PLANCK AND THE EXPANDING UNIVERSE

New maps from Planck mission support the theory of cosmic inflation, the idea that at the moment following creation, space expanded faster than the speed of light. **Planck's observations of the Microwave Background Radiation shed light on everything from the evolution of the universe to the nature of dark matter**. In early February 2015, Planck released new maps of the cosmic microwave background supporting the theory of cosmic inflation, the idea that at one stage space expanded faster than the speed of light, growing from smaller than a proton to an enormity that defies comprehension.

From its orbit 1.5 million km above Earth, the Planck satellite spent more than four years detecting the cosmic microwave background – a fossil from the Big Bang that fills every part of the sky and offers a glimpse of what the universe looked like in its infancy.

Inflation – the theory that the early universe expanded incredibly rapidly – makes a number of generic predictions.

- the geometry of the universe should be very close to flat
  - we can now say that the universe is spatially flat to a precision of about half a percent
- there should be evidence of a polarisation pattern in the Microwave Background Radiation
  - precision measurements of this polarisation has eliminated several other models, such as 'String Theory'

Planck mission leader Dr George Efstathiou is the director of the Kavli Institute for Cosmology at the University of Cambridge

We don't yet understand the fundamental physics that drove inflation, and we certainly don't understand the details of how it worked. The simplest model of inflation requires that the early universe contained what's called a scalar field. This field permeates all of space and is responsible for causing space to expand faster than the speed of light. And, as with all quantum fields, it contains quantum fluctuations. It's those tiny quantum fluctuations that, once they were stretched in size during inflation, generated the structure that we see across the Universe today – all of the galaxies and stars and planets. **That's a simple model of inflation.**

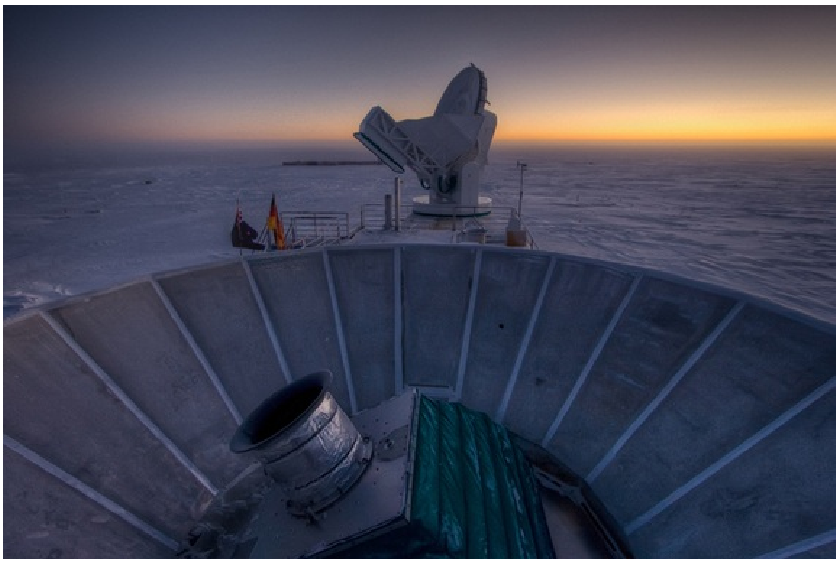
Now, what is that field exactly? We don't know. **There are many theories out there, but really they're all just guesses**. It is really a cartoon of a theory – because we don't understand how inflation works in any fundamental sense. What we need is better experimental data that tells us what the early universe looked like and **hopefully this project will point us toward a sensible theory of inflation.**

Real progress always requires experiments and because the very early universe supposedly involves energy scales so much higher than anything we've been able to test in laboratory experiments here on Earth, that leaves open lots and lots of possibilities. **From the theory point of view, there are just too many options right now**.

Should we detect gravitational waves, which are ripples in the curvature of space-time, that measurement would narrow down the options a lot. It would tell us the energy scale of inflation. **What's more, any detectable level of gravitational waves would establish an empirical link with quantum gravity**. Quantum gravity, which would align the force of gravity with the principles of quantum mechanics, is a very important experimental target, one that is possible to reach with high precision experiments. That would be the most likely experimental development that could actually make contact with physics at the very high energy scales of the early universe.

