FEATURE

Principal Investigator **Stavros Katsanevas**

Research Area : Experimental Physics

Towards a global Astroparticle Physics roadmap

The big question of the universe's fundamental constituents

We live exciting times; exciting in terms of the tasks in front of us and in terms of the richness of the forthcoming new data. We have achieved a lot; we know with high precision the density and geometry of the Universe, its age, the parameters of its evolution and made tremendous progress in understanding the particles of matter forming the visible Universe: the so called Standard Model of particles and interactions. Nevertheless, we still do not know the nature of invisible dark matter and dark energy filling the 95% of the density of this same Universe. In this beginning of the 21st century, our knowledge of the cosmos can be compared to the understanding of the gases at the beginning of the 20th; we know the overall parameters, *its thermodynamics or macrophysics*, but still lack the full knowledge of its elementary constituents, *its microphysics*.

Furthermore, our theories of the visible matter are not yet complete. We need to know whether they stay coherent at the smallest scales possible (equivalent to the highest energies of interaction). It is encouraging that the theories of extension of the Standard Model propose elegant solutions to both the riddles of dark matter and those of the extension at the smallest scales. They also predict the unification of what appears to be different types of interaction and suggest that a series of phenomena, e.g. the finite lifetime of the proton or the properties of neutrinos, give access to these scales.

The birth of astroparticle physics

On the astrophysics side, we have come to a progressive understanding of the mechanisms that through violent cosmic phenomena, stellar deaths or mergers, influence the largest scales, determining galaxy formation and evolution. Here, astrophysics needs to be supplemented with particle physics for the comprehension of the mechanisms and the detection of new sidereal messengers. Observatories of a new type complement the optical and radio telescopes. They use high-energy photons, neutrinos, charged cosmic rays or gravitational waves to probe the astrophysical objects.

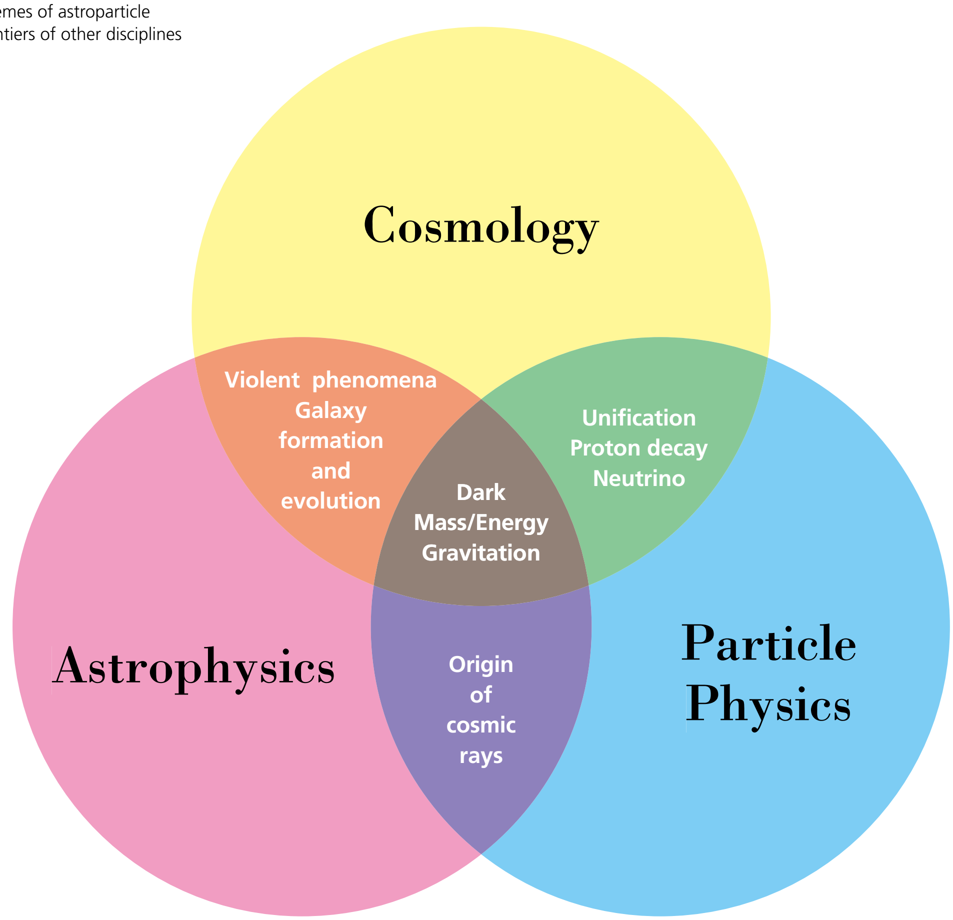
A series of recent seminal results from instruments in operation are reshaping the field. They come from high-energy gamma ray observatories (H.E.S.S, MAGIC, CANGAROO and VERITAS, and shortly GLAST), high-energy cosmic ray observatories (AUGER) and underground detectors (SuperK, Kamland, Borexino). Other observatories have been recently completed or are nearing completion: the neutrino telescopes ICECUBE (Antarctica) and ANTARES (Mediterranean) or the gravitational antennas VIRGO and LIGO. Dark matter and neutrino mass searches have entered a period where one expects large jumps in sensitivity within a few years and the neutrino program (e.g. T2K, DCHOOZ, DAYA-BAY) will complete missing parts of the neutrino property matrix by the start of next decade. The flagship particle physics (LHC, 2008) and cosmology (PLANCK, 2009) projects will have a large impact on the whole field.

