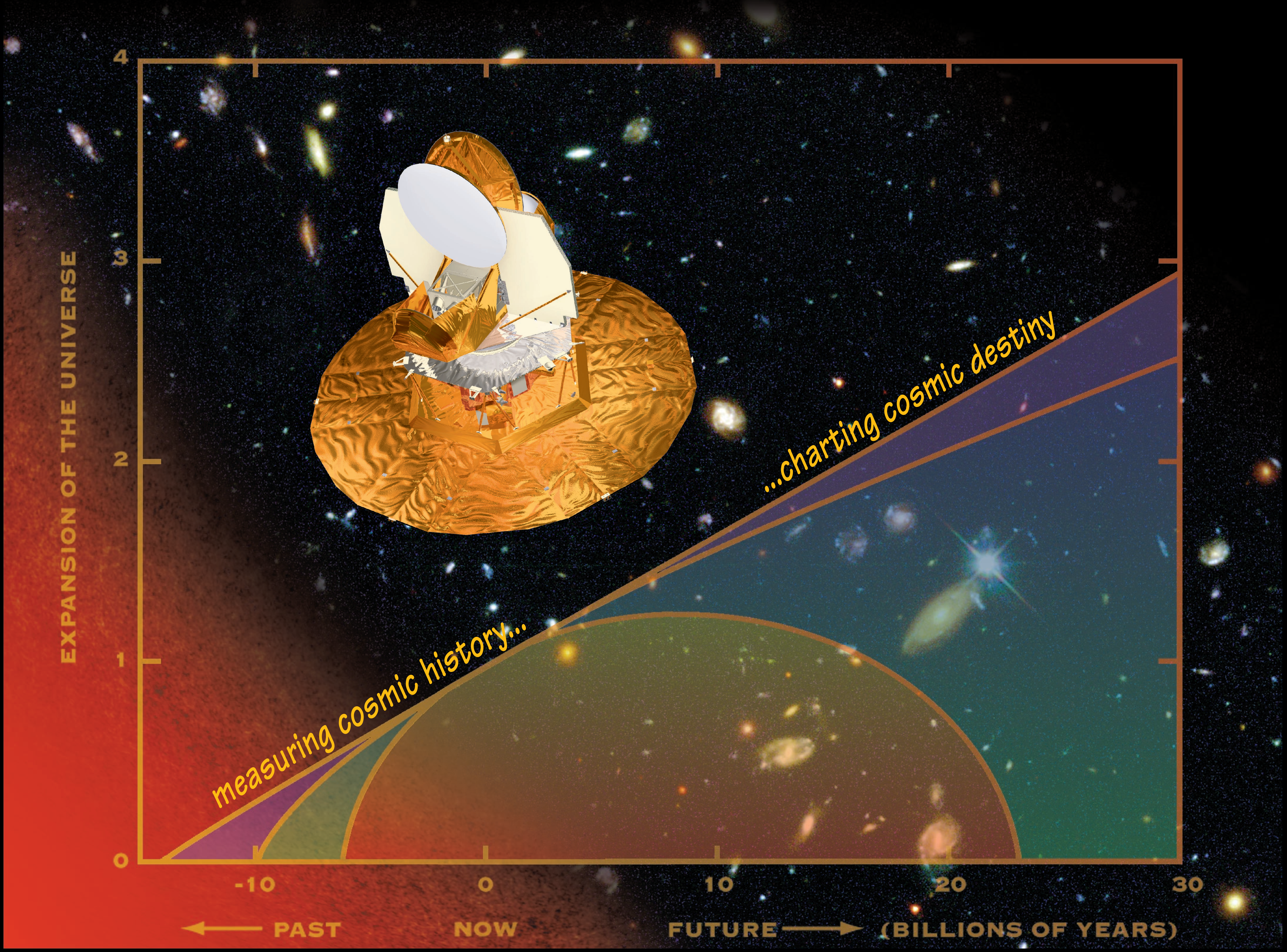
MICROWAVE ANISOTROPY PROBE

MAP



measuring cosmic history...

