Dark energy and the ultimate fate of the universe, an adventure with gravity...

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General Relativity and Cosmology

General Relativity (GR) is Einstein's theory of gravity. In GR, space and time form a single fabric called "space-time". Space-time is distorted by the presence of matter, causing gravity.

In the Standard Model of Cosmology, the universe is modeled as a uniform fluid consisting of 5% atomic matter; 27% cold dark matter, which is some mysterious invisible matter and 68% dark energy, which is energy that even empty space has. This is shown in Image 1, below.

The expansion of the universe is, surprisingly, speeding up. Dark energy is thought to be causing this acceleration. Accounting for dark energy is notoriously problematic, so it is worth considering alternatives.

The answer will tell us if this acceleration will last forever, as expected from dark energy, or if the universe will re-collapse in a "big crunch".

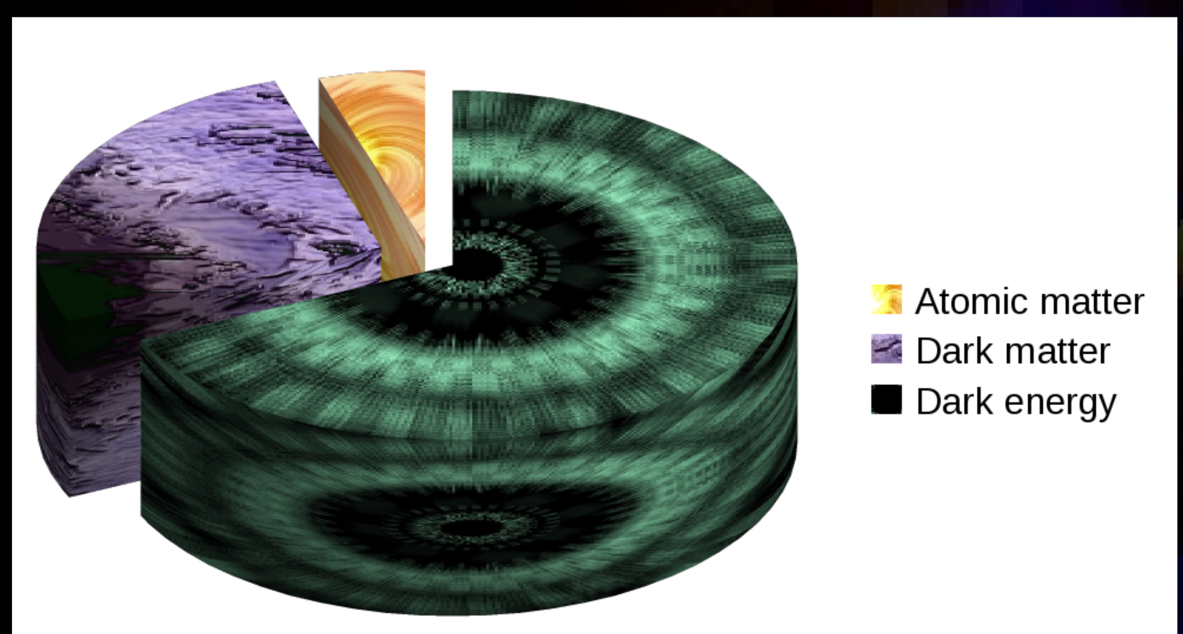

Image 1: The Composition of the universe according to the Standard Model

Cosmological back-reaction

GR is a very complicated theory, so "small-scale" deviations from a uniform universe (e.g. galaxy clusters) might change the expansion rate. The difference between the uniform (see Image 2) and non-uniform (see Image 3) cases is called "back-reaction". Both universes would look the same if you zoom out to very large scales, but their expansion rates might behave differently.

