Bathing in the Big Bang, Astronomers Unravel Mysteries of Our Universe

by Marcel Agüeros

First: Birth
On dark, clear nights, the sky is overwhelmingly busy, dotted with stars and split by our galaxy, the Milky Way. It is also incredibly constant. Come back tomorrow night and perhaps a planet will have appeared, moved, or vanished. But the background, the motionless millions upon millions of bright points, stays the same. For generations, observers have had the same thought: surely the universe has always been—endless, unchanging, ageless. No need for a birthday.

Slowly, however, astronomers began to chip away at the apparent constancy of the universe. In the late 1920s, Edwin Hubble, extending earlier observations made by Vesto Slipher, found that all galaxies are moving away from each other, like polka-dots on a balloon as the balloon is inflated. Hubble concluded that, far from being constant, the universe is evolving, expanding.

By the 1950s, some argued it must therefore have a beginning: run the movie backwards, deflate the balloon, and the vastness shrinks until it is tiny and ultra-dense, an unbearably hot soup of matter and light.

Critics laughed. Hubble’s observations were suggestive, but where was the evidence of the universe’s hot birth, which they derisively labeled the “Big Bang”?

Meanwhile, on a hillside in Holmdel, New Jersey, two Bell Telephone Laboratory employees well removed from this debate were at work. Robert Penzias and Arno Wilson built a detector to identify, in order to eliminate, sources of noise in telephone communications.

By 1964, their painstaking measurements had reduced the noise almost completely—but not quite. One source could not be removed, no matter how hard the duo tried. And that source can never be eliminated: Penzias and Wilson had found the fading light of the Big Bang.

Their noise’s existence was predicted by George Gamow, a Big Bang theorist, in 1948. The universe bathes in a uniform, omnipresent, cold haze of only 2.7 degrees C above absolute zero (or -455 degrees F) the cosmic microwave background (CMB).

The early universe, of course, was far hotter, many billions of billions of degrees. In fact, it was so hot and so dense that it was completely opaque, trapping all the light created in the Big Bang. But from its birth, the universe expanded, cooled, and thinned.

After 380,000 years, the universe—roughly 3,000 degrees C (5,400 degrees F) and about one eleventh of its current size—was sufficiently diffuse that light was no longer trapped by matter, and the CMB was released. For 13 billion years this light traveled undisturbed, cooling as the universe continued to expand, until it was captured by Penzias and Wilson’s detector. Astronomers beheld the evidence for the Big Bang.

Forty years later, a million miles from Earth, Penzias and Wilson’s noise is being recorded by the Wilkinson Microwave Anisotropy Probe (WMAP) as it follows our planet around the Sun. The WMAP satellite is the latest in a series of experiments to produce detailed maps of the CMB. With each new data set, the number of Big Bang skeptics is further reduced.

“Our data are so good. If the theory was screwed up just a little bit, the theory wouldn’t fit our data. But the data are fit beautifully,” says Eiichiro Komatsu, a WMAP postdoctoral research fellow at Princeton.

Two views of the Cosmic Microwave Background (CMB) separated by a decade. The Cosmic Background Observer (COBE) mission was the first to report the existence of small temperature fluctuations in the CMB: red areas are slightly warmer than the background, while blue ones are slightly cooler. COBE’s ability to resolve these fluctuations was poor; however, the WMAP data have produced a much more detailed map of the fluctuations (image courtesy NASA/WMAP Science Team).
Five stages in the 13 billion year history of the cosmos:
The top frame is a map of tiny fluctuations in the Cosmic Microwave Background (CMB), the oldest visible light in the universe, as imaged by the Wilkinson Microwave Anisotropy Probe. The faint wisps in the second frame are created as gravity slowly pulls matter into areas where the density is slightly higher than elsewhere in space. In the third frame, 200 million years after the Big Bang, gravity has concentrated matter sufficiently for the first stars to form. In the fourth frame, many more stars have turned on, and bright galaxies are visible where once there were just faint wisps. Finally, the last frame is today’s universe: billions of billions of stars and galaxies, all of which owe their existence to those ancient, small fluctuations in the CMB (images courtesy NASA/WMAP Science Team).

Second: Composition
Look out on that dark night and the sky is a mixture of emptiness and light, of voids and matter. Aristotle claimed he could account for all of this with just four elements: fire, wind, earth, and water. More recently, physicists constructed short tables of fundamental particles: the building blocks for all we see.
And yet: In 1933, Fred Zwicky noticed something bizarre. Zwicky was observing a collection of galaxies orbiting each other, a galaxy cluster. When measuring how fast the galaxies orbited, which is directly related to the mass of the cluster, he found that they were moving faster than they should. In other words, the galaxies had more mass than what he could see.
Numerous observations have confirmed this surprising discovery. Almost all of the matter in the universe is invisible. Even our own Milky Way is dominated by some unknown stuff that does not emit or absorb light: dark matter.
Astronomers and physicists were still adjusting to this revelation when the universe surprised them again. In the last decade, observations of stellar explosions in galaxies—events used to find the distances to these galaxies—have shown that the expansion of the universe detected by Hubble is accelerating. Something is pushing the polka-dots on the balloon apart faster today than a few billion years ago. Dubbed “dark energy,” this something is even more mysterious than dark matter.
The dark matter is perfectly sensible. Everybody’s favorite model of high energy particle physics predicts that there should be some dark matter, and it might even be stable. That’s not a huge mystery. But having a particular value of the dark energy is very peculiar—some value other than zero,” says Ned Wright, a professor of physics and astronomy at the University of California in Los Angeles. “The universe is shaping up in a way that I would’ve found surprising nine years ago.”

WMAP’s maps of the CMB can test the amount that individual components contribute to the mass of the universe. In conjunction with other observations, it found that the dark energy’s contribution is far from zero. Ordinary, visible matter represents a paltry 3 percent of the universe’s mass. Dark matter is a more respectable 24 percent; the rest—73 percent—is made up of dark energy.
The evidence for both dark energy and dark matter is now very strong. We just have no idea about what they are, says Neil Cornish, an assistant professor of physics at Montana State University in Bozeman, who collaborates with the WMAP science team. “We do really live in a very peculiar universe.”

Third: Evolution
The universe born 13.7 billion years ago looked nothing like the universe today. The CMB is smooth to within one part in 100,000, a homogeneity utterly absent in the night sky. The mature universe we see is full of structure: a web of clusters and superclusters of galaxies separated by vast volumes of empty space. Somewhere the CMB must carry the seeds for this structure. Somehow a rich, varied universe must evolve out of a featureless background.
The Cosmic Background Explorer (COBE), launched in 1989, was the first CMB satellite experiment. Along with making the first full sky maps of the CMB, COBE found the first small fluctuations, or anisotropies, in the CMB’s remarkably homogeneous temperature and density.
COBE, however, lacked the sensitivity to find any but the largest anisotropies. “People said ‘Okay, the fluctuations are really there—it’s time to look at the details,’” says Wright, who worked on the COBE mission and is a member of the WMAP team. WMAP is part of an international effort to produce high-resolution maps of the smaller fluctuations.
These anisotropies are the sought-after seeds from which the universe’s structure grew. Where the background had a tiny overdensity of matter, gravity drew in more and more mass to create the first galaxies. Conversely, in places where the density was slightly lower, the dark energy took over, producing the growing voids we see today.
Simulations today use the information about the early universe to try to replicate our observed universe. Someday we may be able, on a computer, to watch tiny fluctuations formed 380,000 years after the Big Bang evolve over 13 billion years into a cluster of galaxies exactly like that observed by Zwicky. Despite its best efforts, the universe will have been domesticated.

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