...charting cosmic destiny

GODDARD SPACE FLIGHT CENTER ◆ PRINCETON UNIVERSITY ◆ UCLA ◆ CHICAGO ◆ UBC ◆ BROWN

Microwave Anisotropy Probe (MAP)

What Questions Does MAP Seek to Answer?

A century of astronomical observation has unveiled a rich structure of galaxies in our present day universe. Recently, NASA's Cosmic Background Explorer (COBE) satellite discovered subtle features in the remarkably uniform early universe that provided clues about the origin of this structure. In spite of this, there are many questions that remain unanswered:

> *Will the universe expand forever, or will it recollapse?*
> *Is the universe dominated by exotic dark matter?*
> *What is the shape of the universe?*
> *How and when did the first galaxies form?*
> *Is the expansion of the universe accelerating?*

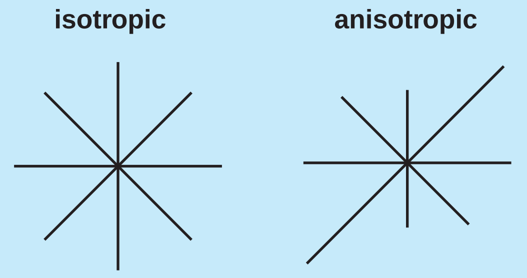
The Microwave Anisotropy Probe (MAP) satellite will produce a much more detailed picture of the early universe than COBE did. This information, which is recorded in the Cosmic Background Radiation, will allow astronomers to address these key cosmological questions.

What is the Cosmic Background Radiation?

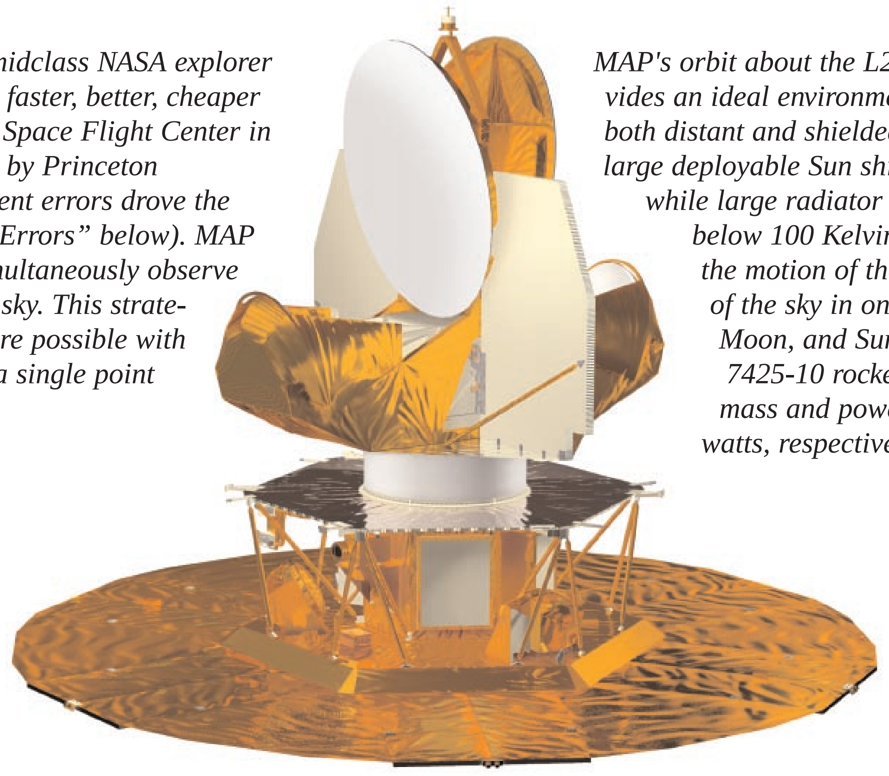
The Big Bang theory is based on Albert Einstein's general theory of relativity and the 1929 discovery that the universe is expanding. This expansion implies the universe was denser and hotter in the distant past, thus it was able to produce the lightest chemical elements such as hydrogen and helium. The Big Bang theory correctly predicts the relative amounts of these light elements. It also predicts that the universe should be bathed in a faint afterglow radiation. This “cosmic background” radiation was discovered as excess microwave static at the Bell Telephone Laboratory in 1965. The Cosmic Background Radiation appears as a glow that is remarkably uniform in all directions in the sky (“isotropic”), though COBE discovered very faint nonuniformities (“anisotropy”) in this glow in 1992.

