A Beginner's View of the The Ekpyrotic Universe

Steve Mastrianni

Abstract

In 2001, physicists Justin Khoury, Burt Ovrut, Paul Steinhardt, and Neil Turok published "Ekpyrotic universe: colliding branes and the origin of the hot big bang". In that paper, the authors attempt to explain the origin of the universe, not as the result of the proverbial "big bang", but rather as the collision of two membranes or "branes", three-dimensional worlds that exist in a hidden dimension.

In this short paper, we contrast the theory of the ekpyrotic universe to the big bang and accompanying inflationary model of the universe as developed in the 1980's by Steinhardt, Alan Guth, Andre Linde, and Andreas Albrect.

Introduction

The term ekpyrotic comes from the ancient Greeks who used the word to describe the creation of the "world in fire". Steinhardt et al used the word to describe their theory of how they believe the universe was created .

The ekpyrotic universe is an alternative theory to the big bang theory of the creation and expansion of the universe. While the widely accepted "big bang" theory assumes a center, a starting point of high density and high temperature where the universe began, the ekpyrotic universe is believed to have been created as a result of quantum effects caused by the collision of two three dimensional worlds. (Steinhardt).

The underlying concept of the ekpyrotic theory is rooted in quantum mechanics, the interaction between subatomic particles which caused photons to be released. The big bang is based largely on Newtonian physics that are not applicable to the ekpyrotic theory.

Not everyone has bought into the ekpyrotic theory, however. According to Brian Greene, the colliding branes would have to be parallel with each other with an accuracy of better than 10^{-60} on a scale of 10^{30} times greater than the distance between the branes (Kallosh and Linde).

The Big Bang

The so-called big bang was not a bang at all; in fact, it was probably no more than a whimper. It is believed to have taken place in a single space, an area of infinite density and extreme heat. In this state, photons interacted in a reaction that caused the universe to be created. The time it took to create the universe was very small, referred to as the Planck time, 10^{-43} seconds.

Pairs of photons collided to form particle pairs such as electrons and positrons, a process called pair production. According to this theory, the universe began to immediately expand and has continued its expansion over time. The current observable distance to the edge of the universe is approximately 46.5 billion light years (Harrison, 2000)

As the universe continued to expand, the density of the universe decreased, along with the temperature. In accordance with Wien's law, the decrease in temperature should lead to longer wavelengths or redshifts which is exactly what Edward Hubble observed in the late 1920's, and his observations helped bolster the big bang theory.

The theory of the creation and expansion of the universe based on the cosmic singularity has been widely accepted and still remains the prevailing theory among most scientists. Scientific studies and measurements seem to corroborate the big bang theory.

Hubble analyzed the redshift observed from remote galaxies and determined that there was a relationship between the amount of redshift and the distance to those galaxies. He concluded that the galaxies were moving away at a rate of approximately 73 kilometers per second per Megaparsec (Mpc), which is referred to as the Hubble Constant, H_0.The reciprocal of this constant can be used to calculate the approximate age of the universe. The result, about 13billion years, seems to agree with the age of the Earth and solar system as calculated using the isotopic composition of lead in the universe, a result of the decay of Uranium.

In the mid 1960's, scientists discovered that the universe contained background radiation, referred to as the cosmic microwave background radiation, or CMBR. The wavelengths of the CMBR indicate distinct patterns of energy indicative of photons, which have been propagating over billions of years.

The temperature of the CMBR also supports the big bang theory. The universe contains more helium than what could have been generated by stars, so scientists have concluded that the large amount of helium must have been produced as a result of very large thermonuclear reactions, so the universe must have been very hot. The temperature of the CMBR today reflects the calculated expected drop in temperature using Wien's law, which corroborates not only the theory of the big bang, but also the approximate age of the universe.

Certain temperature signatures in the CMBR are also consistent with the type of thermal variations that would be generated by quantum fluctuations of matter that existed in a small space. The fluctuations, which take place at the subatomic level, are more aptly described using quantum mechanics.

