# Research Field "Structure of Matter"
# Program Astroparticle Physics
# 2010-2014

Participating Helmholtz Centers:


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**Contents:**


## Summary

The Research Field *Structure of Matter* is composed of four programs

- Elementary Particle Physics
- Astroparticle Physics
- Physics of Hadrons and Nuclei
- Photons, Neutrons and Ions

The proposed research within the Helmholtz Program *Astroparticle Physics* has been developed on the basis of the results from the current funding period 2005-2009 in accordance with the ApPEC Roadmap for European astroparticle physics. They consist of five program topics:

1. **Ultra-high energy cosmic rays.** The Pierre Auger Observatory is recording data of the highest quality since 2004 and is delivering already first exciting science results. The measurements will be continued. It is planned to construct a second, larger observatory on the Northern hemisphere. Two Young Investigator Groups work on multi-messenger analyses and on the radio-detection of cosmic-ray showers.

2. **High-energy neutrino astrophysics.** The IceCube neutrino telescope will be completed and therefore guarantees a wealth of results in the next program period, including the new aspect of multi-messenger analysis, the combination of neutrino astronomy with particle and gamma-ray astronomy.

3. **High-energy gamma-ray astronomy.** In the multi-messenger context, DESY is participating in the preparatory work for the large Cherenkov Telescope Array (CTA). A Young Investigator Group is currently participating in MAGIC.

4. **Direct search for Dark Matter.** FZK is currently participating in the European Dark Matter experiment EDELWEISS. The search for Dark Matter is planned to become a major research field within the Program Astroparticle Physics, which will be reflected by a leading role of Forschungszentrum Karlsruhe in the European project EURECA.

5. **Neutrino physics.** The KATRIN experiment will conduct its measurements in the next program period. The experiment is unique worldwide and of great significance, since it has the highest sensitivity on measuring the neutrino mass or setting the best limits.

Within the Program, theoretical work in astroparticle physics will be conducted in close cooperation at the Universities of Karlsruhe and Potsdam.

# The participating Helmholtz Centers

**DESY**, with its location in Zeuthen, is the pioneering European laboratory in high-energy neutrino astrophysics. In 1988, the laboratory joined the Baikal neutrino project. This successful cooperation is going to be accomplished in 2008. In 1995, DESY extended its activities to the AMANDA project. Since 2004, AMANDA's successor IceCube is being built, with 50% of the components installed in early 2008 and taking data since then. Gamma astronomy is planned to constitute another future direction in DESY. In the spirit of multi-messenger astronomy, a Young Investigator Group (DESY/Humboldt University) is part of IceCube as well as of the MAGIC collaboration. The big, future project is however CTA, the Cherenkov Telescope Array. With IceCube in full observatory mode and CTA taking first data with prototypes and entering the construction phase, DESY has a coherent and challenging program both in construction and physics for the upcoming program period. It also complements the cosmic ray investigation with the Auger Observatory (FZK) and will be a sustainable part of a coherent research program in the Helmholtz Association. There are common professorships with the Humboldt University Berlin and with Potsdam University. The professorship for theoretical astroparticle physics in Potsdam has been created recently. There are cooperations with DFG-funded Collaborative Research Center SFB 676 (Particles, Fields and the Early Universe) at Hamburg University.

**Forschungszentrum Karlsruhe** is one of the largest national research centers with currently about 3500 staff running a broad spectrum of highly multidisciplinary research programs. Astroparticle physics at FZK is rooted in a forty-year tradition of nuclear and particle physics in various institutes. Three institutes will be participating in the next astroparticle physics program: the Institute for Nuclear Physics (IK), the Institute for Data Processing and Electronics (IPE), and the Institute for Technical Physics (ITP), including the Tritium Laboratory Karlsruhe (TLK).

The Karlsruhe Institute of Technology KIT is being created in the fusion of University and Forschungszentrum Karlsruhe. KIT bundles its scientific expertise in theoretical and experimental elementary particle and astroparticle physics in a new organizational unit, the *KIT-Center for Elementary particle and Astroparticle Physics* (KCETA). Within KIT, a full professorship for theoretical astroparticle physics has been newly created.