The early universe was very hot. When the average density of matter in the universe was comparable to air at sea level, its temperature was 2.73 billion degrees! (The average density today is about one proton per cubic meter.) At these temperatures protons and electrons could not bind together to form neutral atoms. The free electrons scattered the Cosmic Background Radiation much as water drops scatter visible light in clouds, so the early universe would appear as a dense fog. As the universe expanded, it cooled. Roughly 400,000 years after the Big Bang, it was cool enough for protons and electrons to combine into neutral hydrogen. Neutral hydrogen is transparent, so the Cosmic Background Radiation has traveled freely through the universe since that time. On a cloudy day, we can look through the air to see the surface of the clouds. Similarly, we can see through the universe out to where it was filled with free electrons and see the “dense fog” that filled the early universe. The reason we can “see” the early universe is that we see objects as they were in the past due to the time it takes light to travel across space. For example, we see the Sun as it existed 8 minutes earlier. We see the “cloud surface” from which the Cosmic Background Radiation was emitted as it was about 13 billion years ago — a view back to 400,000 years after the Big Bang.

anisotropy (an-I-**sah**-tropy) noun — exhibiting properties with different values when measured in different directions. MAP will observe the anisotropy of the Cosmic Background Radiation: differences in its temperature in different directions in the sky.



The Microwave Anisotropy Probe (MAP) *is a midclass NASA explorer (MIDEX) mission — part of a program to provide faster, better, cheaper missions. The observatory is built at the Goddard Space Flight Center in Greenbelt, MD, with key microwave sections built by Princeton University. The reduction of systematic measurement errors drove the MAP design (see “Control of MAP Measurement Errors” below). MAP employs back-to-back Gregorian telescopes to simultaneously observe and compare the temperature in two points of the sky. This strategy allows for more accurate measurements than are possible with an absolute system that measures temperature at a single point on the sky at a time.*



MAP's orbit about the L2 point, ~1 million miles from Earth (see below), provides an ideal environment for observations of this kind: the experiment is both distant and shielded from the relatively hot Earth, Moon, and Sun. A large deployable Sun shield keeps the observatory in continuous shade, while large radiator fins cool the telescope and microwave detectors to below 100 Kelvin (-279 degrees Fahrenheit). From this vantage point the motion of the spacecraft allows the experiment to observe 30% of the sky in only 1 hour, without interference from the Earth, Moon, and Sun. MAP is manifest for a 2001 launch on a Delta II 7425-10 rocket. The nominal mission lifetime is 27 months. MAP’s mass and power consumption are approximately 800 kg and 400 watts, respectively.

Control of MAP Measurement Errors

The scientists and engineers behind MAP are employing several design features to help minimize “random” and “systematic” errors in MAP's measurements, including:

Benign Space Environment

The MAP satellite will orbit near the L2 point, a special point 1 million miles (1.5 million kilometers) beyond the Earth's orbit. This location offers numerous advantages: 1) MAP can observe almost half the sky on a given day while the Sun, Earth, and Moon are well out of view. These bright sources could otherwise easily overwhelm the faint cosmological signal. 2) At L2, the angle between the spacecraft's spin axis and the Sun can be kept constant while avoiding the Earth and Moon. This produces a very stable observatory temperature, which reduces spurious or systematic effects.

Differential Measurements

MAP measures the relative temperature between two points on the sky rather than the absolute temperature. This differential design allows MAP to be highly symmetrical which is a major factor in reducing error (it is analogous to measuring students’ relative heights by placing them back to back rather than comparing each student’s absolute height — see the classroom experiment at right). One way the symmetric differential design of MAP reduces error is the following: If we measured the sky temperature with a single telescope, we would have to correct our measurement for microwave emission coming from the telescope mirror itself. With MAP's back-to-back telescope design, we measure the difference between the brightness seen in one telescope with that seen in the other, so the contaminating emission from the two telescopes approximately cancels in such a measurement. There are many other parts in the detector assembly that give similar cancellations of undesired signals.