It is widely understood that only a coherent analysis of the above data, will be able to advance our scientific world-picture. The interlinked approach to these questions forms what is sometimes called Astroparticle Physics, an interdisciplinary domain, at the frontier of Particle Physics, Astrophysics and Cosmology (see Figure 1). Though one could trace the roots of Astroparticle Physics to the discovery of cosmic rays in the beginning of the 20th century, the detection of the Supernova 1987A with neutrinos (Koshiba, Nobel prize 2002) is seen by many as the birth event of the new "astroparticle" era.

Europe's future experimental plans

My scientific work has touched upon different aspects of the above themes. I have contributed to phenomenological studies and experimental analyses of supersymmetry, the most coherent, to my taste, extension of the Standard Model. In particular, I was one of the authors of the Monte Carlo generator[1]

Figure 1: Main themes of astroparticle physics at the frontiers of other disciplines



used to evaluate sensitivities of the quasi-totality of supersymmetric analyses of the LEP experiments at CERN. I have also largely contributed to the design of the long baseline neutrino beam from CERN to Gran Sasso, the neutrino oscillation experiment OPERA and the high-energy neutrino telescope NESTOR. Since 2002, I work at the *National Institute of Nuclear and Particle Physics* (IN2P3) of the French *Centre National de la Recherche Scientifique* (CNRS) as deputy scientific director responsible for Astroparticle and Neutrino Physics.

Since 2006, I am also coordinating ASPERA,[2] a European agency consortium, funded by EU, aiming at the coming together of European national programs of Astroparticle Physics. ASPERA has studied and compared, up to now, the funding mechanisms in 14 European countries. It has found for instance that, in Europe, 2300 researchers are working in the field and that of the order of 70 M € annually are spent in investment, giving a consolidated total (including salaries) of 186 M €/year. Interestingly, preliminary estimates give the same figures for US. It has also studied mechanisms of common funding of these projects. But, its main task has been to chart the

Figure 2: From the round table discussion on ways of global coordination, during the ASPERA workshop in Amsterdam in September 2007. From left to right: J. Dehmer (NSF/US), A. Coates (STFC/UK), R. Staffin (DOE/US), T. Berghoefer (BMBF/Germany), R. Blandford, C. Spiering, J. Zinn-Zustin (CEA/France), S. Katsanevas (standing), J. Ellis (CERN)

10-year action plan of future ground or underground astroparticle infrastructures. They are about to be published in a report and they are presented briefly below.

In the domain of high energy observatories, the priority projects are the high-energy gamma Cherenkov Telescope Array (CTA) and the high-energy neutrino telescope Cubic Kilometre Network (KM3NET). They extend by an order of magnitude the sensitivities of current instruments and their construction could start by 2012. European Physicists also aspire to the implementation of a larger than AUGER observatory, preferably in the northern hemisphere, in a worldwide context.

In the domain of underground observatories one has a picture that should be clarified in 2 years from now. In particular, for dark matter searches we need to operate one – possibly two – complementary detectors on the ton scale or beyond with low background, capable to reach a 10^{-10} pb sensitivity to dark matter particles. A stepwise approach is presently underway and a prioritization between different technologies will be performed around 2010–2011. On what concerns neutrino mass, the construction and operation of one or two double beta decay experiments on the ton-scale, capable of exploring the inverted-mass region will be pursued. A decision on the construction could be taken around 2013. One also needs to construct a megaton scale observatory to investigate proton decay, neutrino properties and low energy neutrino astrophysics. This detector would be also an ideal target to receive accelerator neutrinos in long baseline experiments. Beyond the well established Kamioka/SuperKamioka water Cherenkov technique, alternative technologies using liquid argon or scintillator are currently in development. The European scientists pursuing all 3

Figure 3: Map of European underground laboratory space, including both major laboratories and smaller or future endeavours

techniques work in synergy in the EU funded design study LAGUNA. Depending on technology, site and worldwide cost sharing, construction could start by the middle of the next decade.

In the domain of gravitational wave observatories, the short-term priority is the upgrade of the present generation gravitation detectors and in particular "advanced VIRGO", while the long-term priority is the Einstein Telescope, a large underground gravitational wave detector. Its construction could start after first discoveries have been made with the current world network, likely around 2016/17.

The estimated investment cost of the above instruments, including a 25% of R&D, maintenance of current experiments and smaller projects, for the next 10 years, is about 1000 MEuros, that is 50% above the projection of currently available European funds.

Calling for cooperation from across the globe

One should not forget that Europe is not the only continent charting roadmaps, similar efforts exist in the US and Asia. They all come to convergent goals on the future infrastructures. Science and budgetary issues call for a worldwide coordination. Following the example of the gravitational wave observatories, one could hope to form worldwide consortia, or since many of these detectors are modular (in particular these of underground laboratories) we could conceive the construction and deployment of these modules in different continents but within the same overall structure. These are "middle scale" projects and a fair distribution in different continents can be negotiated. The domain of excellence of each country should be respected, e.g. it is difficult to imagine a worldwide project of a megaton scale detector where Japan would not play a major role.

As a preparation to this coordination, ASPERA organizes a conference this September in Brussels, where these opportunities will be discussed and where the director of IPMU will report on the situation in Japan. The discussion will continue in the context of the OECD Global Science Forum. It is an ambitious dream of world cooperation, but I firmly believe that the stakes are high and they are certainly worth the effort.

References:
[1]SUSYGEN 2.2: A Monte Carlo event generator for MSSM sparticle production. S. Katsanevas, P. Morawitz, Comput. Phys. Commun. 112: 227-269, 1998
[2]For more details see www.aspera-eu.org