The Karlsruhe Graduate School for Particle and Astroparticle Physics includes 11 professors and about 70 doctoral students, which are supported by several programs of the University and the FZK. The DFG-funded Transregional Collaborative Research Center SFB/TR 27 includes three sub-projects for improved beta spectroscopy and low-energy monitoring detectors (both in the context of KATRIN) and for the search for Dark Matter (in the context of EURECA).

The Young Researcher Tenure Committee at Forschungszentrum Karlsruhe aims at helping accomplished young researchers to obtain a permanent position through a qualifying selection process.

# Topics in the Program Astroparticle Physics

## Topic 1: Ultra-high energy cosmic rays FZK

The projects in this topic include the Pierre Auger Observatory and the further development of the detection of air showers by their radio emission. The Pierre Auger Observatory is a Helmholtz Large Infrastructure (LK-II).

The KASCADE-Grande detector field at Karlsruhe will stop taking regular cosmic ray data at the end of 2008; the scientific analysis will continue for at least three more years and therefore extend into the next funding period. The KASCADE-Grande detectors will still be used for the further development of air shower radio detection techniques, complementing the development of this technique at the Southern Pierre Auger Observatory in Argentina.

Measurements with the Southern Pierre Auger Observatory, which is already recording data of the highest quality, will be continued in order to guarantee a high scientific output. The operation, monitoring and maintenance of the Southern Observatory are very significant tasks, which must be supported by the appropriate resources. Forschungszentrum Karlsruhe is a stronghold in the physics analysis and currently building up a GRID computing environment. Accompanying research includes multi-messenger analyses.

Radio detection is one of three enhancement programs for the Southern Auger Observatory that are currently carried out by the Auger collaboration (i.e. radio detection using a 20 $km^2$ antenna array (RADIO), improved low-energy optical shower detection with *High Elevation Auger Telescopes* (HEAT), and *Auger Muon and Infill Ground Array* (AMIGA) for better detection of muons. Forschungszentrum Karlsruhe takes leading positions in the HEAT and RADIO projects; the latter being pursued also by a Helmholtz-University Young Investigator Group. The construction phase is expected to be finished around 2011 and will be followed by commissioning and integration into the Auger Observatory.

In the next years, the Auger Observatory will collect a large data set with the Southern site for energies above $10^{17}$ eV. The scientific goals include

1. identification and detailed characterization of the sources of the highest-energy particles;
2. search for point sources and anisotropies on all angular scales;
3. study of the transition from galactic to extra-galactic particles;
4. study of galactic and extra-galactic magnetic fields;
5. identification of the cosmic particles themselves and the study of their interactions in extensive air showers.

There are firm plans in the Auger Collaboration how to extend the exciting observations done on the Southern Sky onto the Northern hemisphere. Only in this way we can observe all potential sources of the most energetic particles in the Universe. The Northern Site in Southeast Colorado/USA offers an area of 20,000 $km^2$, all of which needs to be covered by surface detectors and optical fluorescence telescopes. The Northern Observatory will have a focus on the very highest energies above $10^{19}$ eV, because the arrival directions of cosmic particles can be associated with their sources only above the GZK threshold ($\sim 10^{19.6}$ eV). Hence, we plan to deploy 4000 water Cherenkov detectors on a rectangular grid with 2.3 km spacing, supplemented with 400 additional detectors covering 10% of the area more densely. This arrangement will make use of the abundantly existing country roads, which follow a so-called square mile grid. The rich particle physics potential will be exploited by almost full coverage of the area by fluorescence detectors. The combined, large instrument will be able to study particle interactions at center-of-mass energies up to 30 times higher than at the LHC.

The development, construction and commissioning of the fluorescence telescope system and auxiliary components by Forschungszentrum Karlsruhe – together with many partner groups – represents the largest investment program in the upcoming funding period. Preparatory works are being carried out in the context of the HEAT telescopes. The main construction is scheduled for 2010-2015.

## Topic 2: High-energy neutrino astrophysics DESY

This topic includes construction and operation of the neutrino telescope IceCube, physics analysis with IceCube, and R&D on neutrino detection via acoustic signals.