Multifrequency Measurements

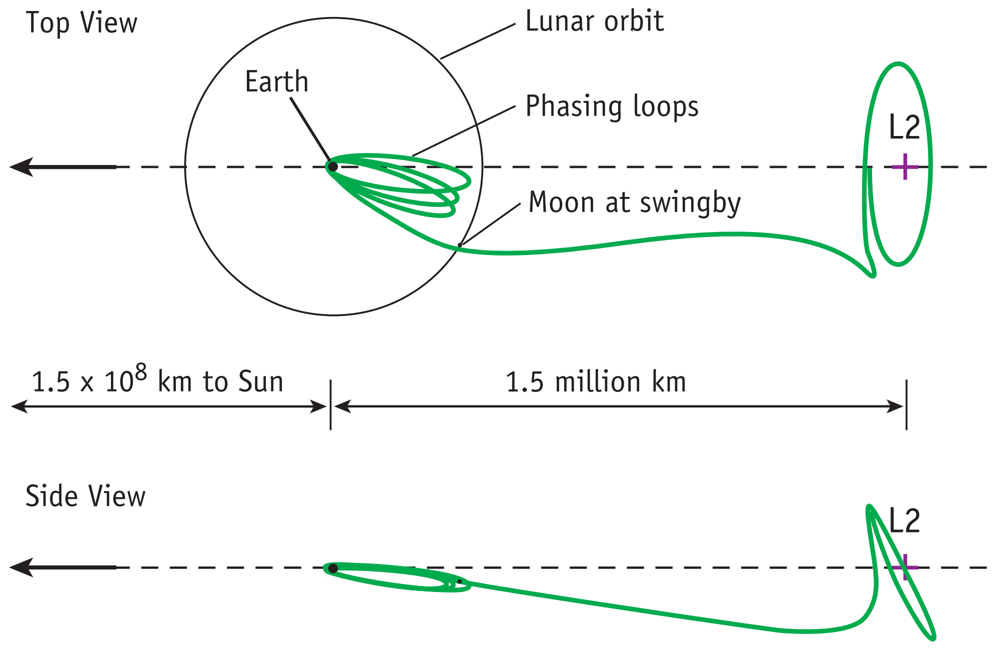
MAP must provide information to help distinguish the Milky Way's microwave emission from the cosmic emission (see the COBE map above). These two sources change in different ways at different frequencies so MAP collects data at five different frequencies in the microwave band (22 GHz, 30 GHz, 40 GHz, 60 GHz, and 90 GHz) to help make the necessary distinction.

Repeated and Rapid Observations of the Sky

Over the course of a year, each pixel in the sky will be reobserved several thousand times, thus reducing the chance that a one-time random error (noise) will contaminate several data points. MAP is also designed to observe a large fraction of the sky every hour before the instrument properties have time to drift. This reduces systematic measurement errors.

MAP Trajectory to L2

The following sketch indicates the path MAP will follow to L2. The trajectory features 3 or 5 lunar phasing loops and a lunar swingby to assist the spacecraft in reaching L2. The cruise time to L2 is approximately 100 days after the lunar phasing loops are completed. Once in orbit about L2, the satellite maintains a Lissajous orbit such that the MAP-Earth line remains between 1 and 10 degrees off the Sun-Earth line to satisfy communications requirements while avoiding eclipses. Station-keeping maneuvers will be required to maintain this orbit.



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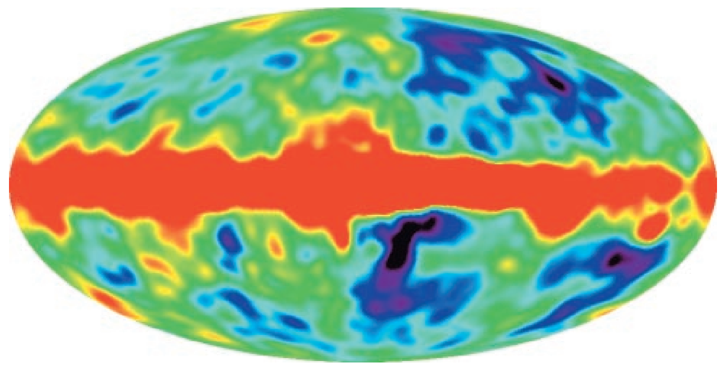
What Will the MAP Results Look Like?

