Proposal for a

Helmholtz-Argentina Joint Research Group

on

Astroparticle Physics

between the

Karlsruhe Institute of Technology, KIT,
Karlsruhe, Germany

and the

Universidad Nacional de San Martin, UNSAM,
Buenos Aires, Argentina

HELMHOLTZ
ASSOCIATION

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Scope and purpose

Astroparticle Physics is a relatively young, highly interdisciplinary research area at the intersections of nuclear and particle physics, astrophysics, astronomy and cosmology. About 2,000 scientists in Europe and 4,300 world-wide address the questions shown in the insert.

The research infrastructures of Astroparticle Physics are large and often located in remote locations, disconnected from well-established laboratories and the requested scientific and technical expertise is distributed all over the world. Hence, international cooperation is a key to advance our understanding of the Universe and particle astrophysics.

Argentina and Germany are the host country and one of the strongest partner countries within the Pierre Auger Observatory, respectively. The applicants to this proposal from both countries express their wish to extend their cooperation to an unprecedented level by establishing a Helmholtz-Argentina Joint Research Group (HAJRG) for Astroparticle Physics.

The HAJRG comprises now 6 researchers/postdocs, 6 PhD students and has a financial volume of 100 k€/a. The current proposal is considered to be a pilot project that may become the seed of larger joint efforts at a later stage.

Astroparticle Physics

What is the Universe made of? In particular, what constitutes Dark Matter and Dark Energy?

What is the origin of the cosmic matter–antimatter asymmetry?

What are the properties of neutrinos? What is their role in cosmic evolution?

What do neutrinos tell us about the interior of the Sun and the Earth, and about Supernova explosions?

What is the origin of cosmic rays? What is the view of the sky at extreme energies?

Can we detect gravitational waves? What will they tell us about violent cosmic processes and about the nature of gravity?

Partner Institutions and Applicants

Germany

In Germany the proposal is submitted to the Helmholtz Association of German Research Centers (HGF). The foreseen funding source is the *Initiative and Networking Fund*. The proposed HAJRG belongs to the Helmholtz Research Field *Structure of Matter*. It is rooted in the Research Program *Astroparticle Physics*.

The Helmholtz Program Astroparticle Physics is conducted by the Karlsruhe Institute of Technology (KIT) and Deutsches Elektronensynchrotron (DESY). It is coordinated by KIT.

The German partner to conduct the proposed HAJRG is the *Institute of Nuclear Physics* (*Institut für Kernphysik*, IKP), which belongs to the *KIT Center Elementary*

Particle and Astroparticle Physics KCETA. IKP is represented by its Director, Professor Dr. Johannes Blümer, and by Dr. Markus Roth, co-applicant and German Principal Investigator to this proposal.

The proposed HAJRG is further supported by the Helmholtz Alliance for Astroparticle Physics (HAP) and by the HGF Program Topic 'Astoparticle Phyiscs' at KIT

Argentina

In Argentina the proposal is submitted to the High Council of the University of San Martin (*Universidad Nacional de General San Martín* – UNSAM), San Martín, province of Buenos Aires. The foreseen funding source is the University´s Research Fund. The HAJRG is connected to the School of Science and Technology (*Escuela de Ciencia y Tecnología*) and the Institute of Technology *"Prof. Jorge A. Sabato"* for academic matters.

The Argentine partner to conduct the proposed HAJRG is the Institute for Detection Technologies and Astroparticles (*Instituto de Tecnologías en Detección y Astropartículas* – ITeDA), Buenos Aires. ITeDA is co-funded by the National Atomic-Energy Commission (CNEA), the National Research Council (CONICET) and UNSAM; it is represented by its Director Dr. Alberto Etchegoyen, and by Dr. Federico A. Sánchez, co-applicant and Argentine Principal Investigator to this proposal.

The proposed HAJRG has further received committed support from CONICET which requires a separate agreement and Board approval before fulfillment.

