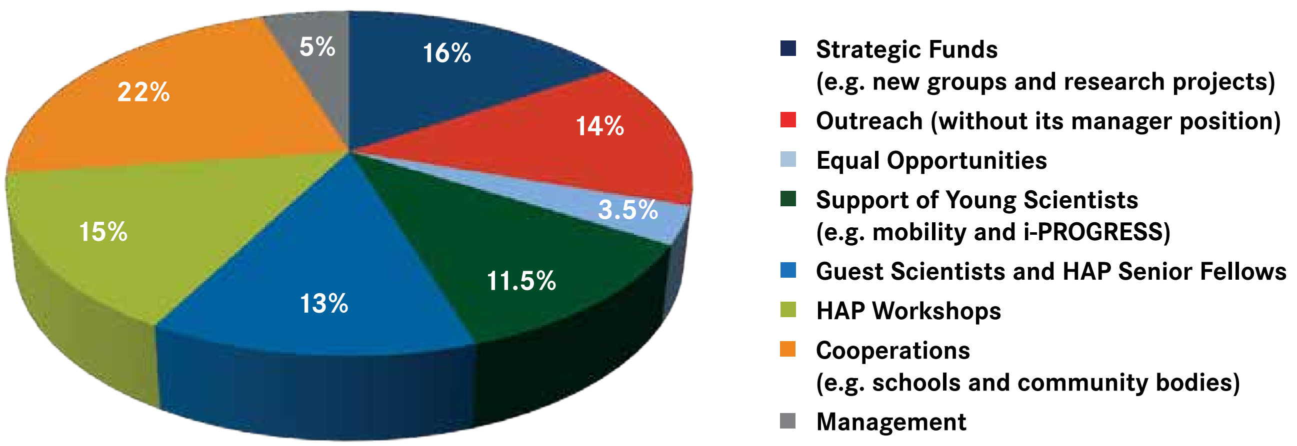
Whether online or in the field, each outreach event found a receptive audience. The creativity and engagement of the HAP community for outreach have shown the dynamism of astroparticle physics and made of each event a success.

Dr. Astrid Chantelauze KIT
Scientific outreach and information manager of the Helmholtz Alliance for Astroparticle Physics



HAP Backbone

About 1 Mio. € were allocated for HAP Backbone Activities. About 32% were used for the position of the HAP outreach manager and the Netzwerk Teilchenwelt coordinator of astroparticle physics. The remaining funds were spent for different categories aiming for increasing the networking activities and for improving the conditions in particular for young scientists.



Workshops and Schools

HAP organized and supported about 30 workshops and 20 schools. These were about three to seven workshops each year between 2011 and 2016 and about one to five schools each year.

Equal Opportunities

Measures for Equal Opportunities were not limited to female scientists but also for young families. HAP supported its scientists with child care at conferences, schools and during research visits, to visit particular seminars e.g. after parental leave, to set up home offices, and to prolong a contract of a PhD student with reduced working hours because of child care duties. Overall, 20 measures were supported by HAP.

Young Scientists

HAP supported its young scientists by a particular travel support to ease their participation in conferences, workshop, and schools. This travel support dedicated for PhD students had a volume of about 42,000 € until end 2016 and was used for almost 60 individual cases.

