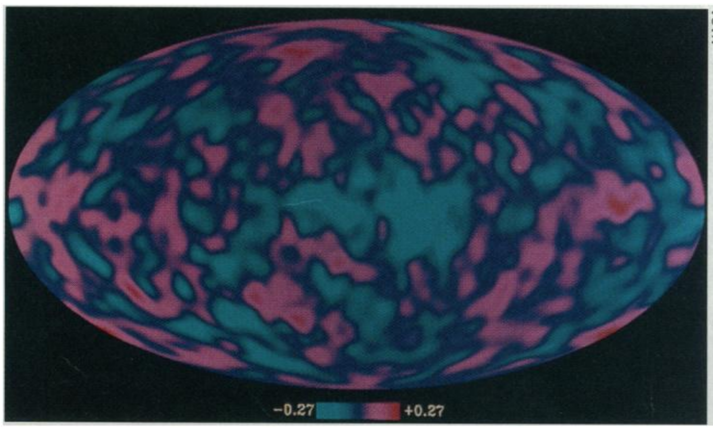
COBE Finds the Bumps in the Big Bang

By taking the temperature of the early universe, researchers working with the Cosmic Background Explorer satellite say they have found the seeds of cosmic structure

Last week, cosmologists suddenly gained a surge of confidence in their ability to understand the first moments of the universe. NASA's Cosmic Background Explorer (COBE) satellite brought back a long-sought piece of the cosmic jigsaw puzzle—faint traces of bumps in the pervasive radiation left over from the Big Bang. Cosmologists think these bumps formed during the universe's first billionth of a second and seeded the formation of galaxies and all other cosmic structures. Providing this extremely subtle finding is borne out, it will not only lend further support to the well-accepted theory of the Big Bang but will also give cosmologists a new handle on what happened next.

"These observations tell us about the universe back to the very beginning," says University of Pennsylvania cosmologist Paul Steinhardt. The discovery, announced at the American Physical Society meeting in Washington, D.C., is already starting a shakeout among the dozens of theories vying to explain how structure was born in the universe. And while it's still too early to declare clear winners and losers, the result supports theories that were already favorites over the long shots.



Cosmic footprints. The texture of the early universe lurks amid pervasive noise, which accounts for most of the patchiness in this image.

For all its monumental impact, this new evidence takes the form of a minuscule effect: subtle hot and cold spots, or to be more exact, cold spots and slightly less cold spots, differing by just one hundred-thousandth of a degree. The spots are embedded in the pervasive bath of cosmic background radiation, which has a spectrum equivalent to a temperature just 3 degrees above absolute zero.

The 1964 discovery of the background radiation itself appeared to clinch the Big Bang theory, which had predicted that the universe would be pervaded by this faint afterglow of the primordial explosion. But in recent years, the background began to pose a major puzzle for cosmologists: the radiation's unexpected evenness. That smoothness was unnerving because the radiation dates from a time in the early universe when the first signs of cosmic structure should have started growing.

Cosmologists say the radiation reflects the condition of space-time when the universe reached its 300,000th birthday. Around that time, they say, a light-trapping sea of charged particles created in the Big Bang combined into the first atoms, for the first time setting radiation free from matter. From then on, the background radiation carried the imprint of the primordial matter-light mix—hotter where the mix had been denser, cooler where it was thinner. "It's our version of a dinosaur footprint," says COBE scientist John Mather.

But it appeared that dinosaur had left an invisible footprint. As of last year, the cosmic background radiation still looked perfectly smooth to COBE's instruments. Theorists were on tenterhooks, because without bumps big enough to leave an impression on the background radiation they couldn't explain how the early universe gave rise to galaxies and clusters of galaxies. And now, as COBE reaches the limits of its precision, the team finally found the long-sought bumps.

The COBE scientists think the patchiness originated as tiny lumps in the newborn universe and expanded from then on. Team leader George Smoot says the spots range over all sizes COBE can see, although even the smallest are far too big to have served as precursors for the greatest observed collections of galaxies. But Smoot says he thinks the smaller spots that seeded the growth of galaxies and clusters should show up soon in other detectors now operating in balloons and at the South Pole.

The new evidence will pare down the dozens of theories of cosmic structure formation that now overpopulate the field, says University of California, Los Angeles, theorist Ned Wright, who is also part of the COBE team. And even if it's too early to choose a winner, one broader theory, an extension of the Big Bang known as inflation, is getting a clear boost. What gratifies Massachusetts Institute of Technology cosmologist Alan Guth, who originated inflationary theory 10 years ago, is that the lumps come in a variety of sizes. Just the day before the COBE announcement, Guth had pointed out in a talk that such a "scale invariant" pattern is one of several key predictions of inflation, which posits a surge of expansion during the universe's first fraction of a second that plumped it up by a factor of 10^{50}.

Any support for inflation also lends support to the cold-dark-matter theory of structure formation, which describes how structures grew around the scale-invariant fluctuations left by inflation. But Steinhardt, who has contributed to both the current version of inflation and the cold-dark-matter theory, says he will be on the edge of his chair during the coming months, watching for confirmation from both additional COBE data and the handful of other cosmic background monitoring experiments. After all, the measured temperature variations are "well below the level of instrumental noise," says Smoot. "You can't point to any one point in the data and say that's signal and that's noise," added Al Kogut of the COBE team in a talk for his fellow scientists. But statistical tests, he says, bear out their finding.

Still, there hasn't been much time to double check a key part of the discovery. Smoot told *Science* that until a month ago, COBE data showed only the largest scale unevenness, something called the quadrupole pattern—two warm and two cold spots. "You have to be careful with that," he says, because it can be caused by other effects, such as the motion of our galaxy through the background radiation. "The real breakthrough came in March," he says, when he decided to subtract out this large-scale effect. "There was something left. And the answer seemed to be scale-invariant fluctuations."

Smoot says he's pretty sure the effect he's seeing is real but adds that there's always a chance it's wrong. "You bet I'm nervous," he says. After devoting 17 years of scanning the cosmic background radiation, though, "I have to have the confidence to come out with this, even though the other experiments don't back me up [yet]. I know I'm going out on a limb."

–Faye Flam