Qualifications of applicants and research portfolio

The Karlsruhe Institute of Technology KIT is one of Germany's largest research and education institutions with approximately 21,000 students, more than 9,200 staff, and nearly 370 university professors. KIT was founded in October 2009 as the merger of the former Universität Karlsruhe (TH) and Forschungszentrum Karlsruhe GmbH. Thus KIT is both a university of the State of Baden-Württemberg and a member of the Helmholtz Association of German Research Centers. The profile areas of KIT are represented by so-called "Centers" and "Focuses". They have a well-defined organization, leadership and a direct link to the governing level of KIT. One of them is KCETA, the KIT Center Elementary Particle and Astroparticle Physics, which was inaugurated on November 10, 2008. It comprises 380 people, thereof more than 100 scientists and around 80 doctoral students.

KCETA is active in nine topics: cosmic ray research, Dark Matter search, neutrino physics, technology development, theoretical astroparticle physics, quantum field theory, computational physics, flavour physics, experimental collider physics, theoretical collider physics, perturbative quantum field theory and collider phenomenology. The KIT part of the Helmholtz Programme Astroparticle Physics represents more than half of KCETA and is conducted jointly by four KIT Institutes: Institute for Nuclear Physics, Institute for Experimental Nuclear Physics, Institute for Data Processing and Electronics, and Institute for Technical Physics. The current proposal is rooted in the Institute for Nuclear Physics (Institut für Kernphysik, IKP); IKP is the direct partner of the *Institute for Technologies of Detection and Astroparticles* ITeDa described below.

IKP conducts cutting-edge research in the field of cosmic rays (Pierre Auger, KASCADE-Grande, LOPES), search for Dark Matter (EDELWEISS and EURECA) and neutrino physics (KATRIN). IKP and KCETA feature a broad range of excellent competences and are highly successful in attracting students and third-party funding.

UNSAM is a young university chartered in 1992. Its main campus is located in the outskirts of Buenos Aires, in an area where several national institutes of research and development have been traditionally settled. Its sustained policy over the years has been to facilitate the association with these institutions promoting a healthy relationship whereby the benefits the university accrues by the influx of first-rate scientists and their projects return to them in the form of motivated students who took their courses and are familiar with their research.

UNSAM has established itself as a research university with strong emphasis in technology development and social sciences studies. It boasts a lead program in the biological sciences, with achievements in biotechnology such as the sequencing of the *trypanozome cruzi* genome and the cloning of bovine livestock. The association with the National Atomic Energy Commission (CNEA) has allowed the university to share on the leadership of studies on the structure of matter, materials science and nuclear technology. It has also brought expertise on environmental studies shared with researchers from the National Institute of Technology (INTI). Metrology is an area where INTI is a countrywide leader and a partner with UNSAM. The Institute for R+D of the Defense Ministry (CITEDEF) is associated with UNSAM in research related to environmental toxicology. The schools of Humanities, Politics and Government and the Institute for Higher Social Studies conduct first-class rated research which has achieved national and international recognition. The university takes pride in the development of novel and outstanding programs in the performing arts and art restoration. Its current enrollment is 14.000 students (2.000 of which are graduate students).

The Institute for Technologies of Detection and Astroparticles (ITeDA) was created jointly by CNEA, CONICET and UNSAM. Its basic aim is to research, develop and train qualified personnel in experiments and technologies associated with the sciences of the universe and astroparticles. It is the first Institute set up between two of the most recognized institutions in Argentina in the field of scientific and technological research, CNEA and CONICET. For half a century, CONICET and CNEA have sustained a fruitful collaboration cemented by hundreds of scientists and technologists of CONICET who work on or are part of CNEA, and by grants awarded by CONICET to supplement multiple research projects of CNEA. UNSAM provides the academic background to train the highly-specialized staff that ITeDA requires; this generates a place of excellence for the completion of graduate programs in astroparticles and engineering.