The IceCube neutrino telescope will consist of 4800 optical modules installed at 80 strings at depths between 1450 and 2450 m, covering one cubic kilometer. IceCube is complemented by IceTop, a one-square kilometer air shower detector at the surface. By April 2008, 50% of

IceCube is installed, and data taking with half a cubic kilometer of instrumented volume has started. The construction will be completed in January 2011.

Until fall 2008, DESY will have completed the planned assembly of a quarter of the optical modules as the common, main German contribution. DESY has also developed and built the front-end electronics, which is used at the Antarctic surface. It acts as European center for the mass processing of experimental and Monte Carlo data and as German analysis center.

The DESY group is leading efforts to detect acoustic signals from neutrino interactions since long. Compared to optical detection, radio and acoustic methods may allow a larger sensitive volume at a less progressive cost. A “South Polar Acoustic Test Setup” (SPATS) has been installed in 2007 and 2008. The aim of the present R&D program is to determine attenuation length and background noise in situ and to assess the feasibility of a huge hybrid radio/acoustic detector around IceCube.

The scientific goals of IceCube include:

1) Search for astrophysical sources of high energy neutrinos like supernova remnants, active galactic nuclei, gamma ray bursts, pulsars or even unknown phenomena.
2) Indirect dark matter search via WIMP annihilations.
3) Measurement of spectrum and mass composition of cosmic rays with IceTop.
4) Particle and fundamental physics (e.g. neutrino oscillations or violation of Lorentz invariance) with half a million atmospheric neutrinos.
5) Search for exotic particles like magnetic monopoles or super-symmetric Q-balls.
6) Monitoring the Galaxy for supernova events.

Years of dramatic sensitivity increase are 2009-2013. Consequently, over the next 5 years, the analysis of IceCube data will have highest priority for the DESY group.

The IceCube neutrino telescope guarantees a wealth of results in the next POF period. This includes multi-messenger analyses, the combination of neutrino astronomy with particle and gamma-ray astronomy (see Topic 3).

## Topic 3: High-energy gamma-ray astrophysics DESY

High-energy gamma-ray astrophysics will complement neutrino astrophysics as the traditional main activity of the DESY astroparticle group. This plan follows the successful principle of a multi-messenger approach. First steps into gamma-ray astronomy have been done by the Young Investigator group and its participation in MAGIC. The next generation Gamma-ray Observatory CTA appears as the best option with respect to the guaranteed physics potential, the complementarity to IceCube, the technical feasibility, and the timing. CTA will provide a huge amount of astronomically relevant observational results and may also contribute to fundamental physics and cosmology. CTA would complete the tool set of high-energy astrophysics in Helmholtz, with Auger, IceCube and CTA representing all three fronts of exploration.

CTA will likely consist of a few very large central telescopes providing excellent efficiency below 50 GeV, embedded in an array of medium sized telescopes giving high performance around one TeV, the latter being surrounded by a few-km$^2$ array of small dishes to catch the bright but rare showers at 100 TeV: altogether 40-70 telescopes. CTA is conceived to cover both hemispheres, with one site in each.

The science goals of CTA include:

1) Investigation of astrophysical sources of high energy gamma-rays, with high spatial and time resolution in the energy range strongly overlapping with the GLAST satellite and extending beyond 100 TeV.

2) Indirect dark matter search via WIMP annihilations.

3) Fundamental physics (e.g. probing space-time via violation of Lorentz invariance).

The project is entering the prototype phase, which will result in prototype telescopes in 2011. Construction of the full array is planned to start in 2012 and to finish about 2017.

For the prototype phase, DESY plans to contribute to the following tasks: a) Array optimization and exploration of physic potential, with a dedicated effort of Humboldt University and DESY on trigger optimization. b) Contribution to the design and cost optimization of the drive and control system, and construction of a prototype of a medium size telescope. c) Contribution to a prototype system for the array operation center. Based on the experience of the prototype phase, DESY plans for the construction phase will be worked out over the next 2-3 years.

## Topic 4: Direct search for Dark Matter FZK

The projects in this topic include the search for Dark Matter with the EDELWEISS detector located in the Fréjus tunnel and the development, construction and operation of the large-scale European Dark Matter search project EURECA (European Underground Rare Event Calorimeter Array).

