Tackling the big questions -- approaching a revolution in our understanding of gravity

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(PhysOrg.com) -- The way galaxies move through the cosmos has recently begun to baffle scientists. Even when the gravitational theories of Newton and Einstein are taken into account, the universe is expanding and galaxies are rotating in ways that do not comply with our current knowledge and predictions.

Now theoretical physicists at The University of Nottingham are examining possible solutions to the 'dark energy' and 'dark matter' problems — tackling the potential theories that would explain why the universe is evolving as it is today.

We are now able to see deep into the universe using satellite telescopes, but ever more powerful technology raises more questions. The rotational curves of galaxies cannot be explained by Newtonian dynamics or Einstein's theories of General Relativity without assuming the existence of some mysterious unseen form of matter — often referred to as 'dark matter'. But dark matter has an even more mysterious cousin, dubbed dark energy — the effects of which can be seen by observing distant supernova. Observations show that this unseen force is speeding up the expansion of the universe, overpowering the gravitational attraction present between stars and galaxies.

Funded by a new grant from the Royal Society, Dr Tony Padilla of the University's School of Physics and Astronomy will examine the potential candidates to explain dark matter and dark energy. These include:

Vacuum energy

Vacuum energy — or the cosmological constant — is the energy left over when all the matter is removed from the universe. It has a special property, negative pressure, which results in the accelerated expansion of the universe. However, current theories suggest that vacuum energy in the universe is huge, while observations suggest it is tiny. How can we reconcile this theory with observation? String theory offers a vast number of vacuum energy solutions — states in which different kinds of universes could exist depending on the level of vacuum energy in each string vacua. In some the vacuum energy may be too large, leading to a collapsing universe or one that expands too fast for stars to form. Some theories suggest that our universe has been selected anthropically from limitless possibilities — the universe has to have a tiny vacuum energy, or humans wouldn't be here to ask questions about it.

Dr Padilla will take a different approach, exploring transitions between different universes. He thinks that we may have ended up where we are today after cascading through a series of different universes, tunnelling quickly from one to another.

In a separate study, Dr Padilla will also explore the concept of degravitation — which suggests that the vacuum energy could actually be huge, but just appears small when observed on large scales as gravity becomes weaker.

Quintessence

This theory suggests that cosmic acceleration could be driven by quintessence — a quantum field with an extremely low mass. The field, which oscillates extremely slowly over very large scales, behaves much like a cosmological constant, exerting negative pressure on the universe and causing the acceleration we see today.

Extra dimensions

Inspired by string theory, this proposes that cosmic acceleration is due to large extra dimensions, beyond the three observable dimensions of space and one of time. This theory poses the idea that we live on a 'brane' — an island universe marooned in a sea of large extra dimensions. Ideas such as degravitation can be realised by allowing gravity to leak into these extra dimensions, making it appear weaker than expected in our island universe. We can also think of dark matter as being hidden in these extra dimensions, observable by us only through the effect of its gravitational field.

"Whether we are excited by old problems like how to model the interior geometry of a rotating star in General Relativity, or newer ones like dark energy, there can be little doubt that we seem to be approaching a revolution in our understanding of gravity," said Dr Padilla. "And it is not all speculation and theory — experiment is catching up. When the Large Hadron Collider begins producing results at CERN, there is a chance that black holes will form in the accelerator and that extra dimensions will start to open up. It sounds scary, but from a physicist's point of view it is enormously exciting!"

Provided by University of Nottingham