At the end of inflation, we think that the universe became very, very hot. Since then, as the universe expanded, we presume it cooled down. And when the universe was 400,000 years old, the temperature was low enough that electrons and protons could combine to form neutral hydrogen. **That hydrogen would have absorbed quasar light at short wavelengths and we wouldn't be able to see them in our measurements today**. So, because we can see this light from quasars when the Universe was 840 million years old, we know that the universe was no longer neutral. **Sometime between the Universe being 400,000 years old and 840 million years old, energy must have been injected into the gas to change this**. The question is, where did that energy come from? Well, it must be that stars formed and started to release energy. But the few stars we see at the 420 million year mark couldn't possibly release enough energy to ionize the hydrogen – as was suggested by previous measurements of the cosmic microwave background made with the **Wilkinson Microwave Anisotrophy Probe – or WMAP – satellite.** Now, with the Planck measurements, we're saying that it happened a bit later, at 560 million years. That difference of about 140 million years may not sound like a lot, but it now brings all of our observations into alignment.

In March 2014, the Background Imaging of Cosmic Extragalactic Polarization 2 (BICEP2) experiment, BICEP2 team announced that they had seen evidence of gravitational waves, offering what seemed to be "smoking gun" evidence of inflation.



The Background Imaging of Cosmic Extragalactic Polarization 2 (BICEP2) experiment, shown here in the foreground, studies the cosmic microwave background from the South Pole, where cold, dry air allows for clear observations of the sky. In March 2014, the BICEP2 team announced that they had seen evidence of gravitational waves, offering what seemed to be "smoking gun" evidence of inflation. Although a Planck-BICEP2 joint analysis has since shown that dust in the Milky Way had mimicked the signal expected from gravitational waves, future experiments may yet discover these long-sought waves. Image via Steffen Richter, Harvard University

We are still a long way from understanding dark matter. The leading candidate is a type of particle predicted by supersymmetry. That theory predicts a partner particle for each particle that we already know. But if that theory is true, **supersymmetric particles should appear in collisions at the Large Hadron Collider. So far, they haven't. So dark matter is still unknown.**

Planck has detected no signal of dark matter. Supersymmetry predicts that dark matter particles should occasionally interact with other dark matter particles and produce a flash of energy – a process called annihilation. But we don't see it. That's really not all that surprising. It's easy to hide. So that's something that future cosmic microwave background experiments might be able to see. **But we haven't seen any signs of annihilating dark matter from Planck.**

We have looked also very carefully at neutrinos – tiny, ubiquitous particles we know come in three types. As far as well can tell, there are no other types of neutrinos that could help account for some of the dark matter. People are also still trying to determine the mass of these three neutrinos. We know from other experiments the least mass that these three particles could have. **Planck has now set a limit on the most mass that they could possibly have.** We're narrowing down the options, and will hopefully soon learn their exact mass. Neutrinos are some of the most mysterious particles in the universe, so this would be an important step toward understanding them.

Some theorists have also suggested that dark matter and dark energy could interact in some way. As far as we can tell, dark energy is completely constant – so there's no evidence that it interacts with dark matter. When the BICEP2 team announced their result, the signal they detected was really big. Previous analysis based on the Planck 2013 data had set a limit on how big the signal could be. And BICEP2's measurements were about twice as big as that. So if BICEP2 really had detected gravitational waves, there would need to be some really strange and unexpected physics at work for us to get such different results. **The BICEP2 group have been working on various versions of this experiment for 7 or 8 years. So from the experimental side, the data is beautiful. They clearly detected something.** That something could have been gravitational waves, or it could have been intervening dust that confused their data. The BICEP2 experiment looks at a very small field of view, and Planck's signal to noise is not very big. So we arranged to collaborate. Essentially, we improved the signal to noise on dust by cross-correlating their maps with ours. **That showed that, as of yet, we still have no statistically significant evidence of gravitational waves**. That resolves the conflict with the original Planck results. And, in the big picture, that's a good thing. No really strange physics is needed to reconcile the two experiments.

So now we're in a situation where we have a limit on the size of a gravitational wave signal, and that number is consistent with the Planck results. It doesn't rule out gravitational waves by any means. If you look at the joint analysis, you see that there's plenty of room for gravitational waves to be lurking there, just below the level we've set by combining the BICEP2 and Planck data. If that's true, it shouldn't take a very long time to dig it out. **So there could be a very important development coming**.

AK, from EarthSky Notes