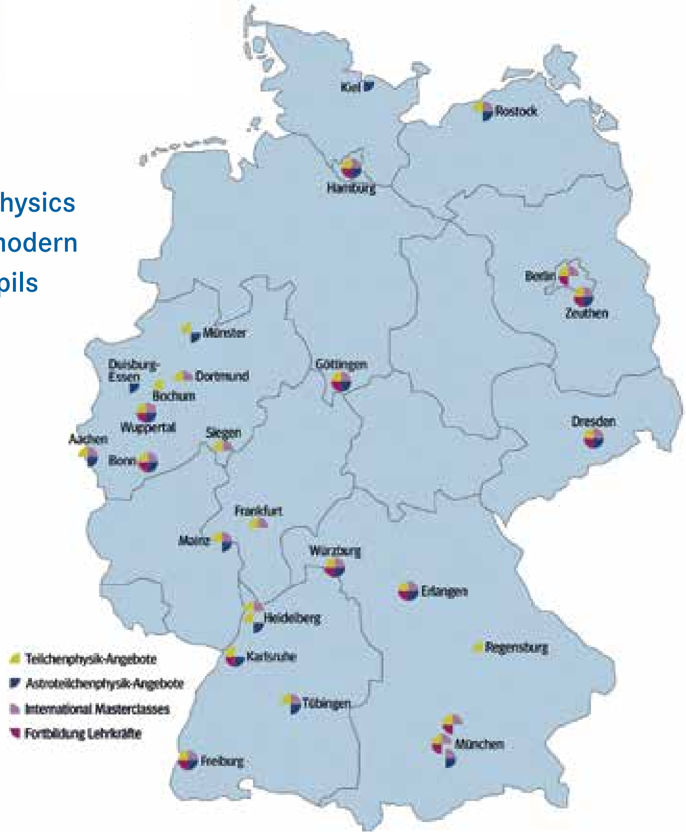
Management

The expenditures for management were very modest. About 44% were spent for annual HAP Member Board meetings, almost 37% went into travels of the HAP management and its Advisory Board members, and only 19% were used for general issues and printing costs.



Netzwerk Teilchenwelt

The network of 28 German astroparticle and particle physics research institutes offers students the experience of modern physics research. More than 100 scientists provide pupils and teachers with insights into their research.



www.teilchenwelt.de

19 institutes offer activities for astroparticle physics within this network. Pupils and teachers can immerse in the world of astroparticles firsthand in masterclasses, workshops, summer courses and internships all over Germany. To provide hands-on experience, three kinds of sets for measuring various aspects of cosmic particles have been developed: scintillation detectors (CosMO), water Cherenkov counters (KamioKanne) and cloud chambers. The experiments enable pupils and teachers to explore cosmic rays in their own projects. The lecturer and PhD students of the participating institutes introduce the research topics and the experiments. The students analyse their own data, and discuss the results with professional scientists. Netzwerk Teilchenwelt encourages discussion with scientists, exploration of the fascinating world of astroparticle physics and teaches a scientific working style.

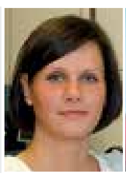
Within Netzwerk Teilchenwelt and the engagement of HAP members, the Auger Masterclass was developed as an education project with the primary goal to bring experimental data and research methods into the classroom. As a “scientist for one day”, high school students learn about ultra-high energy cosmic rays and reconstruct events measured with the Pierre Auger Observatory to find their energy and arrival direction.

DESY with Netzwerk Teilchenwelt have initiated the “International Cosmic Day” which is offered annually since 2012. The event brings together astroparticle-physics outreach projects from all over the world. Student groups work in an international collaboration: analysing data, comparing results with other groups and discussing possible differences gives them a glimpse on how research actually works. For a lasting effect, proceedings with the results of all participating groups are published.

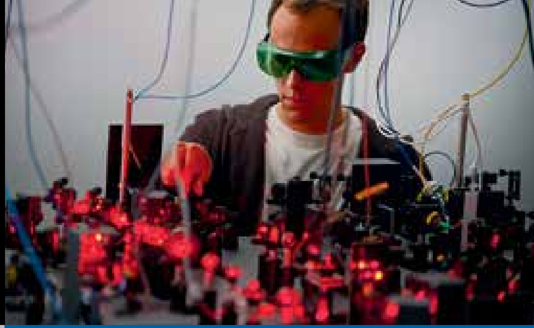
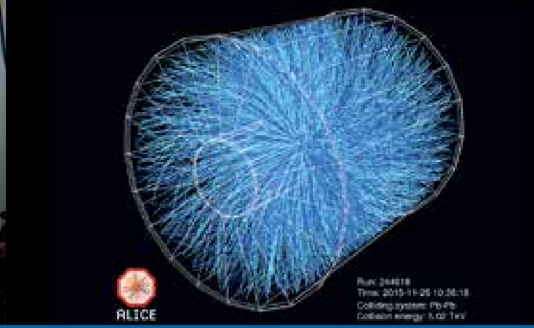
Since 2014, various institutes in Netzwerk Teilchenwelt and a dozen institutions worldwide run the IceCube Masterclass. High school students analyse neutrino interactions and air showers recorded with IceCube, visit laboratories and discuss their results in video conferences with students at other Masterclass sites worldwide. Web applications provide straightforward access to the data and to explain the science background using well-proven didactical concepts.

The outreach activities of Netzwerk Teilchenwelt serve a rising interest in science, especially in research fields beyond the standard high school curriculum.

