A Challenge to inflationary cosmology

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Why this is important

We propose a general criterion for a cosmological model to be consistent with quantum gravity, a criterion which severely constrains inflationary cosmology.

The emergence of the universe from a hot primordial fireball is now well established through a wide range of observations. On the other hand, the nature of this initial hot dense state remains uncertain. An understanding of this initial state is important in order to explain the origin of the structure which we now observe as anisotropies in the cosmic microwave background, the distribution of galaxies, and much more. In the early 1980s, a possible scenario, the inflationary universe, was proposed. It involves a period of exponential expansion of space during the early stages of the primordial fireball, and quantum fluctuations during that phase lead to the seed inhomogeneities which develop into the structure which we observe today. Inflation has become the standard paradigm of early universe cosmology, in spite of the fact that we do not have a good theory of inflation based on a consistent theoretical framework. Even worse, models of inflation are not internally consistent since the exponential expansion of space leads to the fact that the wavelength of fluctuations which we observe today (e.g. the structure on the scale of galaxies) emerges at early times with a length smaller than the Planck length, a regime where the models break down.

Prof. Brandenberger and his collaborators put forward a general criterion, the `Trans-Planckian Censorship Conjecture" (TCC), which cosmological models consistent with quantum gravity must satisfy. The criterion states no consistent model of fundamental physics can lead to a cosmological model in which waves with an initial wavelength smaller than the Planck length are stretched to become cosmologically visible. This criterion is analogous to Penrose' Cosmic Censorship Hypothesis which postulates that no consistent quantum theory of gravity should have solutions which correspond to black holes with charge greater than the mass. Such black holes would have naked singularities and would prevent us from doing consistent physics. Penrose argued that even though the Einstein equations (which are valid at low energies and curvatures) admit such solutions, these solutions should be inconsistent with a fundamental theory. In analogy to this, we argue that cosmological models in which the ``trans-Planckian" region becomes visible to a late time observer performing cosmological measurements must be inconsistent with fundamental theory.

This criterion severely constrains inflationary models. All simple models of inflation are ruled out, and the surviving ones have inflation occurring at very low energy scales. Like in other early universe scenarios, in inflationary models gravitational waves are generated. Their amplitude is determined by the energy scale of inflation, and models of inflation which obey the TCC thus lead to a vanishingly small amplitude of gravitational waves.

Alternative early universe models such as the String Gas Cosmology' paradigm which Brandenberger and Vafa proposed many years ago and which is well motivated by superstring theory, do not involve a period of accelerated expansion of space in the early universe and hence satisfy the new consistency criterion. Thus, Brandenberger et al's work indicates that from the point of view of fundamental theory (e.g. superstring theory), models of the early universe which do not involve a period of inflation are preferable compared to those which make us of inflation. This shows that a paradigm shift in our understanding of the very early universe is required.