

# A Brief Introduction to the Ekpyrotic Universe

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The Ekpyrotic Model of the Universe proposes that our current universe arose from a collision of two three-dimensional worlds (branes) in a space with an extra (fourth) spatial dimension. The proposal is interesting in and of itself, but also because it is the precursor to a more powerful and explanatory theory, the Cyclic Model described in earlier links on this page.

## What is the Big Bang model?

To the public, the model means that the universe began from a single point, underwent an explosion, and has been flying apart ever since.

However, the big bang is not an explosion at all. This is an unfortunate misnomer that cosmologists would like to correct. But the bad name has stuck.

The big bang is the expansion or stretching of space. It is not that things are flying out from a point. Rather, all things are moving away from each other. It is like having an infinite rubber sheet with people sitting on it. Stretch the rubber sheet, and all the people move away from one another. Each thing they are at the center of an explosion. It is an optical illusion - everybody moves away from everybody else and there is no center.

Run the story going back and time and the sheet was more and more unstretched and the people were closer together. When everybody is so close they are on top of one another, that is the beginning of the big bang picture - the cosmic singularity. At that time, the universe has nearly infinite density and temperature.

## Does the new theory contradict the Big Bang model?

Here we must be careful. There are some skeptics who have written "the Big Bang never happened", by which they mean that the universe is not expanding today and it never has been. They say this despite overwhelming evidence in favor of expansion and cooling today and for the last 15 billion years. Our model does nothing to contradict this story. That is, the universe has been expanding for the past 15 billion years.

What our model does is amend the earliest moments of the story. Instead of beginning with nearly infinite temperature and density, the universe began in a very different state - cold and nearly vacuous. The hot expanding universe we know came as a result of collision that brought the universe up to a large but finite temperature and density. The rest of the story is as the Big Bang model would have it, but the beginning is different.

## Why do we need to replace the beginning of the story?

Because the Big bang model, with no amendments, would tend to produce a universe that is highly inhomogeneous, with a warped and curved space, and no natural mechanism for making stars, galaxies and larger scale structures in the universe. Cosmologists have been trying to correct these deficiencies by amending the early history of the universe - within the first billionth billionth billionths of a second or less. One proposal is the "inflationary theory" of the universe, which proposes that the universe began hot and dense, and underwent a period of hyperexpansion. The ekpyrotic model is a new alternative, which is, in many ways, a more radical departure from the Big Bang concept.

## What is the Ekpyrotic proposal?

The model is based on the idea that our hot big bang universe was created from the collision of two three-dimensional worlds moving along a hidden, extra dimension. The two three-dimensional worlds collide and "stick," the kinetic energy in the collision is converted the quarks, electrons, photons, etc., that are confined to

move along three dimensions. The resulting temperature is finite, so the hot big bang phase begins without a singularity. The universe is homogeneous because the collision and initiation of the big bang phase occurs nearly simultaneously everywhere. The energetically preferred geometry for the two worlds is flat, so their collision produces a flat big bang universe. According to Einstein's equations, this means that the total energy density of the Universe is equal to the critical density. Massive magnetic monopoles, which are overabundantly produced in the standard big bang theory, are not produced at all in this scenario because the temperature after collision is far too small to produce any of these massive particles.

Quantum effects cause the incoming three-dimensional world to ripple along the extra-dimension prior to collision so that the collision occurs in some places at slightly different times than others. By the time the collision is complete, the rippling leads to small variations in temperature, which seed temperature fluctuations in the microwave background and the formation of galaxies. We have shown that the spectrum of energy density fluctuations is scale-invariant (the same amplitude on all scales). The production of a scale-invariant spectrum from hyperexpansion was one of the great triumphs of inflationary theory, and here we have repeated the feat using completely different physics.

The building blocks of the ekpyrotic theory are derived from superstring theory. Superstring theory requires extra dimensions for mathematical consistency. In most formulations, 10 dimensions are required. In the mid-1990's, Petr Horava (Rutgers) and Ed Witten (IAS, Princeton) argued that, under certain conditions, an additional dimension opens up over a finite interval. Six dimensions are presumed to be curled up in a microscopic ball, called a Calabi-Yau manifold. The ball is too small to be noticed in everyday experience, and so our universe appears to be a four-dimensional (three space dimensions and one time dimension) surface embedded in a five-dimensional space-time. This five-dimensional theory, called heterotic M-theory, was formulated by Andre Lukas (Sussex), Ovrut and Dan Waldram (Queen Mary Westfield College). According to Horava-Witten and heterotic M-theory, particles are constrained to move on one of the three-dimensional boundaries on either side of the extra dimensional interval. Our visible universe would be one of these boundaries; the other boundary and the intervening space would be hidden because particles and light cannot travel across the intervening space. Only gravity is able to couple matter on one boundary to the other. In addition, there can exist other three-dimensional hypersurfaces in the interval, which lie parallel to the outer boundaries and which can carry energy. These intervening planes are called "branes," short for membranes. The collision that ignites the hot big bang phase of the ekpyrotic model occurs when a three-dimensional brane is attracted to and collides into the boundary corresponding to our visible universe.

### **Where does the term "ekpyrotic" come from?**

The term "ekpyrosis" means "conflagration" in Greek, and refers to an ancient Stoic cosmological model. According to the model, the universe is created in a sudden burst of fire, not unlike the collision between three-dimensional worlds in our model. The current universe evolves from the initial fire.

### **Cautionary note:**

As a final remark, we feel that it is important to realize that inflationary theory is based on quantum field theory, a well-established theoretical framework, and the model has been carefully studied and vetted for twenty years. Our proposal is based on unproven ideas in string theory and is brand new. While we appreciate the enthusiasm and interest with which the paper has been received, we would suggest some patience before promulgating these ideas in order to leave time for us to produce some follow-up papers that introduce additional elements and to allow fellow theorists time for criticism and sober judgment.