Dr. Carolin Schwerdt, DESY in Zeuthen, Netzwerk Teilchenwelt – Koordination Astroteilchen-Projekt
Prof. Lutz Koepke, JGU Mainz
Experimentelle Teilchen- und Astroteilchen Physik





Helmholtz Alliance EMMI

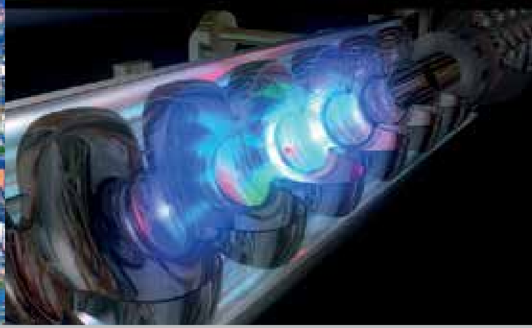
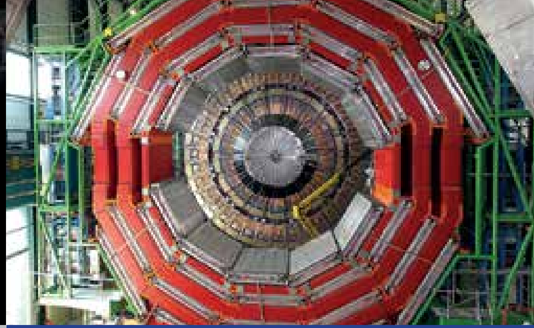
The ExtreMe Matter Institute EMMI is dedicated to fostering research on matter under extreme conditions of temperature and density. The forms of matter investigated by EMMI include the hottest, coldest and densest matter in the universe. Surprisingly, these very different forms of matter are connected by common concepts in their theoretical description.

The ExtreMe Matter Institute EMMI at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt was founded in the framework of the Helmholtz Alliance "Cosmic Matter in the Laboratory". More than 400 scientists at the 13 partner institutions of EMMI study various forms of strongly coupled matter, ranging from the quark-gluon plasma as it existed shortly after the Big Bang, to hot and highly compressed electromagnetic plasmas, to atomic physics in extreme fields, to the dense medium of neutrons that governs supernovae and neutron stars, and to ultra-cold quantum gases. Despite sometimes dramatic differences in density, temperature, field strength etc. (sometimes the differences are more than 20 orders of magnitude) such systems exhibit remarkable similarities, for example in the emergence of characteristic collective behavior of many particles. The key idea of EMMI is to conduct research in an interdisciplinary framework, based upon the common underlying concepts for the theoretical and phenomenological understanding of the phenomena that occur in different forms of strongly coupled matter. EMMI also acts as a think tank for the planning of future experiments, for example at the planned FAIR (Facility for Antiproton and Ion Research) accelerator facility.
Among its activities, EMMI organises topical and interdisciplinary workshops and research programs. As a new, additional workshop format EMMI introduced Rapid Reaction Task Force meetings which bring together a group of about 15 to 25 world-leading experts in order to address a focussed scientific problem in intense discussions. Usually, the results of these meetings are summarised in a publication. As a further element for strengthening the international networking, EMMI runs a very active visitor program.
Through its activities during the funding period of the Alliance, EMMI has gained a very high international visibility in the area of nuclear, particle and atomic physics. The partner institutions have created new full professorships and tenured positions dedicated to extreme matter. EMMI has now become a permanent part of the GSI/FAIR research division. It continues its successful programs and provides a sustained framework for forefront research into matter under extreme conditions, thus taking the momentum of the Alliance into the future. This ensures a long-term impact of the structures and collaborations established in the Alliance.

Prof. Carlo Ewerz
Scientific Coordinator of the ExtreMe Matter Institute EMMI at GSI

EMMI at a Glance

- Alliance funding: 2008 - 2014
- Partner Institutions: GSI Helmholtzzentrum für Schwerionenforschung, Forschungszentrum Jülich, TU Darmstadt, U Frankfurt, U Heidelberg, U Münster, FIAS Frankfurt, MPI für Kernphysik Heidelberg, U Paris VI (France), U Tokyo (Japan), Joint Institute for Nuclear Astrophysics JINA (USA), Lawrence Berkeley National Laboratory LBNL (USA), RIKEN (Japan)
- About 300 publications and 100 proceedings contributions per year
- About 15 workshops of various formats per year
- www.gsi.de/emmi

Physics at the Terascale – the Pathfinder Alliance

"Physics at the Terascale" was one of the first Helmholtz Alliances to see the light of day, and as such played the role of pathfinder and guinea pig. The German particle physics community has drawn sustained benefits from the "Terascale" Alliance that will be felt for a long time in the future.