ITeDA contributes at the international level in the study and detection of radiation from outer space across the electromagnetic spectrum and especially of astroparticles (atomic nuclei and neutrinos). It performs innovative technological developments mainly in electronics, telecommunications, and data-acquisition systems. ITeDA has had a sustained presence in the construction and operation of the Pierre Auger Observatory of which it became part since its inception in 1995 and has been instrumental in its development. It led in the construction of PVC tanks for the surface detector systems (by rotational molding), the design and construction of the battery box, the telecommunication antennas, the plant of pure water, the water storage tanks and transport, and the buildings that house the fluorescence detectors along with the medium voltage lines. ITeDA shared in the construction of the laboratory of photo-multipliers and tested their operation during the production phase. It has built a storage centre as a repository of all data from the observatory at the

Constituyentes Atomic Centre. Researchers from ITeDA were the first to propose the current method for calibration of surface detectors based on the measurement of background muons remotely and automatically, a method which was later experimentally verified. ITeDA currently represents Argentina in the Cherenkov Telescope Array (CTA) in a partnership between CNEA and the Ministry of S&T and together with CONICET and the National Commission for Space Activities (CONAE *Comisión Nacional de Actividades Espaciales*), is the national representative in DS3 (Deep Space Antennae 3) from the European Space Agency.

Project Summary

Composition studies in the energy range $E \geq 5\times10^{16}$ are of paramount importance to understand the transition from galactic to extragalactic sources, to discriminate exotic mechanisms, and for anisotropy searches. Longitudinal profiles and muon numbers are the most sensitive parameters for composition studies. Observation in the so-called second knee region ($0.05 < E < 0.5$ EeV, 1 EeV = 10^{18} eV) deserves further design studies after the publication of a heavy-ion knee structure at 8×10^{16} eV by KASCADE-Grande. Also, this energy region permits an overall comparison of the KASCADE-Grande and Auger spectra with both Observatories and good statistics. A further benefit is that the Auger Observatory will meet the LHC energy range at 10^{17} eV, thus having a more reliable hadronic interaction model. Exotic mechanisms produce gamma-initiated showers which are discriminated straightforwardly by their negligible muon content. Point anisotropy is related to light primaries since heavy nuclei loose track of their source origin due to the galactic and extragalactic magnetic fields. Unveiling hadronic interaction parameters will depend on the knowledge of the primary type.

The Auger Observatory was originally designed to observe primary cosmic ray energies of $E \geq 1.0$ and ≥ 3.0 EeV in the hybrid and surface array modes, respectively. After commissioning the Pierre Auger Observatory in 2008, a second phase was initiated with the construction of the array AMIGA (Auger Muons and Infill for the Ground Array [AMI:07]), the commissioning of HEAT (High Elevation Auger Telescopes [HEA:07]) and AERA (Auger Engineering Radio Array [AER:09]). These enhancements aim at improving both on the quality of data and the observed energy range.

Cosmic rays are mostly charged subatomic particles that reach the Earth with an energy spectrum that covers several orders of magnitude. The flux of cosmic rays follows a power-law function with energy, and ranges from a few hundred per square meter per second at low energies ($E \sim 10^9$ eV), to just a few per km^2 per century for the highest energies ($E \sim 60$ EeV). At these energies, the spectrum has four characteristic zones where its index (i.e. the power of the decay function of the flux with energy) changes abruptly: the \`knee´ ($\sim 4 \times 10^{15}$ eV), the \`second knee´ (above mentioned), the \`ankle´ (~ 3 EeV) and the \`GZK cutoff´ (~ 40 EeV).

Cascades of secondary particles generated by cosmic rays entering the Earth's atmosphere are studied both, with particle detectors and radiation. Two types of event reconstruction techniques are used: a) reconstruction of the lateral distribution of particle detectors distributed on the surface (SD, surface detectors) [AUG:04] or buried in the Earth (BD, buried detectors) [SUP:08] and b) reconstruction of the longitudinal distribution of the particles of the cascade with fluorescence telescopes (FD, fluorescence detectors) [AUG:04] or by means of radio antennas [AER:11].

Such reconstructions provide knowledge about the direction of arrival, the elemental composition and the energy of the primary cosmic ray.

