Statement by the German Astroparticle Physics Community as input to the European Strategy for Particle Physics

17.12.18

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Abstract:
The German Committee for Astroparticle Physics, KAT, is the elected representation of all astroparticle physicists working at German research institutions of the Helmholtz Association, Max Planck Society and at German universities. This paper comprises the statements of the German astroparticle physics community to the 2020 update of the European Strategy for Particle Physics. The three German committees for particle physics, KET, for astroparticle physics, KAT, and for hadronic and nuclear physics, KHuK, in the last 1.5 years jointly arranged a series of workshops where the current status and future plans for the wider scientific field were evaluated and discussed within these three communities. KAT extracted the statements and strategic proposals relevant for astroparticle physics from the joint declaration of these workshops and finalized this paper at its strategy meeting with all group leaders/professors in astroparticle physics in Germany end of November 2018.

The main research topics of astroparticle physics in Germany are the nature of neutrinos and of dark matter, the origin of cosmic rays, and the understanding of the non-thermal Universe. The nature of neutrinos and of dark matter are fundamental questions of particle physics that have a large overlap with accelerator-based particle physics. Therefore, this document focuses on our vision for these subjects as input to the European Strategy for Particle Physics.

Introduction

Astroparticle Physics is a rapidly developing field in the cross roads of particle, nuclear, astrophysics, astronomy, and cosmology. This field has led to key discoveries (e.g. neutrino oscillation, sources of ultrahigh energetic extra-terrestrial and extra-galactic particles, gravitational waves, ...) that shaped our understanding of the Standard Model of particle physics and its extension beyond as well as our understanding of the processes in our Universe, and how it began with the Big Bang. Europe plays a leading role in astroparticle physics.

Because of its overlapping nature with different neighbouring fields and because of historic (and funding) reasons the understanding whether a certain scientific question belongs primarily to astroparticle physics or another research field varies from country to country. Therefore, we would like to clarify the main directions of research of the Germany astroparticle physics community:

- non-accelerator particle physics with cosmic particles
- astrophysics with high energy particle messengers

The main research topics are:

- nature of neutrinos
- nature of dark matter
- origin of cosmic rays
- understanding the non-thermal Universe

The nature of neutrinos and dark matter are fundamental questions of particle physics that have a large overlap with accelerator-based particle physics. Therefore, this document focuses on our vision for these subjects as input to the European Strategy for Particle Physics.

The German Committees for particle physics, KET, for astroparticle physics, KAT, and for hadronic and nuclear physics, KHuK, jointly arranged a series of workshops where the current status and future plans for the wider scientific field were evaluated and discussed. KAT extracted the relevant statements and strategic proposals from the joint declaration and submits them to the 2020 update of the European Strategy for Particle Physics:

Non-thermal high energy Universe

We acknowledge and foster the scientific and instrumental links of particle physics with high-energy astroparticle physics and support their further strengthening.

A main focus of astroparticle physics is the investigation of the non-thermal high energy Universe with cosmic messengers, like cosmic rays, high-energy photons and high-energy neutrinos. We want to understand their origin and how cosmic accelerators at the highest energies work. By the simultaneous observation of more than one messenger from the same source we potentiate our understanding. This multi-messenger approach has recently been joined by the gravitational wave community after the discovery of gravitational waves from black hole and binary neutron star mergers. For cosmic rays the upgrade of the Pierre Auger Observatory to AugerPrime and beyond to a Global Cosmic Ray Observatory as well as for ultra-high energy gamma rays the Cherenkov Telescope Array (CTA) under installation are the leading world-wide endeavours. For high energy neutrinos, the two main projects on a global scale are IceCube with its future extension IceCube-Gen2 and KM3NeT. The German community engages mainly in IceCube-Gen2. All these experiments have in addition an interesting particle physics program including searches for Big Bang relics and indirect signals for dark matter. They are connected to the CERN community by being CERN Recognized Experiments.

Gravitational waves

Synergetic developments on topics regarding science, infrastructure, technologies, and computing related to the next generation gravitational wave observatories are recommended.

With its recent results, the gravitational wave interferometers on ground have opened another observational window to the Universe. The next generation instruments (Einstein Telescope and the space based LISA) will probe even deeper our Universe and the cosmological models as well as the matter / dark matter distribution or new physics beyond the Standard Model of particle physics and beyond standard cosmology. The German astroparticle physics community explores options to get deeply involved in the development of these third-generation experiments.

Dark Matter searches

Experiments searching for WIMPs and axion-like particles, and projects searching for light very weakly interacting particles are strongly recommended.

Experiments using natural particle sources or performed at accelerators in fixed-target or beam-dump setups are able to address fundamental questions that are complementary to collider experiments. Various Standard Model problems are addressed by Beyond the Standard Model theories predicting very weakly interacting particles (neutral leptons, dark photons / scalars, ALPs, WIMPs, but also light dark matter). The German astroparticle physics community is particularly interested in the WIMP search experiment DARWIN, in the solar axion experiment IAXO and in the dark matter axion experiment MADMAX, both planned to be located at DESY.

WIMPs would have been produced naturally at the Big Bang with the correct density. At present, the experiments CRESST-III (low masses) and XENON1T (medium and large masses), with German participation, lead the direct WIMP search. With the further expansion of CRESST-III to 100 detectors and XENON1T to XENONnT, this search will become much more sensitive. The liquid Xenon detector DARWIN is a long-term strategic goal. The significantly increased sensitivity to WIMPs is complemented by a broad neutrino physics program. It is therefore strongly recommended to realize the DARWIN experiment.

