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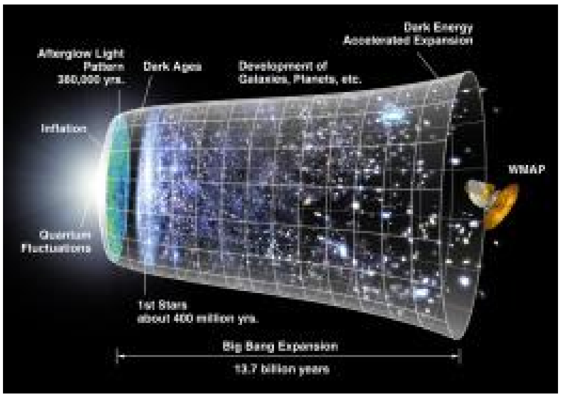
Physicists search for new physics in primordial quantum fluctuations

26 March 2012, by Lisa Zyga



The evolution of the universe from the Big Bang to the present. Quantum fluctuations that arise during inflation develop into the inhomogeneities that lead to the formation of stars and galaxies. Image credit: NASA

(PhysOrg.com) -- Inflation, the brief period that occurred less than a second after the Big Bang, is nearly as difficult to fathom as the Big Bang itself. Physicists calculate that inflation lasted for just a tiny fraction of a second, yet during this time the Universe grew in size by a factor of 10^{78}. Also during this time, a very important thing occurred: fluctuations in the quantum vacuum appeared, which later resulted in the temperature fluctuations in the cosmic microwave background (CMB) that in turn produced large-scale structures such as galaxies. But in a new study, physicists now think that their understanding of the features of primordial quantum fluctuations – also called the inflationary power spectrum – may require a few small corrections due to currently unknown physics. These new corrections could allow scientists to search for experimental evidence to test a variety of quantum gravity theories, including string theory.

Theoretical physicists Mark G. Jackson of the University of Paris-7 Diderot in Paris, France, and Koenraad Schalm of the University of Leiden in Leiden, The Netherlands, have published their study on these possible signatures of new physics in the inflationary power spectrum in a recent issue of Physical Review Letters.

Primordial fluctuations

The physicists' work focuses on the Planck scale, the ultra-high-energy conditions at the time of the Big Bang. Although the universe at this point was almost completely homogeneous, the violent dynamics of inflation produced tiny inhomogeneities from the quantum vacuum. Virtual pairs of particles from the quantum vacuum began popping in and out of existence, some of which could absorb energy and become real. Physicists think that all matter today, from galaxies to living things, originated from these primordial quantum fluctuations. But physicists are even more interested in this era for what it may reveal about quantum gravity.

“The Planck scale is the energy at which the two major theories in physics – gravity and quantum field theory – necessarily combine,” Jackson and Schalm told *PhysOrg.com*. “The resultant theory of quantum gravity is one of the major open problems in physics, though by now there is a lot of evidence that string theory is the answer. In an ideal world one would wish to test this experimentally. Unfortunately, this Planck energy scale is laughably beyond the reach of standard experiments such as particle accelerators: it would be like reaching out your hand to touch the Moon. Fortunately, Nature did once perform an ultra-high-energy experiment possibly capable of probing the Planck scale: the Big Bang. Now while we can't re-do the Big Bang, we can witness its consequences.”

One of the most instrumental methods of detecting the Big Bang's consequences is measuring the CMB radiation – the faint, mostly microwave-frequency background glow that permeates the entire universe. Leftover from the recombination epoch during the early universe when atoms were just beginning to form, the CMB is almost completely uniform, except for some small temperature fluctuations in the radiation that scientists first detected in the early '90s. These temperature fluctuations stem from the primordial quantum fluctuations that occurred during inflation.

The CMB data has enabled scientists to calculate the spectrum of the wavelengths of the primordial quantum fluctuations, providing some of the earliest experimental data of anything. Although the spectrum calculated from observations closely matches the spectrum calculated from current theories, the continuing advance of high-precision experiments could provide an opportunity to observe something new.

“The details of quantum gravity could be encoded in the fluctuations of the quantum field responsible for the rapid inflation of the Universe near the Big Bang,” the physicists wrote. “The primary diagnostic – the power spectrum of these quantum field fluctuations – could contain a wealth of information about high-energy physics taking place during this inflationary period.”

A closer look

By computing universal generic corrections to the inflationary power spectrum, Jackson and Schalm hope to provide a starting point for analyzing a wide variety of new physics theories. The universal corrections are independent of the precise details of any quantum gravity theory or other unknown Planck-scale physics, but future experiments could help narrow down these possibilities. In particular, the upcoming experiments Planck and CMBPol/Inflation Probe, which aim to measure CMB temperature fluctuations with unprecedented sensitivity, might have a shot at detecting the small corrections. If future experiments did observe these corrections, the findings could potentially reveal new physics on the Planck scale.

“We computed exactly what to look for in terms of specific features of the power spectrum,” Jackson and Schalm wrote. “Our hook was that the dominant feature should only depend on the ratio of the scale of inflation to the Planck scale. The significance of our study is that one can now analyze the observational effects of physics theories at energy scales which would have been impossible to study previously. These include quantum gravity theories, such as superstring theory. Complementing the theoretical tools that we have developed is the vast amount of precision cosmological data soon available from the Planck satellite, for example. Researchers will be able to calculate experimental predictions for some model of high-energy physics. If the data turns out to look nothing like the prediction, the model can be ruled out. If it's similar, one can refine the model.”

The physicists describe the corrections as a map, similar to a map a passenger might use to navigate the Paris metro, but in this case the map is to show physicists how to analyze any new physics model they develop. In a sense, it's similar to how the passenger can use a map to get to any destination on the metro line, even if the passenger doesn't yet know where they're going.

“People had studied a few individual models of high-energy modifications during inflation, but the analysis tools were completely specific to that particular model,” Jackson and Schalm wrote. “If one tweaked the model even a little bit, they'd no longer have any idea how to study it. What we've done is to give a map of how to analyze any model. Just take the model, follow some few simple rules and you can calculate anything you please. We give a few simple examples of how to do this, but the tools are not specific to those models. This is why we claim that we have developed the model-independent set of tools to analyze high-energy physics.”

The physicists hope that the new map will prove useful in the future, even if they don't know exactly where they're headed, or what type of high-energy physics may have existed during inflation.

“If experiments indeed find some features in the power spectrum,” they said, “we may not yet understand precisely what physics causes these features, but it will demonstrate that there is some new very high-energy modification to inflation, and this may be a result of quantum gravity.”

More information: Mark G. Jackson and Koenraad Schalm. “Model Independent Signatures of New Physics in the Inflationary Power Spectrum.” PRL 108, 111301 (2012). DOI: 10.1103/PhysRevLett.108.111301

APA citation: Physicists search for new physics in primordial quantum fluctuations (2012, March 26) retrieved 4 December 2020 from https://phys.org/news/2012-03-physicists-physics-primordial-quantum-fluctuations.html