There is strong evidence from cosmological and astrophysical observations that ordinary matter accounts for only 4% of the Universe's matter-energy density while 23% are Dark Matter and 73% are Dark Energy, the nature of which remains a mystery for now. Dark Matter and a small admixture of massive neutrinos have likely played a central role in the formation of large scale structures in the Universe. The discovery of Dark Matter particles would confirm a key element of the way we understand the Universe today and at the same time extend the picture of particle physics beyond the present Standard Model. Indirect searches (e.g. such as possible also with the IceCube neutrino detector) look for annihilation signatures of Dark Matter particles, whereas direct searches aim to detect signals of the scattering off target nuclei in detectors.

The cryogenic bolometer experiment EDELWEISS located in the Fréjus road tunnel between Italy and France has commenced a second phase with target masses in the range of 10kg. The goal is a sensitivity extending below scalar cross-sections of $2x10^{-44}cm^2$, which is envisaged to be attained during the first half of the next funding period.

The search for Dark Matter is gaining further significance through new astronomical observations. We plan to assume a leading role of Forschungszentrum Karlsruhe in the European project EURECA. This project includes basically all present groups of the CRESST and EDELWEISS experiments and already a few selected new groups. The aim is to explore scalar cross sections down to $10^{-46}$ $cm^2$ with a target mass of up to one ton. A major advantage of EURECA is the planned use of more than just one target material for identification of the scattering particles. In preparation for this large-scale experiment, R&D for EURECA is provided through the current phases of EDELWEISS (and also of CRESST).

There exists a unique opportunity in Europe for integrating the EURECA setup into an underground space at the Laboratoire Souterrain de Modane (LSM). A decision was taken in 2006 to excavate a new safety tunnel along the Fréjus road tunnel between France and Italy. Accordingly, there is a time window until 2011/12 to develop a very large integrated underground facility (ULISSE) as well as pre-assembling key elements for EURECA. It is proposed that Forschungszentrum Karlsruhe participates in the design of this underground laboratory and becomes a strategic partner of the extended LSM/ULISSE facility.

## Topic 5: Neutrino physics FZK

The activities in this topic are centered on the Karlsruhe Tritium Neutrino Experiment KATRIN. KATRIN is a Helmholtz Large Infrastructure (LK-II), which is currently being built at the Karlsruhe

Tritium Laboratory. The KATRIN collaboration comprises about 140 people from the Czech Republic, Germany, Russia, UK, and the USA.

The KATRIN experiment is unique worldwide and of greatest significance. Detailed simulations show that a sensitivity of 0.2 $eV/c^2$ (90% C.L.) for the electron neutrino mass can be reached, with statistical and systematic uncertainties contributing about equally. A positive detection would be possible with 0.3 $eV/c^2$ at three standard deviations. The results of this measurement will provide important input for particle physics and help constraining the model-dependent parameters of cosmology.

The KATRIN experiment will perform the commissioning phase of the complex system and conduct its measurements during the upcoming funding period. The detector consists of a windowless gaseous Tritium source, differential and cryogenic pumping sections, a low-energy electrostatic filter and a high-resolution electrostatic spectrometer. The neutrino mass measurement poses unprecedented challenges for Tritium handling, cryogenic technology, monitoring of running conditions and their stability as well as precision metrology of high voltages and electric and magnetic field configurations.

The sustained operation of KATRIN over an effective measurement time of at least 3 years (at least five years real time) is one of the highlights and challenges of the forthcoming funding period for Forschungszentrum Karlsruhe.

# Concluding remarks

Regular schools for astroparticle physics (Erlangen School, ISAPP and CORSIKA School) are supported by Forschungszentrum Karlsruhe and DESY. Participation is made available to all young scientists.

Talent Management in order to promote excellent young scientists is achieved by different measures depending on the state of their career. In all aspects of our work we will address gender issues carefully and thoroughly, exploiting the programs for female researchers existing in the partner institutions, such as the *Helmholtz Cross Mentoring Program* at Forschungszentrum Karlsruhe and *Tandem Plus* (mentoring program for female doctoral students at the University of Karlsruhe).