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What is in a Vacuum?

The problems in understanding the true nature of the “vacuum” of space were discussed by theoretical physicist Alvaro de Rújula from CERN (the European Council for Nuclear Research) in Geneva, Switzerland, and a professor of physics at Boston University at the EPL symposium, “Physics In Our Times” held on Thursday 10 May 2007 at the Fondation Del Duca de l’Institut de France, Paris.

“As it turns out, the vacuum is not empty - there is a difference between the vacuum and nothingness,” he stated. “Surprisingly, of all known ‘substances’, the vacuum is the least well understood.”

From the point of view of cosmology, the vacuum appears to have an energy density, which is sometimes called “dark energy” or the “cosmological constant”, responsible for the observed accelerated expansion of the Universe. From a particle physics viewpoint, the vacuum is permeated by a “Higgs Field” - named after physicist Peter Higgs. In the Standard Model of particle physics (which has mapped the subatomic world with remarkable success for over 30 years), the masses of all particles are generated as a result of their interactions with this field.

It should also be possible to detect excitations of the Higgs field in the form of a particle known as the “Higgs boson”. Detecting the Higgs boson- the only particle in the Standard Model that has not been observed experimentally - is therefore one of the outstanding challenges in particle physics today. Scientists hope to detect the Higgs using CERN’s Large Hadron Collider (LHC), due to come online in November this year. The LHC will be the world’s largest particle accelerator, colliding protons on protons at a total energy of 16 TeV ($16x10^{12}$ eV) to generate what physicists hope will be a slew of new particles, including the Higgs boson.

The LHC will also search for many hypothetical particles other than the Higgs boson in what is called “physics beyond the Standard Model”, with “supersymmetry” being a promising candidate idea. Supersymmetric extensions of the Standard Model predict that all fundamental particles - such as quarks, photons and electrons - have ‘cousins’: their so-called `superpartners’, yet to be discovered.

Dr de Rújula’s favourite achievement to date, in collaboration with Sheldon Glashow and Howard Georgi, has been understanding the masses of particles made of quarks. “My colleagues Arnon Dar and Shlomo Dado and I also believe we have recently solved the two main problems of high-energy astrophysics, gamma ray bursts and cosmic rays, but astrophysicists do not (yet) agree with this,” explained Dr de Rújula.

Looking to the future, Dr de Rújula believes that the LHC will teach us “something fundamental”. Apart from finding the Higgs boson, it is possible that the collider will produce the “dark matter” particles indirectly observed in the universe. “However, even if the LHC finds nothing this would also be very interesting because it would tell us that we haven’t understood anything about the vacuum. A complete lack of understanding often precedes a scientific revolution” he said.

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