The fascinating quest for Quantum Gravity

What is Gravity?

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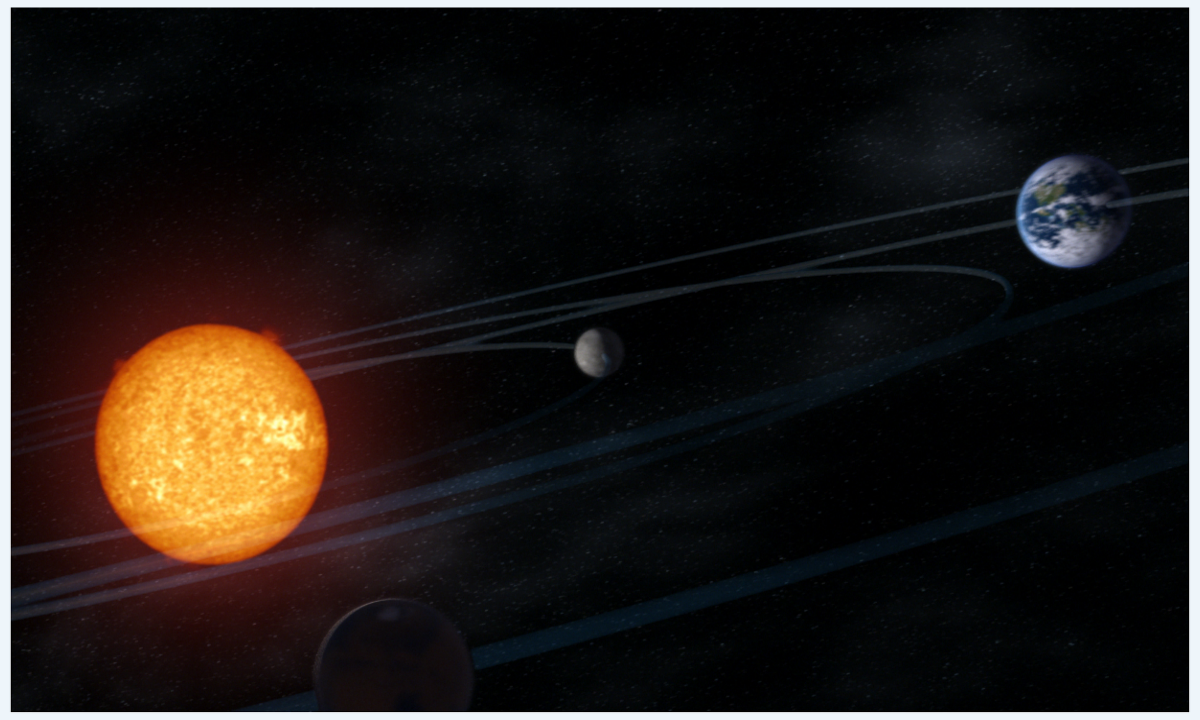


