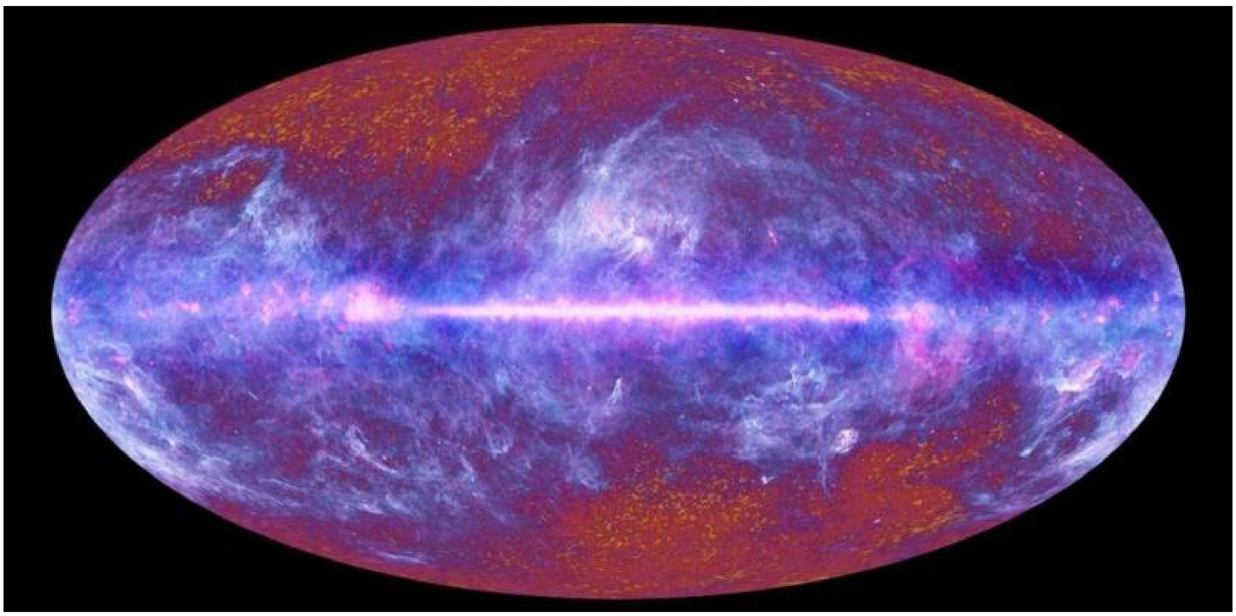
From dark gravity to phantom energy: what's driving the expansion of the universe?

June 7 2016, by Geraint Lewis, University Of Sydney



There are two broad ways to measure the expansion of the universe. One is based on the cosmic microwave background, shown here, along with our own galaxy viewed in microwave wavelengths. Credit: ESA, HFI & LFI consortia (2010)

There is something strange happening in the local universe, with galaxies moving away from each other faster than expected.

What is driving this extra expansion, and what does it mean for the cosmos? To explore this, let's start with the observations.

The rate of cosmic expansion is encapsulated in the "Hubble constant", although don't let the name fool you, as it's not a constant and changes as the universe expands.

To determine this constant, astronomers must relate the distances to galaxies to the velocity they're travelling away from us. But measuring astronomical distances has always proven difficult. This is because we lack convenient signposts, known as standard candles and rulers, to chart the heavens.

So astronomers have built up cosmic distances through a series of steps, using overlapping methods to span the heavens. But each step in this cosmological distance ladder has its own quirks and uncertainties, and extraordinary effort over many decades has been expended to calibrate the various methods.

A new paper has pushed this calibration even harder, using a number of methods to tie down the Hubble constant to an accuracy of 2.4% within a few hundred million light years (which is local by cosmic standards).

A great success! But there's a problem.

We can also determine the universal expansion from observations of the cosmic microwave background, which is the radiation leftover from the Big Bang.

Unlike local observations, this reveals the global expansion of the universe. And this is where the problems begin, as this global expansion is 9% slower than that seen in the local universe. In both measurements, the astronomers have worked hard to reduce the uncertainties, and so are confident this difference is valid.

So what can explain this tension in cosmic measurement? Here are a few of the contenders.

Cosmic contenders

Dark matter

The first potential culprit is dark matter, the dominant *mass* in the universe. We know it is not smoothly spread through space, so perhaps the lumps and bumps, like the galaxies and clusters of galaxies, are exacting less gravitational pull in the local universe.

