BOOMERANG CMB FACT SHEET

Looking Far Away Means Looking Back in Time

The cosmic microwave background (CMB) provides us with a view of the early universe. We see astronomical objects as they were in the past because of the time it takes light to travel across space. When we look at the Sun, we see it as it was 8 minutes ago, because it takes light 8 minutes to travel from the Sun to us. It takes light 4 years to reach us from the next nearest star, and 2 million years to reach us from Andromeda, the nearest galaxy. Looking far away in distance is like looking far back in time. When we look at the CMB, we are looking back billions of years, to a time before the first stars and galaxies were formed, when the universe was only a few hundred thousand years old.

The Big Bang Model

The Big Bang model, which states that the universe was once much smaller, hotter and denser in the past, is based on Einstein's theory of general relativity and stands on three key observational pillars:

- ***Expansion of the universe.*** Discovered in 1929, this implies that the universe must have been have been smaller, and thus denser and hotter in the past.
- ***Lightest elements.*** The observed amounts of light chemical elements, such as deuterium, helium, and lithium, could not have formed in stars. These elements were created in the first few minutes, when the entire universe was hot enough for nuclear fusion to occur.
- ***Cosmic Microwave Background (CMB).*** The CMB, which is virtually uniform in all directions, presents a spectrum that cannot be attributed to any source other than a hot, uniform, dense early universe.

Observing the CMB

The CMB, discovered in 1965 as excess noise in a microwave receiver, has a nearly uniform temperature across the entire sky: 2.73 degrees Kelvin above absolute zero. Superimposed on this uniform background are tiny (about 10 parts per million) variations in temperature. This departure from uniformity, called anisotropy, was first observed by the COBE satellite in 1991. The BOOMERANG map of the CMB is over 40 times more detailed than the COBE map.

What Can the CMB Tell Us About the Universe?

Measurements of the CMB directly probe conditions of the early universe and are a powerful tool for examining properties of the universe, including:

- The geometry of the universe
- Whether the universe will expand forever or collapse
- The amount of matter in the universe
- The amount and nature of dark matter and dark energy
- The expansion rate of the universe
- The age of the universe
- The primordial seeds of galaxies and clusters

How the CMB Formed

When the universe was very young, it was much hotter and denser than the center of our Sun. It was an opaque soup of sub-atomic particles and light (photons) colliding with each other. As it expanded, the universe became cooler and less dense.

There were small density variations in the soup from one place to another, which would eventually grow gravitationally to become the galaxies and clusters of galaxies we see around us today. These density variations were extremely weak, but strong enough to affect the temperature of the photons. The more dense regions correspond to hot spots in the CMB and the less dense regions correspond to cold spots in the CMB.

When the universe was roughly 300,000 years old, it had cooled enough that the sub-atomic particles could come together to form atoms. This made the universe transparent; the photons could travel through it without scattering or being absorbed. These photons, which last interacted with matter when the universe was 300,000 years old, form relic radiation which is today called the CMB.

Gravitational collapse, starting when the universe was about 1 billion years old, created large structures, such as galaxies and clusters of galaxies, from the early density variations. Thus the CMB is a link between the hot, smooth early universe and the cool, "lumpy", 10 to 15 billion year old universe of today.