Up to energies around 10^{15} eV, our own galaxy is believed to be the source of cosmic rays. Several acceleration mechanisms are certainly at play but it is widely expected that the dominant one is first order Fermi acceleration in supernova remnant shock waves. These Galactic accelerators should theoretically become inefficient between 10^{15} eV and 10^{18} eV. The KASCADE-Grande experiment has measured the energy spectra for different mass groups in this energy range and found that there is a steepening of the spectra at an energy that increases with the cosmic ray mass [KG:11]. As a result, the mass-composition becomes progressively heavy. It is also thought that extra-galactic sources can start to contribute to the total cosmic ray flux as the energy increases. The onset of such an extra-galactic component would probably produce another change in composition. The depth of shower maximum (X_{max}) measurements from the HiRes-MIA experiment have been interpreted as a change in composition, from heavy to light, starting at 4×10^{17} eV and becoming proton-dominated at 1.6×10^{18} eV [ABU:01] while the measurements from the Pierre Auger Observatory hint at a light or mixed composition that becomes increasingly heavier beyond 2×10^{18} eV [AUG:10].

The techniques for inferring the mass composition of cosmic rays can be split in two categories, depending on whether they exploit the sensitivity to X_{max} or to the muon contents of the air shower. Direct measurements of the fluorescence emission fall in the first category, and so do the various measurements of the Cherenkov light as well as of the radio emission produced by air showers. Most ground-based detector observables depend, one way or another, on the number of muons in the air shower. The measurement of the number of muons and electrons in the air shower can be done directly, for example, the way it was performed with the KASCADE facility [KG:10].

It is vital that the entire energy region from 5×10^{16} eV and up to the highest energies be explored by a single observatory, with a single set of data with complementary techniques, and with well understood detector resolutions and systematic uncertainties. Both, the longitudinal profile and the muon content of the shower must be measured. This is the aim of the AERA (radio), AMIGA (muons) and HEAT (fluorescence) enhancements to the basic design of the Auger Observatory. Any progress to be achieved in the field of cosmic-ray physics will involve a substantial improvement in the detection of the composition of cosmic rays. Hence, we propose a multi-hybrid approach to the data analysis and simulations, namely a combination of fluorescence, charged particles, high-energy muons, and radio detection of extensive air-showers. This is possible for the first time at an observatory and worldwide unique.

For this project, we are focusing on two essential work packages.

First, analysis procedures for a super-hybrid array will be optimized, i.e. data from the surface array, AMIGA, and AERA will be coherently reconstructed, and compared with detailed simulations. The detectors of AMIGA and the radio detection antennas of AERA will be integrated. Radio detection provides the data of the longitudinal profiles all through the MHz band of the spectrum. For the first time, high-energy muon measurements will be correlated with radio measurements. In particular this research group will concentrate on the air-shower reconstruction for inclined showers as here both, the muon content and the radio signal are stronger relative to the electromagnetic component which allows the verification of hadronic air shower models underlying the analysis. In addition, the group will investigate if a scintillator array superimposed to the surface array of water tanks will improve the quality of composition measurements. For that, the decommissioned scintillation detectors of the KASCADE array can be used to build at least a first prototype of such a hybrid surface array. The purpose of the scintillators is to increase the sensitivity to the electromagnetic part of the air shower. Such a detection system could to be finally installed over an area ~30 km^2, where the first AERA radio antennas and AMIGA muon detectors have already been installed in the same small (ca. 1 km^2) sub-area of the Auger Observatory.

In the second work package, we will further explore the possibility of extending a muon and a radio detection system to a significant part of the whole Auger array. It is the next natural step forward towards the understanding of the composition of cosmic rays with energies around and above the GZK cutoff. A major advantage of collecting muon data and radio emission will be the duty cycle approaching 100%.

Innovative Aspects

This is a science program aimed at answering fundamental questions of nature related to high-energy cosmic rays. For such a purpose the development of innovative detection technologies is required, including fast high-density multi-layer electronics with low power consumption and low noise, wired and wireless telecommunications, photovoltaic power systems suitable for remote locations and rugged, sustainable mechanics of detection modules.

This multi-detection system observatory will be close to a ultimate observatory for understanding the high-energy cosmic ray composition without which this branch of science cannot advance any further. The present project is the unique chance to develop such sophisticated detection systems. Immediate application to cosmic ray physics at lower energy serves as test bench for a use in a future, large-scale, next generation cosmic ray experiment. Hopefully, final answers will be given to unsolved problems in cosmic-ray physics that have been with us for the last hundred years.