The Alliance was founded in 2007 to foster collaboration among German particle physicists, a community of over 1000 scientists at around 20 institutions – Helmholtz centres, Max Planck institutes, universities. The Alliance acted as a platform for long-term strategic planning and coordination among all partners. It concentrated on the pillars physics analysis, detector development, accelerator research, and grid computing and had the ambition to further increase the German impact at current or future facilities like the Large Hadron Collider (LHC) or in the developments towards future electron-positron colliders. Within the Alliance, the community agreed on central areas which needed strengthening in Germany and then strategically and nation-wide invested in them – among others with about 50 new long-term positions.
Communication – a key tool of the Alliance - happened at many levels: There were coordinating bodies, workshops, conferences, but also a very active and broad education and school programme. Successful attempts were also made to reach out into neighbouring communities, e.g. by organising common schools and workshops with nuclear and astroparticle physics – a development that later resulted in the new programme structure in POF III. Together with the structures provided by the Komitee für Elementarteilchenphysik ("Committee for Elementary Particle Physics") and the BMBF Forschungsschwerpunkte for ATLAS and CMS, the Alliance created strong and productive bonds between experimentalists and theorists, between the different partner institutions, and even between the ATLAS and CMS groups in Germany! The result: Better knowledge of each other, better overview of the field, better coordination of efforts and resources, and a stronger common voice in the global community. Since the end of dedicated funding for the Alliance in 2014, many of the activities are no longer centrally supported. However, core activities like a vibrant and broad programme of schools and workshops are continuing and carry the momentum and the ideas of the Alliance into the future.
Looking back, the Terascale Alliance fulfilled most of its ambitions: The German particle physics community today is better organised and more efficient than it was 10 years ago, and the links between Helmholtz and Max Planck laboratories and the university community are much stronger. The spirit and the structures created by the Alliance live on and are a vital asset to the community.

Physics at the Terascale at a Glance

- Founded in 2007; full funding until 2012
- 21 institutes with roughly 1000 scientists, among them more than 500 Ph.D. students
- Research topics: Physics analysis, detector development, accelerator research, grid computing
- 10-15 workshops and schools per year
- About 225 publications and 80 conference contributions with Alliance relevance per year

Prof. Ties Behnke DESY in Hamburg, scientific coordinator of the Terascale Alliance and speaker of the Helmholtz programme "Matter and Technologies"
Dr. Thomas Schörner-Sadenius DESY in Hamburg, coordinator of the Terascale Analysis Centre, last scientific manager of the Terascale Alliance


Image Credits

Front page
NASA, ESA, and the Hubble SM4 ERO Team

Content page
Helmholtz Alliance for Astroparticle Physics/A. Chantelauze

Welcome to the Helmholtz Alliance for Astroparticle Physics
Helmholtz Alliance for Astroparticle Physics/A. Chantelauze

The Genesis of HAP and its Future
DESY

Dark Matter Searches within HAP
EDELWEISS Collaboration; HAP; European Space Agency, NASA and J.-P. Kneib (Observatoire Midi-Pyrénées, France/Caltech, USA)

Dark Matter Candidates and Signatures
M. Pohl; Helmholtz Alliance for Astroparticle Physics/A. Chantelauze; DESY

The Origin of Cosmic Rays
KIT, KASCADE-Grande Collaboration; Pierre Auger Collaboration, R. Engel

Cosmic Rays at the Ultrahigh-Energy Frontier
S. Saffi; Pierre Auger Collaboration

i-Progress
Project8 Collaboration; D. S. Parno, U Washington; Pierre Auger Collaboration

Neutrinos on the Rocks: IceCube
Ch. Krueger, IceCube/NSF; IceCube Collaboration

Neutrinos in the Mediterranean Sea
L.Fabre/CEA, 2006; CEA Irfu; Antares Collaboration; KM3NeT Collaboration

The Fermi Large Area Telescope
NASA/DOE/Fermi LAT Collaboration

The H.E.S.S. Experiment
H.E.S.S. Collaboration; SkyView, A. Mellinger; M. Braun et al. (1997); http://dirty.as.arizona.edu/~kgordon/research/mc/mc.html; M. A. Garlick; DESY, S. Klepser

Journey to H.E.S.S./Journey to Auger
Karlsruhe Institute for Technology/M.-N. Rolland; Helmholtz Alliance for Astroparticle Physics/A. Chantelauze

German Science, Astroparticle Physics and HAP
Dark Matter MultiDark simulation, www.multidark.org

