DESTINY

If the new cosmology fails, what's the backup plan?

plan B for the Cosmos

BY JOÃO MAGUEIJO

Although cosmic inflation has acquired an aura of invincibility, alternative theories explaining the evolution of the universe continue to attract some interest among cosmologists. The steady state theory, which until the 1960s was widely regarded as the main alternative to the big bang, has been kept alive by a small band of proponents. The pre–big bang theory, a reworking of inflation that has been motivated by string theory, also turns some heads. But the most promising and provocative alternative may be the varying-speed-of-light theory (VSL), which my colleagues and I have been developing for several years. If nothing else, these dissenting views add color and variety to cosmology. They also give expression to a nagging doubt: Could the enthusiasm generated by inflation and its offshoots conceal a monstrous error?

Mainstream cosmological theories such as inflation are based on a crucial assumption: that the speed of light and other fundamental physical parameters have had the same values for all time. (They are, after all, known as constants.) This assumption has forced cosmologists to adopt inflation and all its fantastic implications. And sure enough, experiments show that the presumed constants are not aging dramatically. Yet researchers have probed their values only over the past billion years or so. Postulating their constancy over the entire life of the universe involves a massive extrapolation. Could the presumed constants actually change over time in a big bang universe, as do its temperature and density?

Theorists find that some constants are more agreeable than others to giving up their status. For instance, the gravitational constant, G, and the electron's charge, e, have often been subjected to this theoretical ordeal, causing little scandal or uproar. Indeed, from Paul Dirac's groundbreaking work on varying constants in the 1930s to the latest string theories, dethroning the constancy of G has been exquisitely fashionable. In contrast, the speed of light, c, has remained inviolate. The reason is clear: the constancy of c and its status as a universal speed limit are the foundations of the theory of relativity. And relativity's spell is so strong that the constancy of c is now woven into all the mathematical tools available to the physicist. "Varying c" is not even a swear word; it is simply not present in the vocabulary of physics.

Yet it might behoove cosmologists to expand their vernacular. At the heart of inflation is the so-called horizon problem of big bang cosmology, which stems from a simple fact: at any given time, light—and hence any interaction—can have traveled only a finite distance since the big bang. When the universe was one year old, for example, light could have traveled just one light-

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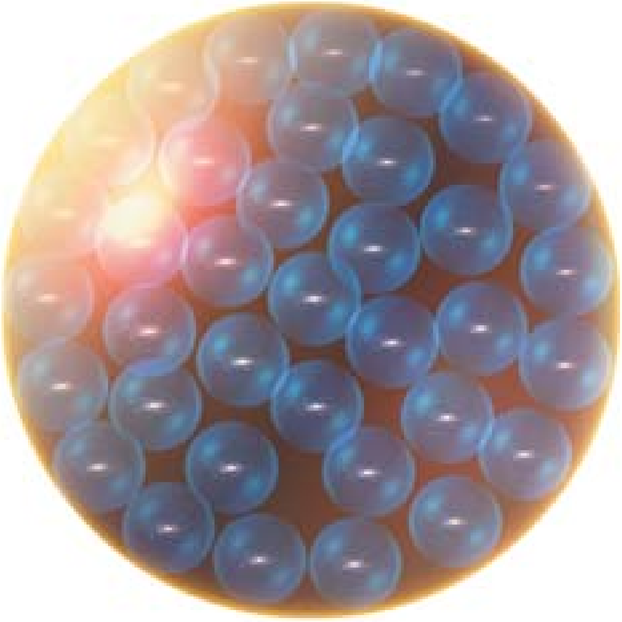

TROUBLE ON THE HORIZON

At the stripling age of one year, the universe was subdivided into isolated pockets, demarcated by "horizons" one light-year in radius (*blue spheres*). Today the horizon is about 15 billion light-years in radius (*red sphere*), so it takes in zillions of these pockets. The odd thing is that despite their initial isolation, all the pockets look pretty much the same. Explaining this mysterious uniformity is the great success of the theory of inflation.

ILLUSTRATIONS BY ALFRED T. KAMAJIAN

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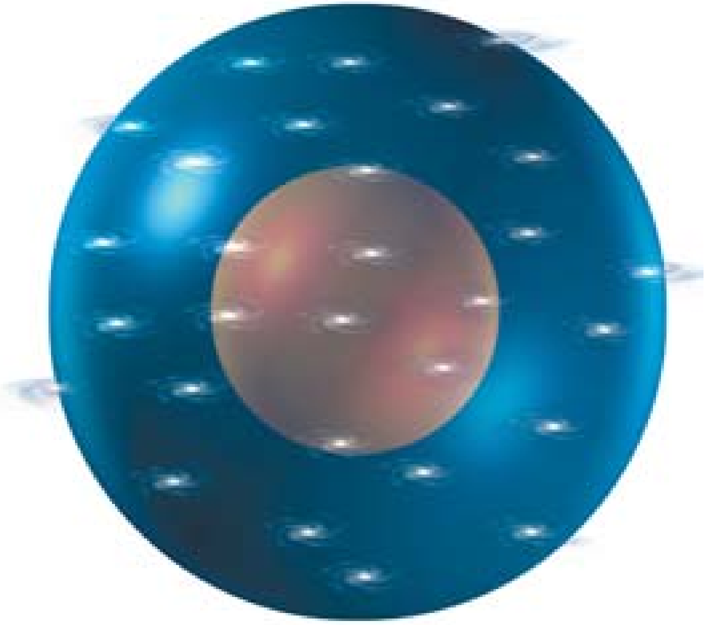
year (roughly). The universe is therefore fragmented into horizons, which demarcate regions that cannot yet see one another.