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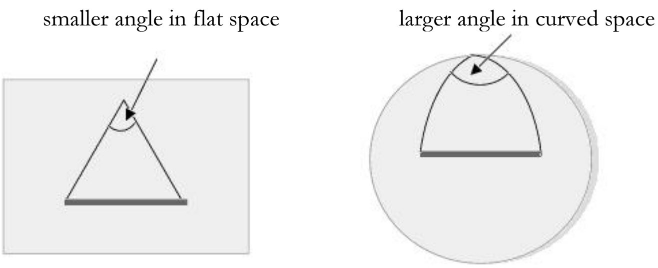
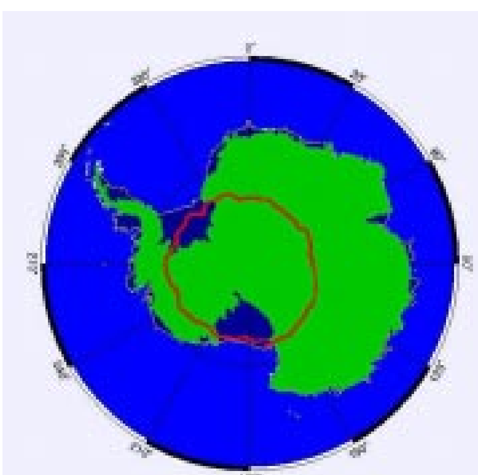
The Shape of the Universe



General relativity tells us that gravity is due to the way mass and energy curve spacetime. If the universe contains enough mass and energy to counteract its expansion, it will eventually collapse. If not, it will expand forever. By measuring the curvature of the universe, we can determine the amount of mass and energy in the universe, and thus its fate.

If spacetime is curved, light travelling to us from the edges of a distant object will follow the curve of spacetime, and it will appear to be a different angular size. In the diagram above, the thick line in the spherically curved space is the same size as the thick line in the flat space, but it spans a wider angle. For the CMB, we can measure the angular size of the hot and cold spots and thus determine the curvature and fate of the universe.



BOOMERANG's 10.5 day journey took it slowly around Antarctica at an altitude of 120,000 feet, riding the stratospheric polar vortex. We tracked its status via satellite link. The payload was dropped on a parachute to a spot about 30 miles from the launch pad, for an easy recovery.

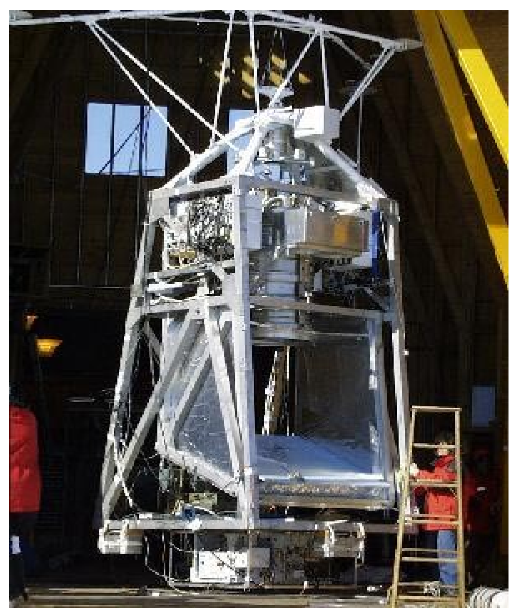
BOOMERANG Overview

BOOMERANG flew around Antarctica, carried by a stratospheric long-duration balloon (LDB). The balloon takes the instrument above most of the atmosphere, which can interfere with our measurements. Our 1998 LDB flight was 10.5 days long, more than 30 times longer than traditional flights flown from North America. The instrument measures the sky at four frequencies to help us separate faint Galactic emissions from the CMB.

Flight: December 29, 1998 - January 9, 1999
Altitude: 37 km (120,000 ft)
Weight: 3100 lbs
Telescope: 1.2 meter primary mirror, off-axis
Thermal: Detectors cryogenically cooled to 0.28K
Detectors: Bolometric array

Frequencies (GHz):	90	150	240	400
Wavelengths (mm):	3	2	1.25	0.75
Resolution (FWHM, deg):	0.30	0.17	0.23	0.22
Number of Channels:	2	6	4	4

Sky Coverage: 1800 square degrees (3% of the sky)



The BOOMERANG gondola, without most of its outer shielding. The cryogenic system containing the detectors is at the center of the gondola, and the primary mirror is near the bottom underneath a protective cover. The gondola hangs from a balloon during flight, and scans back and forth repeatedly over the selected observing field to map the CMB.