In 1992 NASA's COBE mission detected tiny variations (“anisotropy”) in the intensity, or temperature, of the Cosmic Background Radiation. These temperature variations trace the origin of the large-scale pattern of galaxies we see today.

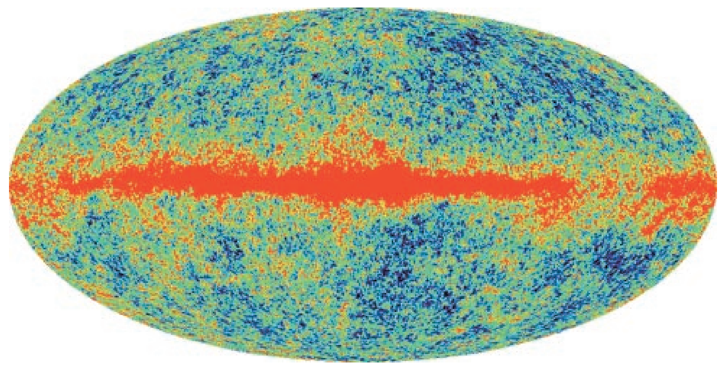
COBE Sky Map

The picture at right is a projection of the Cosmic Background Radiation temperature over the full sky. The average temperature is 2.725 Kelvin (degrees above absolute zero temperature; equivalent to about -270 C or -455 F), and the temperature is remarkably uniform across the sky. The variations seen are tiny: The red regions are 0.0002 degrees warmer than the black regions. These temperature variations are so small that they are like height variations of only 4.65 inches on a mile-high plateau. In addition to the cosmic radiation, emission from our Milky Way galaxy is seen as the red horizontal band across the middle of the map, corresponding to the plate-like disk of our galaxy seen edge on.



Simulated MAP Sky Map

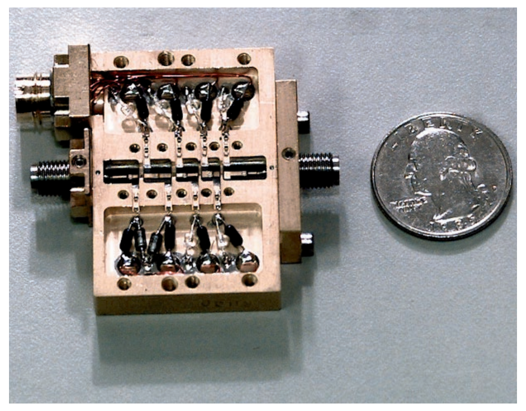
As illustrated to the right, MAP will measure fluctuations in the Cosmic Background Radiation temperature with much better focus than the COBE satellite. The additional information in this highly detailed image will shed light on major scientific questions about the origin, content, and fate of the universe.



New Technology on MAP

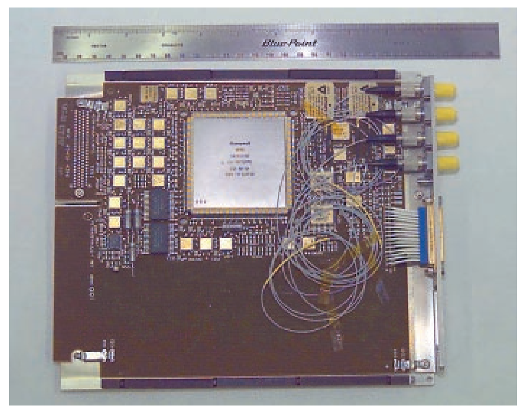
Microwave Radiometer System

MAP employs a state-of-the art microwave radiometer system. At the heart of the system are High Electron Mobility Transistor (HEMT) amplifiers designed and fabricated at the National Radio Astronomy Observatory (NRAO) in Charlottesville, VA. The amplifiers are integrated along with other microwave components at Princeton University into a differential pseudo-correlation radiometer system.