Astroparticles in Europe, from Adolescence to Maturity
Composite Credit: X-ray: NASA/CXC/CfA/ M. Markevitch et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U Arizona/D. Clowe et al.; Optical: NASA/STScI; Magellan/U Arizona/D. Clowe et al.; L. Fabre/CEA (2006)

The Cherenkov Telescope Array
G. P. Diaz, IAC, SMM; Akihiro Ikeshita, Mero-TSK, International

Particle Physics with Neutrino Telescopes
Group of S. Böser

Blazar Monitoring Using SiPM Photosensors
M. Bergmann; FACT Collaboration; D. Dorner; T. Krähenbühl

FUNK – Search for Hidden-Photon Dark Matter
D. Veberic; R. Engel

HAP Workshops
HAP; W. Hassenmeier, U Münster

Facts and Figures about HAP
Helmholtz Alliance for Astroparticle Physics/A. Chantelauze

Particle Physics at the Highest Energies
CMS-Collaboration; Pierre Auger Collaboration; J. Oehlschläger and R. Engel, both KIT

High-Energy Particles in the Universe
www.esa.int/spaceinimages/Images/2013/11/Milky_Way; www.nasa.gov; Hubble Interacting Galaxy UGC 8058 (2008-04-24); Wikimedia Commons

Multi-Messenger Astronomy
NASA/JPL-Caltech/University of Wisconsin

Support for Schools for Young Scientists
School for Astroparticle Physics; ISAPP

Support for PhD Students and Postdoctoral Researchers
F. Riehn, R. Engel; A. Sandrock; IceCube Collaboration; MPI für Kernphysik/Heidelberg; K. Freund/GERDA Collaboration; Pierre Auger Collaboration

HAP Senior Fellows
C. Grupen; ALEPH Collaboration; Helmholtz Alliance for Astroparticle Physics/A. Chantelauze; Caramete, Dissertation U Bonn; Zier, Dissertation U Bonn; P. L. Biermann

Key Technologies for Dark Matter Search
S. Schneider, U Münster; W. Hassenmeier, U Münster

New Technologies for Cosmic-Ray Detection
Tunka-Rex Collaboration, F. Schröder; Pierre Auger Collaboration; Antares Collaboration; KM3NeT Collaboration; S. Böser; KIT, R. Smida, F. Werner

Novel Light-Sensors for Astroparticles
P. Winandy; IceCube Collaboration; NASA/B. Rodman, https://www.nasa.gov/feature/wallops/2017/nasas-super-pressure-balloon-takes-flight-from-new-zealand; W. Painter, KIT

The Digitisation of Astroparticle Physics
https://handbuch-digitalisierung.de, CC BY-SA 3.0 DE; Wikimedia, A. Pruzaniec, CC BY-SA 2.0

Outreach
Helmholtz Alliance for Astroparticle Physics/A. Chantelauze

Netzwerk Teilchenwelt
DESY; DESY/Netzwerk Teilchenwelt

Helmholtz Alliance EMMI
X-Ray: NASA/CXC/J. Hester (ASU); Optical: NASA/ESA/J. Hester and A. Loll (ASU); Infrared: NASA/JPL-Caltex/R. Gehrz (U Minn.) [left], GSI/Y. de Andres [middle], CERN [right]; C. Ewerz

Physics at the Terascale – the Pathfinder Alliance
ATLAS-Kollaboration/CERN; DESY; CMS-Kollaboration/CERN; DESY/G. Born;
T. Schörner-Sadenius

