Institute of Origins

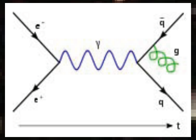
mathematics

UCL

Mathematics & High Energy Physics

ELEMENTARY PARTICLE PHYSICS

One major mathematical challenge facing theoretical physics today is understanding the origins of elementary particles. Subatomic particle physics is important both in the search for the ultimate building blocks of matter and as a testing ground for the Special Theory of Relativity and quantum mechanics. A proper union of these two theories leads to relativistic quantum field theory, currently the starting point for almost all attempts to provide a fundamental description of subatomic particles.



When the quantum theory is applied to the electromagnetic field, it leads to quantum electrodynamics (QED), a consistent theory of electrons, positrons and photons in interaction. Central to this theory is the idea that electrons and positrons interact by exchanging photons, allowing the photon to be regarded as a 'messenger' particle conveying the electromagnetic force between particles of matter.

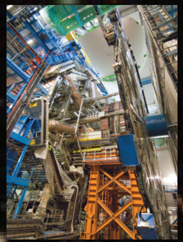
One key to the success of QED is that the electromagnetic field possesses an abstract, but powerful sort of symmetry know as gauge symmetry. Undertanding that QED was based on gauge theory led to the electroweak force, which connects the weak and electromagnetic forces and the extension of gauge theories to incorporate the strong force.

The strong force holds quarks and gluons together to form protons, neutrons and other particles. A gauge theory of the interquark force called quantum chromodynamics (QCD) suggests that gluons play the role of the 'messenger' particles that get exchanged between quarks, which makes it a close analogue of QED with gluons in place of the photons. QCD also introduces a new strong force 'charge' called 'colour', leading to the term *chromo*dynamics.

Quarks joined by a string of gluons

Neutron

UCL's Mathematics Group works on the theoretical development of the Standard Model of particle physics which is based on the ideas of QED and QCD. Of particular interest are quark and gluon distributions and the application of QCD to the physics at particle colliders, especially on the Large Hadron Collider (LHC) just turned on at CERN.



The High Energy Physics group (HEP) is involved in the LHC with its work on ATLAS; one of two general purpose detectors being constructed to study proton-proton collisions at the highest energy achieved to date. One primary goal of the collider is the Higgs boson, named after UCL alumni Peter Higgs (1950's), which is the last unobserved particle among those predicted by the Standard Model.

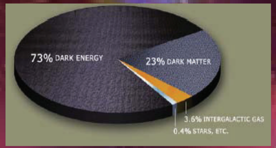
The ATLAS Detector on the LHC at CERN

For decades, the Standard Model of particle physics has served physicists well as a means of understanding the fundamental laws of Nature, but it does not tell the whole story. The Institute of Origins will provide a forum for communication between Mathematics and High Energy Physics so UCL's experimental and theoretical modelling can be combined into a cohesive approach to these fundamental issues.

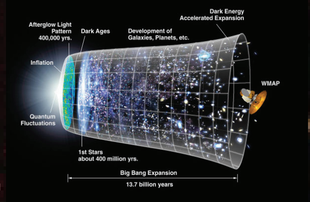
Mathematics and Physics & Astronomy

COSMOLOGY

Another major mathematical challenge is to understand why the expansion rate of our Universe is accelerating not slowing down. Theories abound to explain this curious result, at the forefront of which are dark energy and dark matter models and modifications to Einstein's theory of General Relativity.



Dark matter and dark energy theories suggest our Universe is 25% filled with dark matter; an invisible component whose presence can be inferred from its gravitational effects on visible matter and 70% filled with a bizarre fluid dubbed dark energy. Dark energy and dark matter together form the dark sector of the Universe.

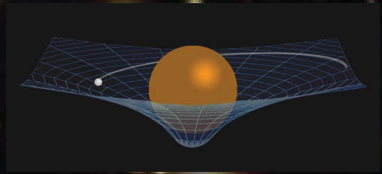


In recent years, many dark energy models have been proposed such as interacting models in which the early Universe contains only dark matter that is slowly converted into dark energy. Another model is based on a Fermionic description of dark matter and dark energy called dark spinors and uses scalar fields similar to those of inflationary cosmology or other forms of vacuum energy to model the observed expansion.

UCL Mathematics group is a driving force behind development in these areas, both theoretically and with emphaseis on using what we can learn from observations. Both UCL's Maths and Astrophysics groups are members of the Dark Energy Survey (DES), an optical imaging survey that will make precision measurements of dark energy using techniques such as counts of galaxy clusters, cosmic gravitational lensing and supernova.

Dark Energy is not the only possibility to explain the observed expansion and modifications to Einstein's theory of General Relativity could also provide a valid explanation. General Relativity uses differential geometry to lay the foundations to formulate gravity but whilst it is the most successful established theory describing the large-scale behaviour of spacetime there are still many questions that remain unanswered.

For example Einsteins Equations do not naturally fall into any of the standard classes of partial differential equations and the manifold on which a solution is defined is determined by the solution. These make physical interpretation of the solutions particularly difficult.



The Institute of Origins is taking advantage of UCL experience to couple mathematical models which reconstruct the expansion rate of the Universe to the expertise and knowledge of the Physics & Astronomy group in interpreting the results. This multi-disciplinary approach will allow the complex issues to be considered in both fundamental and physical ways, potentially furthering our understanding of the Origins and Evolution of the Universe.