Distributed Architecture

MAP uses a fiber optic bus system to interconnect electronic systems which use newly developed Remote Services Nodes (RSNs). This architecture, developed at the Goddard Space Flight Center, mimics modern computing systems by distributing computer control to each electronics box.

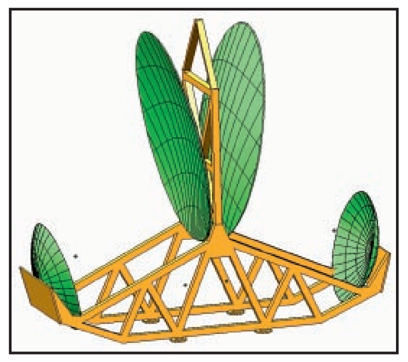


Star Tracker

Lockheed Martin is developing an optical CCD star tracker that MAP will use to determine spacecraft attitude (orientation). The tracker will correct for star streaking due to MAP's constant 2.6 degree/sec scan motion. It is also unique in that it carries its own computer and star catalogue to determine spacecraft attitude autonomously. Previous trackers would relay star positions to the ground or to another spacecraft computer for independent attitude determination.

Composite Materials

MAP is constructed using modern composite materials to achieve a strong and lightweight design. For example, the telescope assembly shown here, consisting of two 1.6 m (63”) primary mirrors, two 0.8 m (31”) secondary mirrors, and supporting structure, would weigh 33% more if constructed from aluminum. This assembly will rest on a cylinder composed of another composite, called gamma-alumina, with very low thermal conductivity to insulate the cold instrument detectors from the rest of the warm spacecraft.



For the Classroom

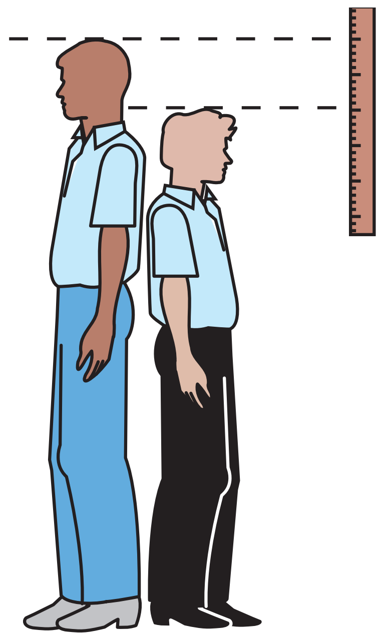
Understanding Measurement Error

In any experiment, two types of errors will inevitably be encountered: systematic errors and random errors. The ability to identify, eliminate, and subtract these types of errors is crucial to obtaining reliable data. MAP is designed to minimize both random and systematic errors. This classroom experiment demonstrates these two types of error.

Take two students of nearly equal height and send them to opposite corners of the classroom. Now, let the other students measure their heights with two different 1-foot rulers. Due to the limitations of the measuring technique, students will make “random errors” in their measurements. By repeating the measurement many times and averaging the result, you can eventually reduce the random error.

If the two rulers were not identical, the measurements would be subject to an even more dangerous type of error,:”systematic error,” because every measurement that you take with that ruler will contain the same error. In fact, you would not even know that your ruler was a source of systematic error until you compared it with a “perfect” ruler. Systematic errors are often much harder to recognize than random errors and can be more harmful to the final result.

To finish, bring the two students together and place them back to back and compare their heights. This is a differential measurement. Differential measurements are often much less prone to systematic errors than “absolute measurements.” As noted at left, MAP is an intrinsically differential instrument to minimize systematic errors.



The Poster Front

The front of the poster depicts MAP observing the Cosmic Background Radiation, shown as the glow in the lower left of the picture. The properties of this radiation should reveal a great deal about the basic nature of our universe, such as whether it will continue to expand forever or eventually cease expanding and recollapse (the upper and lower of the three curves shown, respectively). The radiation should also reveal many clues about how structures of galaxies came to arise out of the nearly smooth conditions that existed when the radiation was emitted.

***Learn more about the MAP satellite by visiting our web page:* http://map.gsfc.nasa.gov/**