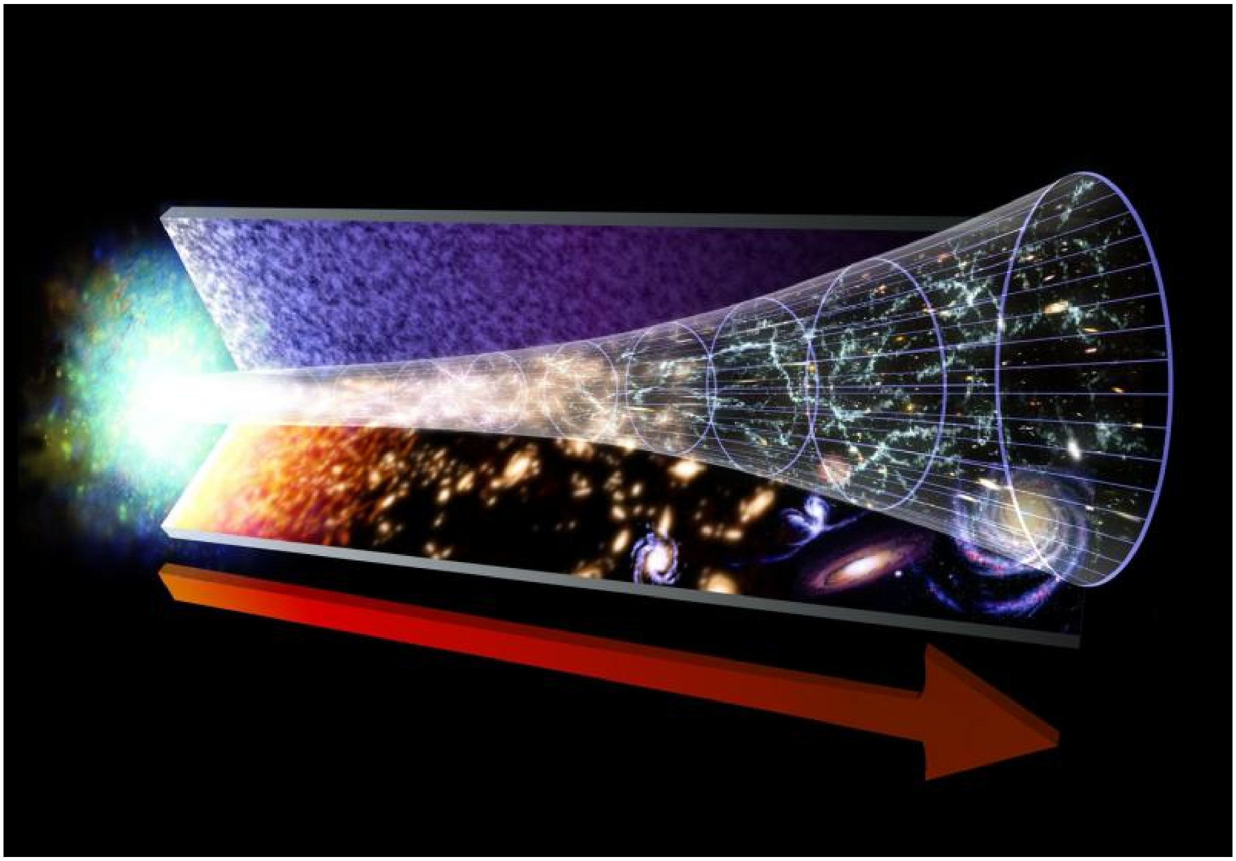
Perhaps we are in a cosmic void, a region whose density is below the universal average.

If this were the case, we would have to be inhabiting a strange corner of the universe, sitting at the centre of immense emptiness not very unlike anything expected in our cosmological ideas.

Dark energy

And then there is dark energy, the dominant *energy* in the universe. This component is responsible for accelerating the cosmic expansion, but is assumed to have a very simple form, eternal and unchanging over all of history.

But what if dark energy is dynamic and evolving, changing its properties as the universe expands? If it changed quite recently (in cosmic terms), the additional expansion could be imprinted on the local universe, but have not yet impacted the global expansion.



A diagram representing the evolution of the universe, starting with the Big Bang to present day. The red arrow marks the flow of time. New research suggests it's expanding even faster than shown here. Credit: NASA/GSFC

If this is the case, the universe has something to worry about, as this new form of dark energy would be a "phantom", driving universal expansion faster and faster into a "big rip", which is more dramatic than it sounds.

Dark radiation

Another potential solution is "dark radiation", which consists of hyper-fast particles that zipped around in the early universe.

While there is no single definition on what constitutes dark radiation, a favoured candidate is a new member of the neutrino family, affectionately known as sterile neutrinos.

While dark radiation is theoretical, there is little observational evidence for its existence. But if it had been present in the early universe, it would have influenced the early expansion of the universe, which would still be imprinted on the global value of the Hubble constant, but would now be washed out of the local value.

Dark gravity

The potential solutions so far have considered modifying the properties of components in the universe, but there is the more drastic alternative: dark gravity.

This suggests that we don't fully understand the fundamental nature of the universe, and that gravity does not follow the rules laid out by Albert Einstein in his general theory of relativity.

Such theories of modified gravity have existed for a long time, and come in many forms, and it is not clear how we deduce the impact of such gravity on the universal expansion.

Dark speculations

So there are several alternatives that could potentially explain the discrepancy between the local and global measurements of the Hubble constant. Which one is correct?

At the moment, the observations are rather raw and do not discriminate between the possibilities. And so we enter the realm of theoretical speculation, where ideas are tried and discarded until viable explanations are discovered.

At the same time, astronomers will seek more data, and will continue to tie down calibrations and methods. This brings us to our final possibility.

No observations are perfect, and much of science is about understanding the uncertainties of measurements. Scientists can generally wrangle random errors and understand how uncertainties in measurement impact uncertainties in results.

But there is another uncertainty: the systematic error, which can strike fear into a researcher. Instead of scattering results, systematic errors shift all results one way or another.

Systematic errors can also influence astronomical distance measures. And if they propagate through the distance ladder, they could potentially shift the local measurement of the Hubble constant away from the global value.

With new data and methods, this tension may evaporate. Some astronomers are already suggesting that this is a "more reasonable explanation".

This article was originally published on The Conversation. *Read the* original article.

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