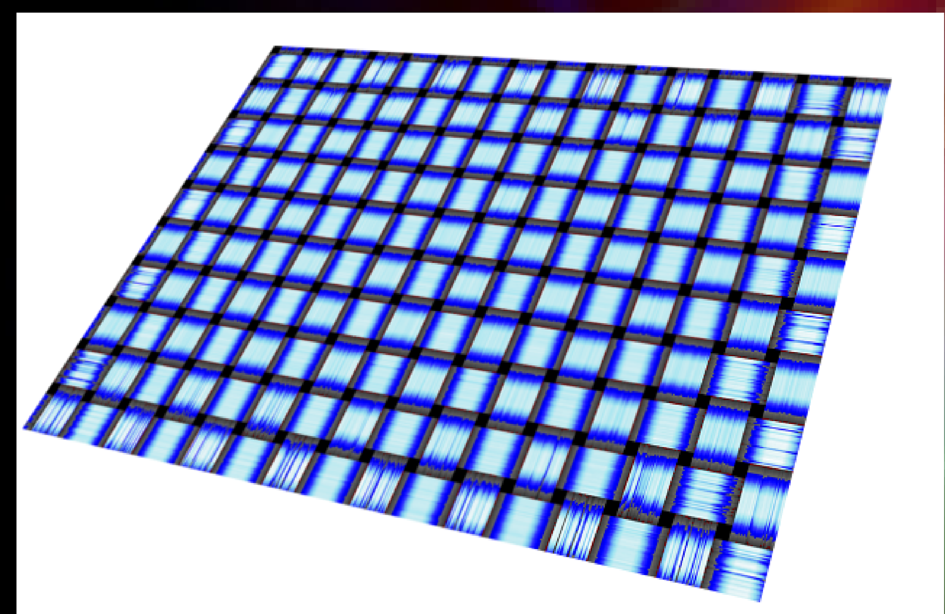

Image 2: Geometry of a uniform universe

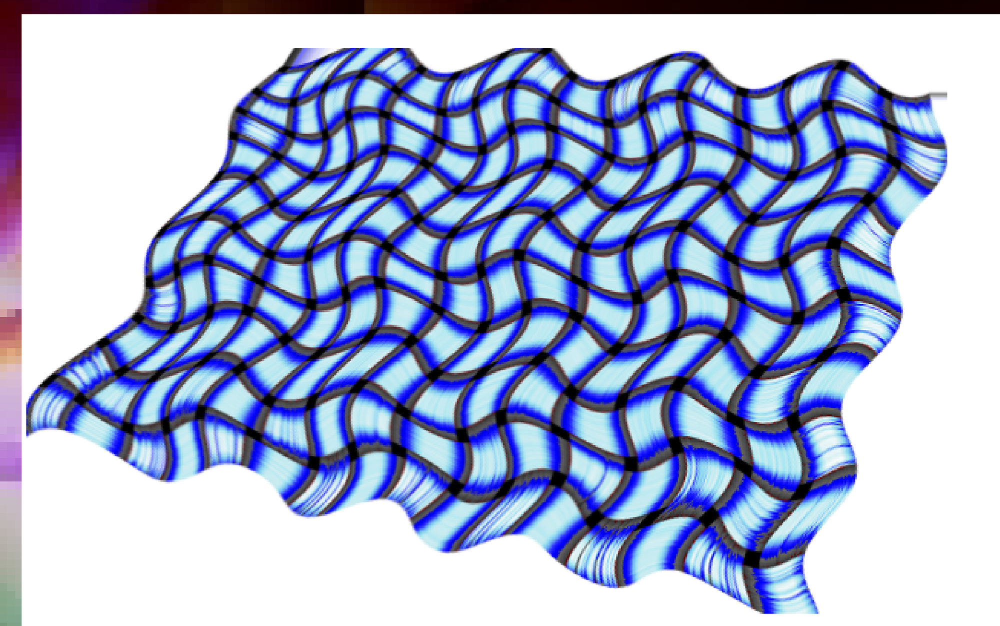

Image 3: Geometry of a non-uniform universe

Modified Gravity

Another way to account for the accelerating expansion of the universe is to suggest changes to GR. My research uses a very simple extension of GR. This extension adds a new length scale to the theory. This then poses new challenges as the theory behaves differently at different length scales. In Image 4, below, the complicated physics of GR and this extension is condensed into one line of mathematics.

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}\left(R + \frac{R^2}{6M^2} - 2\Lambda\right) + \mathcal{L}_{Matter}\right]$$

Image 4: The "action" for GR modified with an R^2 term, M sets the length scale

An explanation for dark energy?

My research develops a mathematical framework for understanding back-reaction with modified gravity. The back-reaction behaves as if it were an extra fluid in the universe. The back-reaction in unmodified GR imitates radiation, such as gravitational waves. The effect of this on the modern universe is negligible.

Together with my supervisor, Tim Morris, I demonstrated that the back-reaction in modified gravity has an extra component that might mimic a positive quantity of dark energy. For this to work, we either require a more complicated gravity model sensitive to large structures in the universe or exotic new physics yet to be discovered at tiny length scales, possibly corresponding to Grand Unified Theories of particle physics, see Image 5.

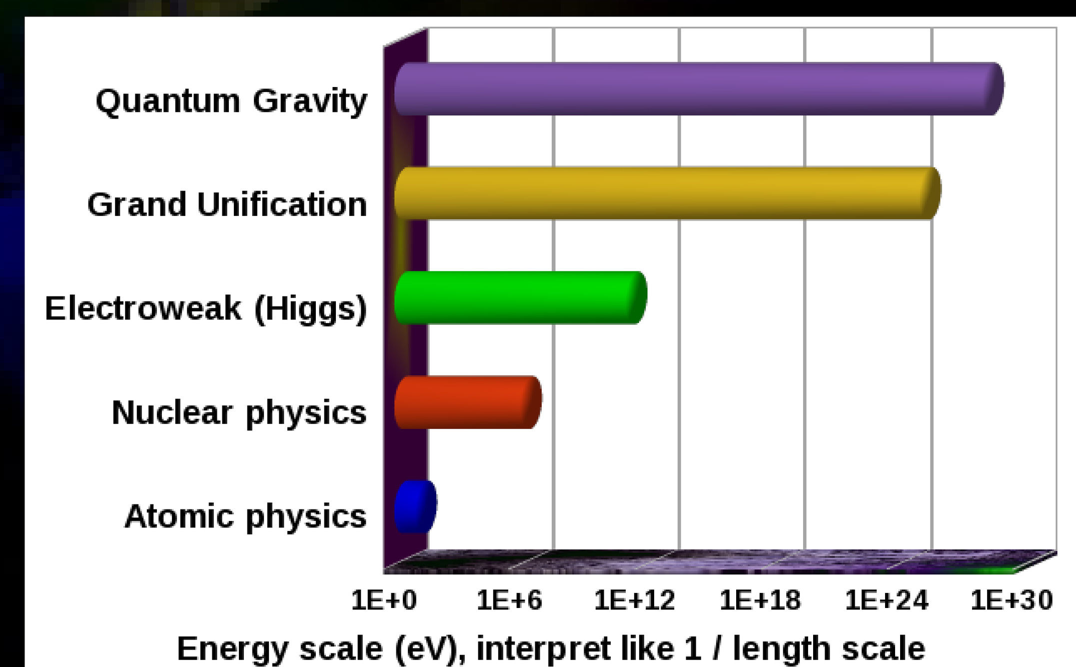

Image 5: Energy scales in particle physics, note logarithmic scale

SHEP Southampton High Energy Physics

SHEP website: http://www.hep.phys.soton.ac.uk/

For technical details, see arXiv: 1406.5398, Journal ref. JCAP09(2014)017

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