Neutrino Projects

A visible European participation in double beta decay experiments and a strong effort to increase the direct neutrino mass sensitivity of laboratory experiments are strongly recommended.

Neutrino physics is a dynamic field with great potential providing a unique window to physics beyond the Standard Model. The major scientific questions include the hierarchy and absolute scale of neutrino masses as well as their particle-antiparticle properties. The measurements of mass hierarchy, oscillation parameters, and leptonic CP violation require complementary experiments using neutrinos from reactors and accelerators as well as atmospheric neutrinos. For the long-term future, a precise measurement of leptonic CP violation is a key scientific objective in particle physics.

The investigation of the ß-decay of tritium and the electron capture of Ho-163 gives access to the absolute mass scale of neutrinos with sub-eV sensitivity, as well as to sterile neutrinos on the eV and keV scale with high sensitivity. The KATRIN experiment is unique in the world and its sensitivity should be increased further. The development of both complementary techniques, cyclotron radiation emission spectroscopy with Project 8, and cryo-bolometers with ECHo, should be supported to cover the area of the inverted mass scale beyond KATRIN.

Experiments on neutrinoless double beta decay search for the violation of the lepton number and investigate the nature of neutrinos (Majorana versus Dirac particles). The uncertainty of the nuclear matrix elements requires the investigation of the process with at least two different isotopes. The unique discovery potential of neutrinoless double beta decay should be intensively pursued through the expansion from GERDA to LEGEND-200 and possibly further to LEGEND-1000. DARWIN will play a strong role, in addition to the search for WIMPs, in neutrinoless double beta decay, in the measurement of solar neutrinos and as detector for supernova neutrinos.

Understanding the mass hierarchy of neutrinos is very important for neutrino models and for determining the CP violating phase. A significant determination of the mass hierarchy is pursued through three complementary oscillation measurements with reactor, accelerator, and atmospheric neutrinos. An important contribution in this field is given by the strong German participation in the reactor experiment JUNO with a 20 kt liquid scintillator starting in 2021 and with the atmospheric oscillation experiments, where the realisation of at least one of the two experiments with atmospheric neutrinos (ORCA, PINGU) is highly desirable.

Theory

A strong theory program is essential both for strategic decisions and for the success of experiments. Substantial support is therefore mandatory.

All projects discussed above will provide important, sometimes even crucial, input to advancing the theoretical foundation of fundamental physics. The physics interpretation of the experimental results is based on an ever deepening theoretical understanding. Close collaboration between experiment and theory is therefore a prerequisite to advance the research field. Theory also establishes the links between the various topics and identifies opportunities for future experiments at an early stage.

Advances in Technology

Research and development in detector technologies, as well as in computing and software are a prerequisite for all future projects.

Many of the discussed topics and projects require substantial technological developments in the areas of detector, computing and software. Examples are cost-effective single photon detectors with high granularity or ultra-pure materials w.r.t. radioactivity. Unprecedented data rates and volumes will require the exploitation of state of the art computer science methods to develop adequate computing concepts and innovative algorithms for data handling, reconstruction and analysis. The entire research field will enter a new era of the research data management, leading to the development of a sustainable and interdisciplinary open science culture. Due to the very long time scales of many of the currently proposed projects, it will be essential to keep and further develop the technological expertise within the community.

Research Infrastructure

For astroparticle physics there is no central infrastructure such as CERN for particle physics. Dedicated research infrastructures located at the best places for these purposes are essential for astroparticle physics experiments. For experiments requiring ultra-low background the Italian laboratory LNGS must maintain its leading role in low energy astroparticle physics in

Europe, and further develop its potential. This situation requires the continued close collaboration of national laboratories, institutions and universities.

Astroparticle Physics in Europe build on infrastructures distributed over national and international laboratories and highly specialized observatories. For astroparticle physics in Germany, besides the international observatories like CTA, IceCube or the Pierre Auger Observatory the Italian underground laboratory, LNGS, and its infrastructure is of particular importance. The further development of LNGS, by compensating its moderate depth by artificial passive and active shielding technologies, is a prerequisite to maintain world-class research in Europe. The Neutrino Platform at CERN and the frontier technologies developed there, have been beneficial already for a direct dark matter experiment. The cooperation on technology between CERN and non-accelerator based particle and astroparticle physics experiments should be extended further.

Research Conditions - Promoting Young Scientists

The research conditions must guarantee the maintenance and further evolution of the expertise during the long project lifetimes and be attractive for junior scientists.

An outstanding European research landscape in astroparticle physics is the basis to ensure scientific progress and the attractiveness of the field. In order to guarantee the continuity and evolution of indispensable expertise in research and collaborative research infrastructure (computing, software and detectors), the personnel structures must be adapted to the long-term duration of experiments. Young scientists are often the source of new ideas and have the cutting-edge competence in many areas. Their scientific and technical contributions should be given high visibility and they need promotion and predictable career prospects.

Outreach

The commitment of scientists to activities that create public awareness and support is crucial and must be recognized as beneficial to their career record. Inspiring the next generation through outreach activities is an indispensable task.

Outreach and science communication aim at communicating current research questions and results, thereby raising public awareness of the societal benefits of fundamental research and securing the support of the general public. Outreach programs also create opportunities for young people to encounter role models and to obtain insight in the research process. Access to open data online or in masterclass programs enable participation of the public in scientific research. Scientists have the opportunities to share their enthusiasm in outreach and communication efforts worldwide.