The shortsightedness of the universe is enormously irritating to cosmologists. It precludes explanations based on physical interactions for puzzles such as why the early universe was so uniform. Within the framework of the standard big bang theory, the uniformity can be explained only by fine-tuning the initial conditions—essentially a recourse to metaphysics.

Inflation cunningly gets around this problem. Its key insight is that for a light wave in an expanding universe, the distance from the starting point is greater than the distance traveled. The reason is that expansion keeps stretching the space already covered. By analogy, consider a driver who travels at 60 kilometers an hour for one hour. The driver has covered 60 kilometers, but if the road itself has elongated in the meantime, the distance from the point of departure is greater than 60 kilometers. Inflationary theory postulates that the early universe expanded so fast that the range of light was phenomenally large. Seemingly disjointed regions could thus have communicated with one another and reached a common temperature and density. When the inflationary expansion ended, these regions began to fall out of touch.

It does not take much thought to realize that the same thing could have been achieved if light simply had traveled faster in the early universe than it does today. Fast light could have stitched together a patchwork of otherwise disconnected regions. These regions could then have homogenized themselves. As the speed of light slowed, those regions would have fallen out of contact.



BROADENING THE HORIZON

Inflation is not the only answer to the horizon problem. Instead maybe conditions in the early universe allowed light to travel faster than its present speed—a billion times faster or more. Zippy light made for bigger pockets (*blue sphere*). As light slowed to its present speed, the horizon shrank (*red sphere*). As a result, we now see just a part of one of the initial pockets, so it is no longer a mystery why the universe looks so uniform.

This was the initial insight that led Andreas C. Albrecht, then at the University of California at Berkeley, John Barrow of the University of Cambridge and me to propose the VSL theory. Contrary to popular belief, our motivation was not to annoy the proponents of inflation. (Indeed, Albrecht is one of the fathers of inflationary theory.) We felt that the successes and shortcomings of inflation would become clearer if an alternative existed, no matter how crude.

Naturally, VSL requires rethinking the foundations and language of physics, and for this reason a number of implementations are possible. What we first proposed was a reckless act of extreme violence against relativity, albeit with the redeeming merit of solving many puzzles besides the flatness problem. For example, our theory accounts for the minuscule yet nonzero value of the cosmological constant in today's universe. The reason is that the vacuum-energy density represented by the cosmological constant depends very strongly on c. A suitable drop in c reduces the otherwise domineering vacuum energy to innocuous levels. In standard theories, on the other hand, the vacuum energy cannot be diluted.

But our formulation is just one possibility, and the urge to reconcile VSL to relativity is motivating much ongoing work. The more cautious implementations of VSL pioneered by John Moffat of the University of Toronto and later by Ian T. Drummond of Cambridge are easier for relativity theorists to swallow. It now appears that the constancy of c is not so essential to relativity after all; the theory can be based on other postulates. Some have pointed out that if the universe is a three-dimensional membrane in a higher-dimensional space, as string theory suggests, the apparent speed of light in our world could vary while the truly fundamental c remains constant. It has also been suggested that a varying speed of light may be part and parcel of any consistent theory of quantum gravity.

Whether nature chose to inflate or to monkey with c can only be decided by experiment. The VSL theory is currently far less developed than inflation, so it has yet to make firm predictions for the cosmic microwave background radiation. On the other hand, some experiments have indicated that the so-called fine structure constant may not be constant. Varying c would explain those findings.

It remains to be seen whether these observations will withstand further scrutiny; meanwhile VSL remains a major theoretical challenge. It distinguishes itself from inflation by plunging deeper into the roots of physics. For now, VSL is far from being mainstream. It is a foray into the wild. SA

MORE TO EXPLORE

Time Varying Speed of Light as a Solution to Cosmological Puzzles. Andreas Albrecht and João Magueijo in *Physical Review D,* Vol. 59, No. 4, Paper No. 043516; February 15, 1999. Preprint available at **xxx.lanl.gov/abs/astro-ph/9811018**

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Lorentz Invariance with an Invariant Energy Scale. João Magueijo and Lee Smolin in *Physical Review Letters,* Vol. 88, No. 19; April 26, 2002.