Legals

Helmholtz Alliance for Astroparticle Physics
June 2017

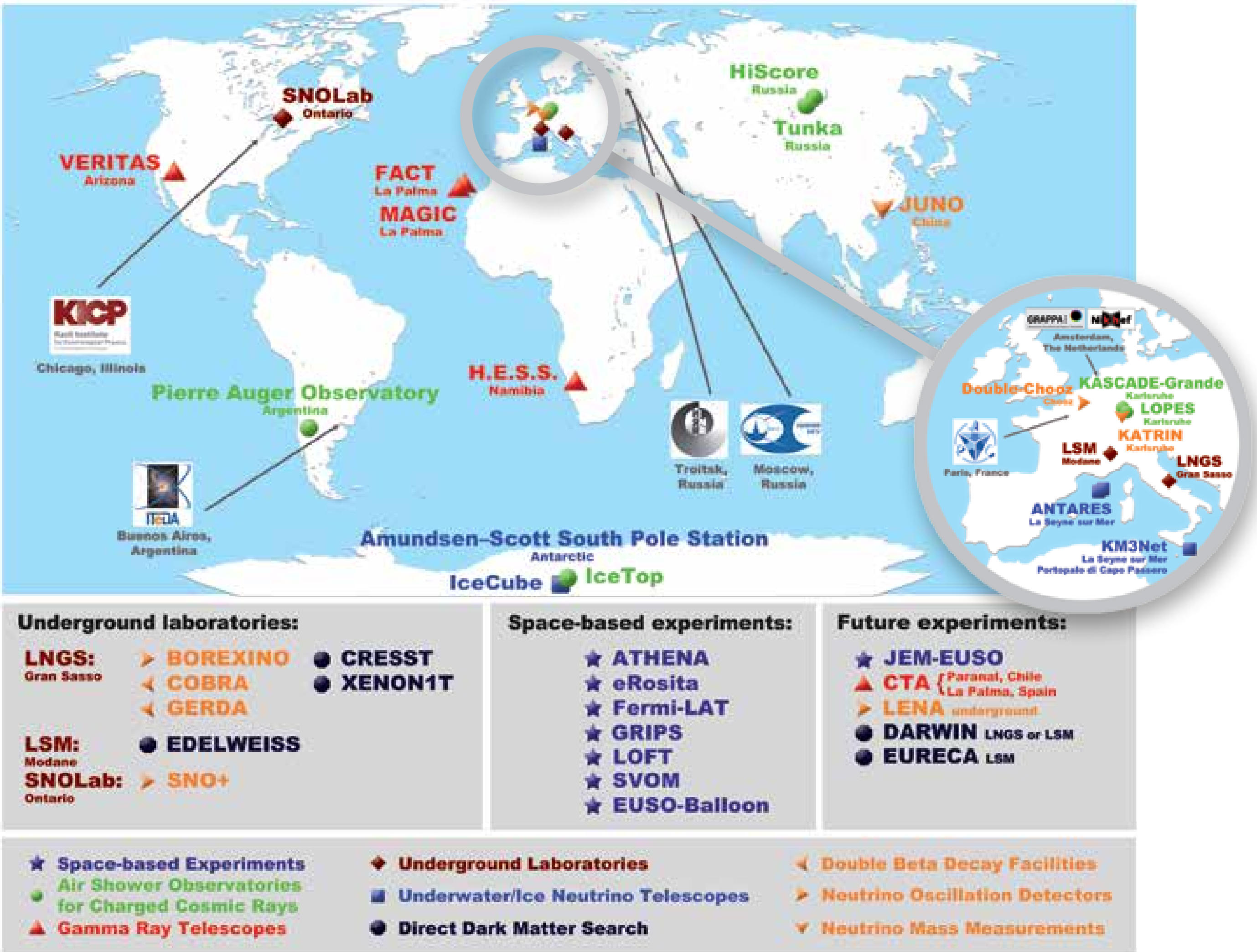
Funded by the Initiative and Networking Fund of the Helmholtz Association under project number HA-301 and coordinated at the Helmholtz Center Karlsruhe Institute of Technology (KIT)
Kaiserstr. 12, 76131 Karlsruhe, Germany

Scientific Coordinators:	Prof. Dr. Josef Jochum Dr. Bianca Keilhauer
Partners:	DESY, Universities Aachen, Berlin (HU), Bonn, Dortmund (TU), Dresden (TU), Erlangen-Nürnberg, Hamburg, Mainz, Münster, München (TU), Potsdam, Siegen, Tübingen, Würzburg, Wuppertal
Associated Partners:	MPIK Heidelberg, MPP München, MPE München, Laboratoire AstroParticule et Cosmologie (APC) Paris, Kavli Institute for Cosmological Physics (KICP) Chicago, Instituto de Tecnologías en Detección y Astropartículas (ITeDA) Buenos Aires, Institute for Nuclear Research RAS Troitsk, Skobeltsyn Institute of Nuclear Physics Moscow (SINP-MSU), National Institute for Subatomic Physics (Nikhef) Amsterdam, Gravitation Astroparticle Physics Amsterdam (GRAPPA)
Layout:	Beatrix von Puttkamer

Printed by Systemedia GmbH on 100% recycled paper with the quality label „Der Blaue Engel“

HAP in Germany

HAP-related Experiments and associated Partners in the World



HELMHOLTZ
ASSOCIATION

Alliance for Astroparticle Physics