Future perspectives

Pending the prototype developed in WP2 of this proposal, we will be able to propose an upgrade for the full Auger surface detector array which needs deep discussion and eventual approval of the full Auger collaboration. The technical developments in WP2 as well as the scientific results of WP1 will also serve as input for designing a future ground-based cosmic ray observatory and for evaluating the physics case for such a next generation facility, respectively. Through the proposed bilateral German-Argentinean research group, both partners will reach a high visibility in this process.

Role of Young Investigators

Our plans for student involvement in this project are substantial. PhD students are planned to work on the subtasks under the supervision of the respective group leaders and key scientists. Given our experience in the past, we expect to attract further students on bachelor and master level to work within the scientifically high-level project. Mutual visits of the project partners in the other institutes will not only lead to the exchange of knowledge to the entire groups of the partners, but also be used to held seminars to the students of the entire faculties. In addition, common workshops on the project will be organized, where also students not involved directly in the project will participate. The project is open for undergraduate students where laboratory studies on detection techniques, electronics, and mechanics for physicists and engineer students can be performed.

KCETA: Currently, 2 master students are already working on specific topics of the proposed work packages. We plan to involve more students (2-3 per year) in the project, who will be supervised by the group leader and key scientists. The Helmholtz young investigator group of Tim Huege is working on topics of the radio detection technique with AERA and will assist the radio part of the project in terms of simulations, data analysis and operation of AERA. Further overlaps are provided by a PhD student (Olga Kambeitz), who has recently started investigating the capability of radio detection to horizontal air showers and the small HRJRG of Frank Schröder, who studies correlations of the radio signal with the Cherenkov light measurements at the Tunka experiment in Siberia. The analysis of data from the Auger Infill Array is a speciality of Markus Roth and his group (e.g. Hans Dembinski and a diploma student presently delegated to ITeDA for a period of six months).

ITeDA was created to perform research in astroparticle physics and therefore it is already fully involved as an institute in above-mentioned WP1. In order to achieve the project goals it has already assigned specifically to it one postdoc (Manuel Figueira), a graduate student (Brian Wundheiler, soon to get his PhD) and three graduate students (two physicists and one electronics engineer). It is foreseen, according to the needs of the project, to increase this commitment.

Funding, Work Packages and Milestones

Funding

UNSAM will provide € 50.000/yr for three years (36 months). These funds will be dispatched to and managed by ITeDA.

Helmholtz will provide € 50.000/yr for three years (36 months). These funds will be dispatched to and managed by IKP.

The exchange program of young researchers, an important and necessary topic of this project, requires that the air fares are to be paid by the home institution whereas accommodation and daily allowances are to be paid by the receiving end. ITeDA will budget the participation of German young researchers in Argentina to Collaboration Meetings at the Auger Observatory.

Work Packages

Essentially two work packages will build the nucleus of this project and the bilateral co-operation. First, in order to increase the sensitivity of the present installation to the elemental composition for energies around the second knee and transition from galactic to extragalactic origin of cosmic rays, the super-hybrid system consisting of the dense infill ground array, the AMIGA muon detectors, the AERA radio antenna array, and eventually a scintillation detector array will be optimized and the reconstruction procedures provided. The second work package will further explore the possibility of extending the concept of a super-hybrid detection to larger scales and therefore to higher primary energies.

WP1: Pierre Auger Observatory enhancements

In this work package, we will focus on the design and prototyping of the hybrid surface array built with the detectors of AMIGA, the radio antenna array AERA, and with the scintillation detectors of KASCADE. Moreover, we will study the benefits of combining the information of the particle detectors, in particular the muon measurements, with the complementary measurements of the AERA radio antennas. Preparing the software and analyzing the available data for a hybrid detection and corresponding reconstruction of the primary cosmic ray energy spectrum and elemental composition is the main goal of the workpackage. This work package will be the most demanding in human resources.

