Possible Pasts in a Universe of Universes

Is our universe one in an infinite number of pocket universes? Richard Easther plans to apply a new approach to find out.

by JEFF KANIPE

FQXi Awardee: Richard Easther, Yale University — August 24, 2007

One of the most mind boggling concepts ever to emerge from twentieth-century cosmology is the theory of inflation, which asserts that a fractional moment after the Big Bang, the universe expanded exponentially, perhaps at least 10^{30} times. Equally mind-boggling is the theory's prediction that the inflation process may go on forever — in so-called "eternal inflation."

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> - *Richard Easther*

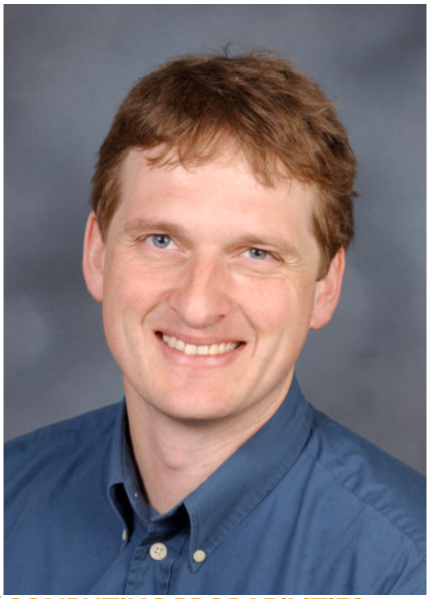
Even more astonishing, however, is the prediction that in an eternally inflating universe, our universe may be only one of an infinite number of separate, or "pocket," universes, residing inside of a "multiverse," a mega-structure vastly more immense than our universe.

The idea of a "multiverse" raises exciting – and disconcerting – issues, says physicist Richard Easther of Yale University. For example, if other pocket universes exist, we are nevertheless limited to only measuring the properties of the pocket universe we inhabit. On the other hand, quantum theory can be applied to explore the probabilities and compute the properties of different pocket universes in an eternally inflating multiverse.

With a $106,594 grant from The Foundational Institute, Easther will do just that, examining "Possible Pasts in the Multiverse," in two distinct but interrelated projects.

Looking In The Pocket

In the first project, Easther and his colleagues Eugene Lim, also of Yale University, and Liam McAllister, of Princeton University, plan to compute the probabilities of the multiverse without resorting to an imposed coordinate system



COMPUTING PROBABILITIES OF MULTIVERSE Richard Easther

Many apparent predictions of eternal inflation depend on an imposed coordinate system, which, says Easther, consists of both the spatial and temporal dimensions of a "slice" of multiverse. "You can slice the universe in different ways, each of which corresponds to a different definition of time," he explains. "It is like slicing a loaf of bread: you can choose to make the cuts on angles or perpendicular. In the case of a bread loaf there is a natural way to do this, but in cosmology there is not necessarily an obvious way of slicing and you don't want your answers to depend on this choice."

Easther's second project is based on the premise that much of the theoretical support for the multiverse comes from the "string landscape" — a complex multidimensional surface defined by the tightly wrapped shapes of the hidden extra dimensions required by string theory. Easther's team hopes to compute the properties of the string landscape from dimensionality, not "stringy" considerations.

"One can argue that any complicated potential would lead to the possibility of many different kinds of pockets," Easther says, "so that this part of the landscape is not something that is special about string theory. However, string theory can make more detailed predictions about the kinds of pockets one might find, and this sort of information would not be uncovered by our approach. We are trying to figure out which aspects of the landscape are explicitly stringy."

Easther, born and educated in New Zealand, has worked in many fields since graduating from the University of Canterbury in 1994, from inflationary models to cosmological implications of string theory. "Richard has a wide range of interests in cosmology and high-energy theory and has produced a significant body of work on the physics of the early universe," says colleague Hiranya Peiris, currently a Hubble Fellow at the Kavli Institute for Cosmological Physics. "He is very interested in testing these theories with data."

Creating a Pocket: It's Harder Than It Sounds

The suggestion that our universe may be one of an infinite number of universes has rich history dating back centuries. However, not until the mid-twentieth century was quantum mechanics applied to the question, and not until recently did physicists consider the idea in terms of eternal inflation.

Previous incarnations of the multiple universe idea were collectively referred to as "bubble universes." Seven years ago, MIT physicist and member of the

FQXi Scientific Advisory Panel, Alan Guth re-dubbed them "pocket" universes, to avoid the suggestion that they are round. ("While bubbles [that] formed in first-order phase transitions are round," he wrote in a 2000 paper, "Inflation and Eternal Inflation" for Physics Reports,* "the local universes [that] formed in eternal new inflation are generally very irregular.")

Today, it is thought that a universe, such as our own, is born into an energy state known as a "false vacuum," called "false" because, unlike the "true" vacuum in which our universe abides, it is unstable. The false vacuum consists of particles with energy density that vary through space: in some regions the energy density is high (peak) and in others it is low (valley), with the lowest region – corresponding to true vacuum – having almost no energy density at all. The overall impression the false vacuum gives is one of a rolling "landscape" – or roller coaster ride.

A universe arises when a region, or field, of the false vacuum decays. Like a roller coaster car perched at the top of a steep, freefall descent, which flattens out to a long, gentle incline and terminates in a shallow, bowl-like hollow, if nudged a little, the car (or field) will rapidly "roll down" (or decay) to a lower energy state, slowing as it traverses the inclined track.

As the region of the false vacuum decays, it also expands (exponentially). Only when the car-field finally oscillates to a stop, in the hollow, is energy released – in an expanding fireball of particles. In eternal inflation, the expansion rate is always faster than the rate of decay. So, once inflation begins, it never ends – and universes are created at an astonishing rate.

Eventually, space will have expanded so much that parts of the remaining primordial false vacuum will have reached the size of the original false vacuum. But they, too, will follow the same course of decaying and inflating into other universes. This process of expansion outrunning decay continues forever, endowing, in Guth's words, "a fractal structure to the universe."

Pocket Full of Discovery

In this fractal multiverse, Easther wants to sample the distribution of hypothetical observers, to determine the probability of finding an observer inside a given pocket, each pocket potentially having different properties. For instance, in one pocket, the electron mass may differ from ours; in another, the electric force may be stronger or weaker than ours.

To make his sampling realistic, Easther will calculate probabilities in an eternal inflating multiverse by using a "worldline measure" of congruent observers. That is, Easther will place hypothetical observers together, switch on the multiverse, and follow the observers' trajectory through space-time to determine which pocket universe they fall into.

"We don't care about the path, just where they end up," Easther says. "The fundamental problem is to determine whether one type of pocket is preferentially produced relative to the others."

Easther's projects promise to provide physicists with a meaningful glimpse at a most profound landscape — the multiverse.

*Physics Reports, 333, 555-574 (August 2000)