Astroparticle Physics - A Pathfinder to New Physics

Monday 30 March 2009 - Thursday 30 April 2009

Nordita

Scientific Programme

Cosmology

The vacuum energy density of the Standard Model (SM) of particle physics cannot be extracted from any

traditional particle physics observable. However, the vacuum energy is measurable, just not by particle
physicists. It can be measured because Einstein gravity couples to all energies regardless of their source, and so
in particular gravity responds to the energy density of the vacuum. A net vacuum energy of the SM fields is
equivalent to including the presence of Einstein's cosmological constant into the gravitational field equations,

and it can lead to measurable effects for the expansion history of the Universe.
By using standard candles (SN Ia supernovae), the value of the cosmological constant can be inferred.
These observations pose very serious challenges for our understanding of fundamental physics, both for the

ultraviolet and infrared regimes of the SM. In the ultraviolet, a consistent short-distance completion of our field
theories is required, possibly involving a quantum theory of gravity. In the infrared, the very framework of the

SM as an effective field theory is challenged. In fact, it is the electron mass that gives rise to an expected
vacuum energy density that is 35 orders of magnitude above the measured value.
The contribution of SM fields below the electroweak scale to the cosmological constant cannot be cured
by supersymmetry. Since nobody has ever measured the vacuum energy density by any means other than
gravity, it can be expected that the solution of the cosmological constant problem lies in the gravitational sector.

In recent years, consistent modifications of Einstein gravity have been explored that address this problem, but
leave the ultraviolet regime untouched. In these theories, the graviton becomes effectively a resonance that
filters infrared sources. Since it is not possible to formulate a consistent theory of gravitons with only a finite

number of massive excitations, this can be seen as a strong indication for extra dimensions.

Dark matter

The dark matter problem is another of the unsolved mysteries in modern cosmology. From a particle physics

point of view, there are plenty of candidates for the dark matter and the focus lately has been on examining these candidates in terms of their relic density (i.e., their contribution to the observed dark matter content of the Universe) and various direct and indirect detection methods. At the time of the proposed program, we expect to have gained much new knowledge about the dark matter from new experiments and observations. For example, the Large Hadron Collider (LHC) is expected to have delivered its first results. The new results of the charged cosmic ray satellite PAMELA are also expected together with new results from e.g. IceCube and direct detection experiments (e.g. XENON100). With these new observations, we expect to be at a very interesting and demanding time, where many theories will be confronted (with or without success) with these results. The

proposed program will bring together scientists in various fields, helping to interpret these results and their impact on theory building.

Neutrino physics

Neutrino physics is another of the topics to be covered in the proposed scientific program. This topic has

received a huge amount of attraction in the last decade, because of the novel neutrino oscillation experiments such as Super-Kamiokande in Japan and SNO in Canada. Recently, the exploration of precision measurements has continued the endeavor with experiments such as K2K, KamLAND, MINOS, and others. In the future,

upcoming experiments like NOvA, Double Chooz, CERN-CNGS, and T2K will be ready to pin down the errors

on the fundamental neutrino parameters. In connection with the experiments, it is natural to have

phenomenological investigations of the description of physics. One aim of the program is to be able to answer open questions of the following kind: Are neutrinos their own anti-particles or not? What are the values of the

fundamental neutrino parameters? Is the correct description normal or inverted mass hierarchy? What is the value of the absolute neutrino mass scale? All these open questions are important for creating an extended

version of the SM for particle physics.
Since neutrinos are so weakly interacting, they are very useful for probing extreme astrophysical environments which are otherwise inaccessible, making them one of the most important ingredients in astroparticle physics. One example is the fact that we observe neutrinos coming from the center of the Sun, in effect opening a window through which to the deep interior of the Sun can be investigated. Another, even more

extreme example comes from supernovae (SNe), the most energetic events in our present Universe. More than 99 % of the total energy of a SN is emitted in neutrinos and in fact neutrinos from one relatively recent SN were detected directly. Detecting neutrinos from the next explosion of a galactic SN would greatly advance our

understanding of stellar explosions and neutrino properties. The detection of the diffuse SN neutrino background will shed light on star formation in the early Universe.
Conversely, astrophysical and cosmological observations can shed light on neutrino properties. From observations of large scale structure in the Universe, it is possible to probe both the absolute neutrino mass scale as well as the effective number of flavor states present in our Universe.
Models for neutrino masses may give rise to mechanisms for generating the matter-antimatter asymmetry in the Universe. Leptogenesis is one such model that is based on the seesaw mechanism, which is a popular model for the smallness of neutrino masses. In this model, the decay of very heavy neutrinos generates a lepton asymmetry which is subsequently transferred to baryons via non-perturbative electroweak processes.

Ultra-high energy cosmic rays

Another example of the interplay between particle physics and astrophysics which is still in its infancy is the

study of ultra-high energy cosmic rays. Very recently it has been established by the Pierre Auger Observatory

that active galactic nuclei are the sources of these very rare high energy particles, and these observations therefore offer a unique possibility for studying physics close to the central black holes of such galaxies.