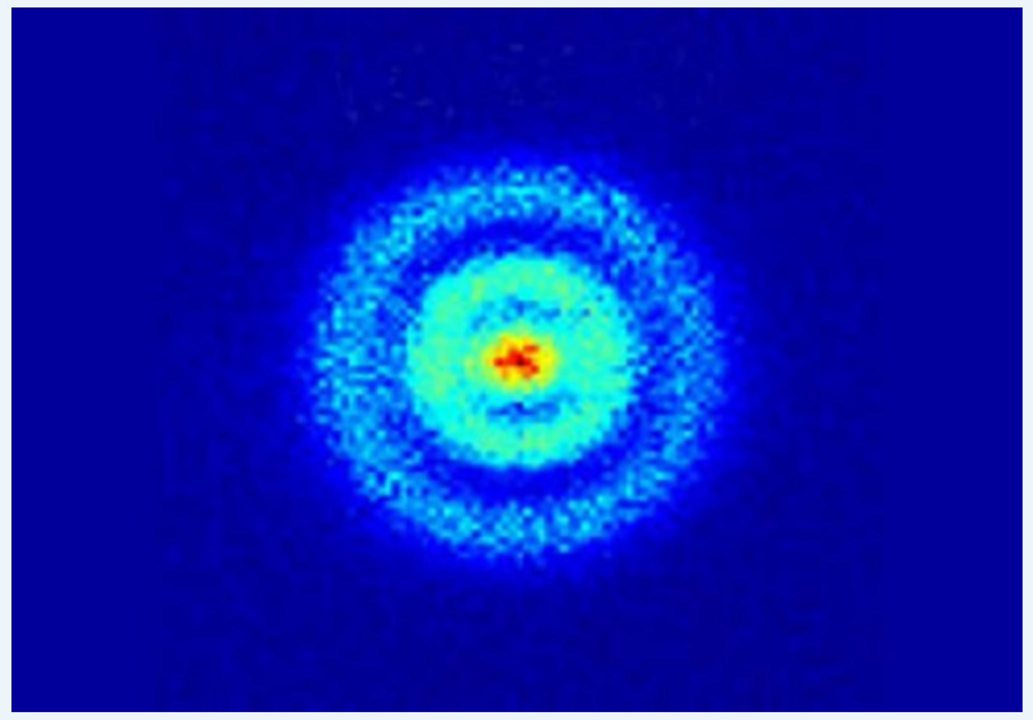
Gravity is an attractive force between massive bodies which we experience continuously in our everyday world. Gravity pulls us to the ground and, more generally, describes how bodies fall.

The laws of gravity are ***deterministic***, i.e. they can be used to calculate a unique prediction for a given system.

For example, we can use gravity to predict a planet's unique position in its movement around its central star at any given moment in time. The result will not involve any probabilities which are the hallmark of Quantum Mechanics. On the other hand, all of the other three forces of Nature have been successfully united with Quantum Mechanics. Gravity so far has resisted all efforts to do so…

What is Quantum Mechanics?

Stodolna et. at., PRL 110



Quantum Mechanics governs the world of the very small. Ever since its development in the early 20th century it has led to many counterintuitive consequences, the most fundamental of which is the following:

Quantum Mechanics furnishes us with ***probabilistic*** predictions and *does not* uniquely predict the state of a system.

The illustration above shows the structure of the position probability of the electron in a Hydrogen atom as measured by experiment. At a given moment in time the electron is more likely to be found in the bright areas. Since the electron's position is given by a probability distribution, this is an example of a non-deterministic system.

What happens with Gravity if we go to very small systems?

classical → Quantum Gravity ← quantum

What precisely is the problem?

The strength of Gravity is described by a number of parameters, called couplings, one of which is Newton's constant. These couplings change depending on the distance at which Gravity is operating, i.e. they will have a different values for the gravitational force between two electrons than for the gravitational pull between planets.

The challenge is to describe the variation of the couplings in a consistent way.

Research strategy:

Standard techniques for describing the variation of couplings do not work in the case of Gravity because they require the couplings to be smaller than one. The approach I am using, ***the exact renormalisation group***, can accommodate couplings greater than one and is therefore well suited for tackling Gravity.

$$g < 1 \rightarrow 0 < g < \infty$$

My actual work consists in performing explicit calculations using the exact renormalisation group to decide if the couplings change in such a way that a physically meaningful theory of Quantum Gravity is possible.

Why do we need to do this?

Quantum Gravity will further our understanding of nature in a way which can only be compared to similar revolutions such as Quantum Mechanics itself.

We need to know Quantum Gravity to answer some of the most fundamental questions of physics:

- What is the nature of space and time?
- How is mass generated?
- How does the strength of gravity change with distance?

Excitingly, preliminary answers to some of these questions can already be given on the basis of results derived in the framework described here. For example, the four dimensions of space and time might actually reduce to only two dimensions at the microscopic level…

Juergen Dietz; Supervisor: Prof. Tim Morris   J.A.Dietz@soton.ac.uk   http://www.hep.phys.soton.ac.uk