One of the problems with the big bang theory is that it doesn't quite fit the outcome we observe today. It does not provide an explanation of why the universe is essentially flat, nor does it provide mechanisms for the creation of stars and galaxies.

The big bang theory did not initially explain why the background radiation is isotropic, which tends to indicate that the universe did not begin with the cosmic singularity. In an attempt to resolve some of this discrepancy, scientists have modified the big bang theory to include a period of very rapid expansion where the universe expanded by a factor of a million trillion trillion times in less than a millionth of a trillionth of a trillionth of a second (Greene). This modification to the big bang theory provided an explanation of the uniformity of the CMBR.

While it is the best theory that scientists have created, some missing pieces cannot be explained away using the big bang model. Supporters of the big bang are constantly tweaking their theories in an attempt to reconcile some of these inconsistencies to fit the big bang model.

The Ekpyrotic Genesis

Burt Ovrut, Paul Steinhardt, and Neil Turok originally presented the ekpyrotic theory at a meeting of the Space Telescope Science Institute in 2001. The authors posited that the universe began not in a state of infinite temperature and density as described by the big bang theory, but in a cold, vacuous state. From this state, the hot universe we know of was born. Expansion continued in the way we understand. The major difference between the ekpyrotic universe and the universe generated by the big bang is in how the universe actually began.

According to the ekpyrotic theory, the universe began as a collision between two adjacent branes. The result was the release of energy in the form of quarks, electrons, and photons. The collision happens everywhere at the same time, so there is no one point of cosmic singularity. The result is a homogeneous universe that has a uniform density and temperature.

During the collision, ripples along the flat geometric surfaces generate fluctuations in the microwave background, which are believed to stimulate the formation of galaxies (Steinhardt).

The fundamental concepts of the ekpyrotic theory are rooted in M-theory, a theory that describes the movement or vibration of one-dimensional strings in a multidimensional space. The ekpyrotic theory is based on unproven ideas in String theory that include an 11-dimensional space, while the big bang inflationary model is based on the well-understood and accepted Quantum Field theory. Despite wide acceptance and support, String theory has not been proven. It has been suggested by the world's leading most prominent physicist Edward Whitten that String theory may require a new mathematical language all its own to describe it.

In the ekpyrotic universe, we would expect to find that the CMBR is isotropic and uniform, the same regardless of position or location. We would also expect to find no gravitational wave effects in the CMBR, nor would we expect to find strong magnetic poles, as the lower temperature of the ekpyrotic universe would likely prevent them from being created.

The existence of very massive magnetic monopoles is a necessary consequence of most unified theories of the strong, electromagnetic, and weak interactions (Longo). These massive monopoles which consist of magnetically charged particles would be present in a universe created by the big bang, but would be absent in a universe created at a lower temperature as massive particles would not be released.

A Bang or a Whisper

While the big bang theory has undergone many years of scrutiny, the concept of the ekpyrotic universe is still relatively new. Although quantum field theory is well understood, the quantum effects that are thought to have generated the ekpyrotic universe have yet to be proven or recreated. Superstring theory is still just a theory, although it is beginning to gain traction. However, only a relatively few years ago we thought the atom was the basic building block of the universe.

Both the big bang and ekpyrotic theories are likely to be debated for many years to come as scientists work to unravel the basic building blocks of the universe. While we don’t know which, if any of the theories are correct, they have given us not only a better understanding of our world, but the motivation to continually push the envelope in an attempt to understand the origin of the universe.

References

Greene, Brian. The Fabric of the Cosmos. New York: Random House, 2004.

Harrison, E.R. Cosmology. Cambridge: Cambridge Universtiy Press, 2000.

Kallosh, Renata and Andrei Linde. "Pyrotechnic Universe." High Energy Physics (2001): 35.

Longo, Michael. "Massive magnetic monopoles: Indirect and direct limits on their number density and flux." Physical Review D (1982).

Steinhardt, Paul. A Brief Introduction to the Ekpyrotic Unverse. n.d. 27 November 2010 <www.princeton.edu/~steinh/npr/>.