WP2: Auger upgrades and R&D for next generation experiment

The activities of this work package will yield the preparation of the ground to furbish the current water Cerenkov detectors with the technology developed with the muon counters (scintillators or RPCs) and the radio detector stations. It will be necessary to write the software codes and conduct the design and simulation before moving on with the installation of prototype detectors. All the work will be done in the light of possible designs of integrated particle detector station for a cosmic ray experiment of next generation. The work package culminates with a prototype within the period of the HAJRG.

Milestones

WP	TASK	Period (month)	Milestone (Deliverable)
WP1.1.	Design + simulation	1.- 12.	Report
WP1.2.	Software coding	1. – 18.	Report
WP1.3	Prototyping	12. – 30.	Intermediate report
WP1.4	Data analyses	24. – 36.	Final report
WP2.1	Design studies	16. – 26.	Meeting
WP2.1	Simulation	16. – 36.	Report
WP2.2	Prototype	30. – 36.	Final Report

There is agreement between the partners that the cooperative work will be continued after the runtime of the present HAJRG. New milestones and work packages will be defined by the end of the three year period.

Group Structure

The group consists of 11 members, whereby 3 of them (one from ITeDA, two from KIT) work exclusively for the project. In addition, diploma, master, and Bachelor students will be involved in the research.

#	Name	Home	Position	Core expertise and goals for the project	FTE for project
1	Markus Roth	KIT	Staff	project management, physics analysis	0.2
2	**N.N.**	**KIT**	**Phd Student**	**hybrid infill analysis hybrid detector R&D**	**1.0**
3	Hans Dembinski	KIT	Postdoc	infill analysis methods…	0.3
4	Andreas Haungs	KIT	Staff	R&D large-scale applications, radio data analysis	0.2
5	Frank Schröder	KIT	Postdoc	hybrid simulations and data analysis, merging of muons and radio	0.3
6	**N.N.**	**KIT**	**Phd Student**	**radio detection R&D, hybrid data analysis**	**1.0**
7	Olga Kambeitz	KIT	Phd Student	large-scale development radio	0.2
8	Federico A. Sánchez	ITeDA	Staff	project management, physics analysis	0.3
9	**N.N.**	**ITeDA**	**Phd Student**	**hybrid infill analysis hybrid detector R&D**	**1.0**
10	Manuel Figueira	ITeDA	Postdoc	hybrid data simulation and analysis	0.3
11	Brian Wundheiler	ITeDA	PhD Student	R&D studies muon detectors	0.2

Budget at ITeDA

Personnel (Person-months)

Year	1	2	3	TOTAL	(4)	(5)
Staff*	20	20	20	60	20	20
Students**	36	36	36	108	36	36
TOTAL	56	56	56	168	56	56

* Includes staff researchers, postdocs and support engineers

** Graduate students

Funding (k€)

Year	1	2	3	TOTAL	(4)	(5)
Salaries (YR)	29	29	29	87	29	29
Travel & Per Diem*	21	21	21	63	21	21
TOTAL	50	50	50	150	50	50

* Two visits/yr x 0,5yr (6mo) @ €1,500/mo = € 18,000. Two airfare tickets (Economy) €1,500 ea = €3,000

Budget at KIT

Personnel (Person-months)

Year	1	2	3	TOTAL
PhD students	24	24	24	72

Funding (k€)

Year	1	2	3	TOTAL
Salaries (total)	78	78	78	234
Salaries (by HAJRG)*	50	50	50	150
TOTAL HAJRG	50	50	50	150

* Salaries and expenditures exceeding the project funding will be covered by the Helmholtz Program Astroparticle Physics

Summary

As a summary, this project intents to build on the strong experience and commitment over the years of the two participating institutes to the existing and successful Auger Observatory, in an effort to unravel the cosmic-ray chemical composition towards a deep understanding of this ever-growing branch of astroparticle physics which is deemed to be on the edge of fundamental discoveries.

Applicant Signatures

This document is presented to the Helmholtz Association and to the Universidad Nacional de San Martin as a joint application signed by the Principal Investigators on each side.

Karlsruhe, October 22, 2012

Johannes Blümer

Buenos Aires, October 22, 2012

Alberto Etchegoyen

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