EARLY UNIVERSE

Cosmologists Celebrate the Death of Defects

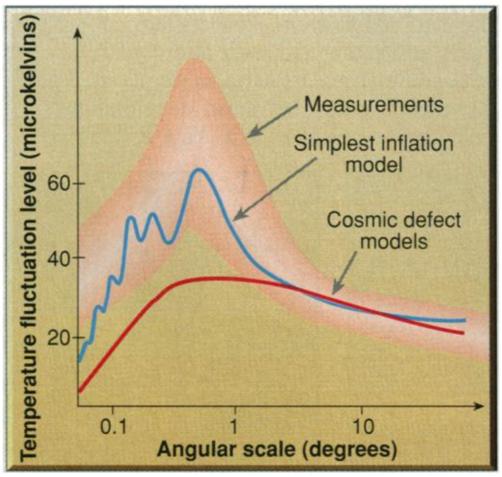
Cosmologists are sounding the death knell for one of the two main theories vying to explain how the universe unfolded in the fraction of a second after the big bang. In a bruising encounter with real data, the cosmological model known as defect theory was itself found to be defective. "A really good candidate for explaining large-scale structure [of the universe] has failed," says Paul Steinhardt of the University of Pennsylvania.

Cosmologists are far from downcast, however. Even champions of defect theory are oddly upbeat about its demise, announced in several recent papers that compared its predictions with measurements of the cosmic microwave background, the radio hiss that reveals the contours of the early universe. "I'm not in the slightest discouraged. I regard this as a great success," says Cambridge University's Neil Turok, the leading proponent of defect theory. The reason? The death of defects heralds a new era in which cosmologists can test their theories against data from new generations of ground- and space-based instruments. "[We] are at the threshold of a golden age of cosmology," says Andreas Albrecht of London's Imperial College. "The demise of the standard defect scenarios is the first great success of this new golden age."

The starting point of modern cosmology is the big bang, the birth of the universe between 10 billion and 20 billion years ago. But theories of the big bang say little about how the universe's largest structures, such as galaxies and clusters of galaxies, came into being. Cosmologists believe these features were seeded by irregularities in the early universe, which are evident in the irregularities of the microwave background. "What created the inhomogeneities in the universe that produced galaxies and large-scale structure?" asks Steinhardt. This, he says, is "a basic puzzle of cosmology."

One possibility is inflation, a brief period of superfast expansion first proposed by Alan Guth of the Massachusetts Institute of Technology in the mid-1980s. The surge of growth, between 10^{-34} and 10^{-32} seconds after the big bang, would have amplified microscopic quantum fluctuations in the infant universe into large density variations. Areas of higher density would then draw in more and more matter and create galaxies.

According to the rival hypothesis, defect theory, the seeds of structure were sown in a transition that took place about 10^{-36} seconds after the big bang, when the observable universe was no bigger than a grapefruit. Until then, nature's fundamental forces had been united in a single force, but as the infant universe cooled from unimaginably high temperatures, they disentangled into the distinct forces seen today. This disentangling took place through a process called symmetry breaking. Defects, misalignments in the fabric of space, "are formed because different regions underwent symmetry breaking in a different manner," says Turok, who in 1989 proposed many of the defect models now in question.



Fatal curves. Defect models do not fit the level of temperature fluctuations seen in measurements of the cosmic microwave background.

Such defects resemble the faults in crystals formed by rapidly freezing a liquid: Particles do not have the time to arrange themselves into a single, faultless crystal, so boundaries form between regions with different alignments. Cosmic defects amount to localized concentrations of energy density, which attract matter: "That would have seeded the origin of galaxies and clusters of galaxies," says Turok.

Now, however, Turok has found fault with his own defect theory, as he reported in the 1 September issue of *Physical Review Letters* (*PRL*). Working with Ue-Li Pen at Harvard College Observatory and Uroš Seljak of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, Turok has found that at least the simpler versions of the theory are in conflict with observations of the microwave background made by NASA's COBE satellite.

The data were collected in the early 1990s, but fashioning a test of the defect theories was not easy. "The defect models are highly nonlinear and notoriously difficult to calculate," says Albrecht. "What we've done is invent a technique which we can use to calculate what the effect of any event happening in the early universe will be on certain observable quantities," explains Turok. The heart of what Princeton University astrophysicist David Spergel calls "an elegant calculation" is a trick for taking a theory of what is fundamentally a random process, the evolution from original defects to large-scale structures, and rewriting it as a sum of a series of nonrandom, ordered, predictable processes.

Turok and his collaborators took the measured fluctuations in the cosmic microwave background, fed them into their new defect-evolution algorithm, which runs on a supercomputer, and used it to predict the distribution of galaxies we see in the universe today. "What we found … is that the level of fluctuations predicted for the galaxy distribution was wrong by about a factor of 2," says Turok. "A factor of 2 discrepancy is regarded as fatal."

Complementary calculations from other groups support that conclusion. In the 6 October *PRL*, Albert Stebbins at Fermi National Accelerator Laboratory near Chicago and his collaborators published a more limited calculation that reaches conclusions Turok calls "qualitatively … very similar to ours." And Albrecht, along with Richard Battye and James Robinson of Imperial College, has done a simplified version of the calculation that also "zeroed in on the predictions which cause defect models the most problems," according to Albrecht. Taken as a whole, the new defect theory results are "a complete, irreconcilable disaster, in my judgment," says Steinhardt. "I think the defect enthusiasts agree."

But the proponents of inflation theory should hold off popping the champagne corks just yet, warns Stebbins. "At the moment, the inflationary theories do a better job of fitting the microwave-background observations and the observations of large-scale structure," says Spergel. But inflation theory has problems of its own. "The simplest inflation model fails by just as much as the simplest defect models do," says Turok, as it predicts more galaxy clustering than is seen, he explains. What gets inflation off the hook is its adjustability.

But for cosmologists, perhaps just as important as the fate of this or that theory is the fact that ideas can now be precisely tested against experiment. "Cosmology is in the midst of an experiment-driven scientific revolution," says Spergel. "A few years ago, theories that deviated from observations by factors of 2 would be considered successful." Now, the demand is for a few percent or better. Says Turok: "We are just on the threshold of getting the data which will test any theory to the limit."

–Andrew Watson

Andrew Watson is a writer in Norwich, U.K.

ILLUSTRATION: L. CARROLL SOURCE: N. TUROK/UNIV. OF CAMBRIDGE