A remnant from the beginnings of the Universe

# Perfect Black Body

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**Research on the cosmic microwave background radiation, left behind from the early youth of the Universe, has already earned scientists two Nobel Prizes**

The cosmic background microwave radiation is a relic from the first 300,000 years after the Big Bang, which initiated the evolution of the Universe 14 billion years ago. The Big Bang theory entails three fundamental predictions. Firstly, space should be expanding. Indeed, evidence of that expansion came with Edwin Hubble's great discovery in the 1920s of the red-shift observable in the spectra of galaxies, indicating that they are moving away from one another. Secondly, the atoms in the Universe should predominantly take the form of hydrogen and helium (all heavier ones being just traces). This prediction was likewise borne out by Cecilia Payne Gaposhkin back in the 1930s. The third prediction, posited by George Gamow in the late 1940s, was that the entire Universe is filled with thermal radiation of a temperature several degrees above absolute zero. That radiation is a relict of primordial hot plasma at the beginning of cosmic evolution, in which particles of matter and light were in thermodynamic balance.

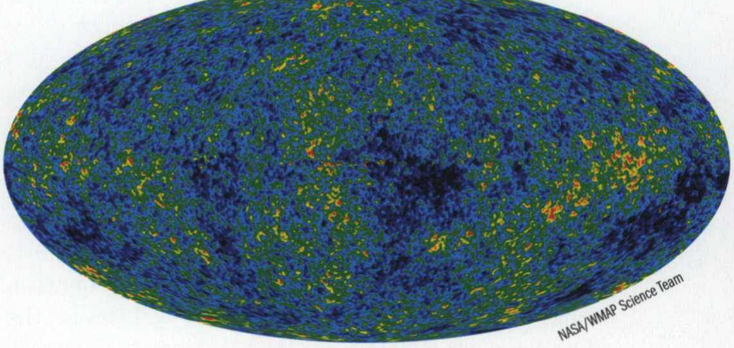
## The oldest light

The matter filling the Universe in the initial moments following the Big Bang was very dense and very hot (at a temperature of a several trillion degrees, more than a million times hotter than the center of the Sun), then the expansion of the Universe caused that matter to become rarer and cooler. Several hundred thousand years after the Big Bang, when the temperature had dropped to around 3000 K, electrons combined with hydrogen and helium nuclei and the Universe became transparent to radiation. Over the 14 billion years that have passed since the Big Bang, that radiation has retained its thermal nature but dropped to 2.7 degrees above absolute zero (approx. -270°C) - a figure which represents the current temperature of our Universe! All of space is filled with this microwave background radiation, every cubic centimeter of space surrounding us containing some 300 photons. The maximum intensity of the radiation is observed at the 1.9 mm wavelength. This is the oldest light in the Cosmos, as it has taken nearly the entire age of the Universe to reach us and is therefore the light coming from the farthest areas we can see.

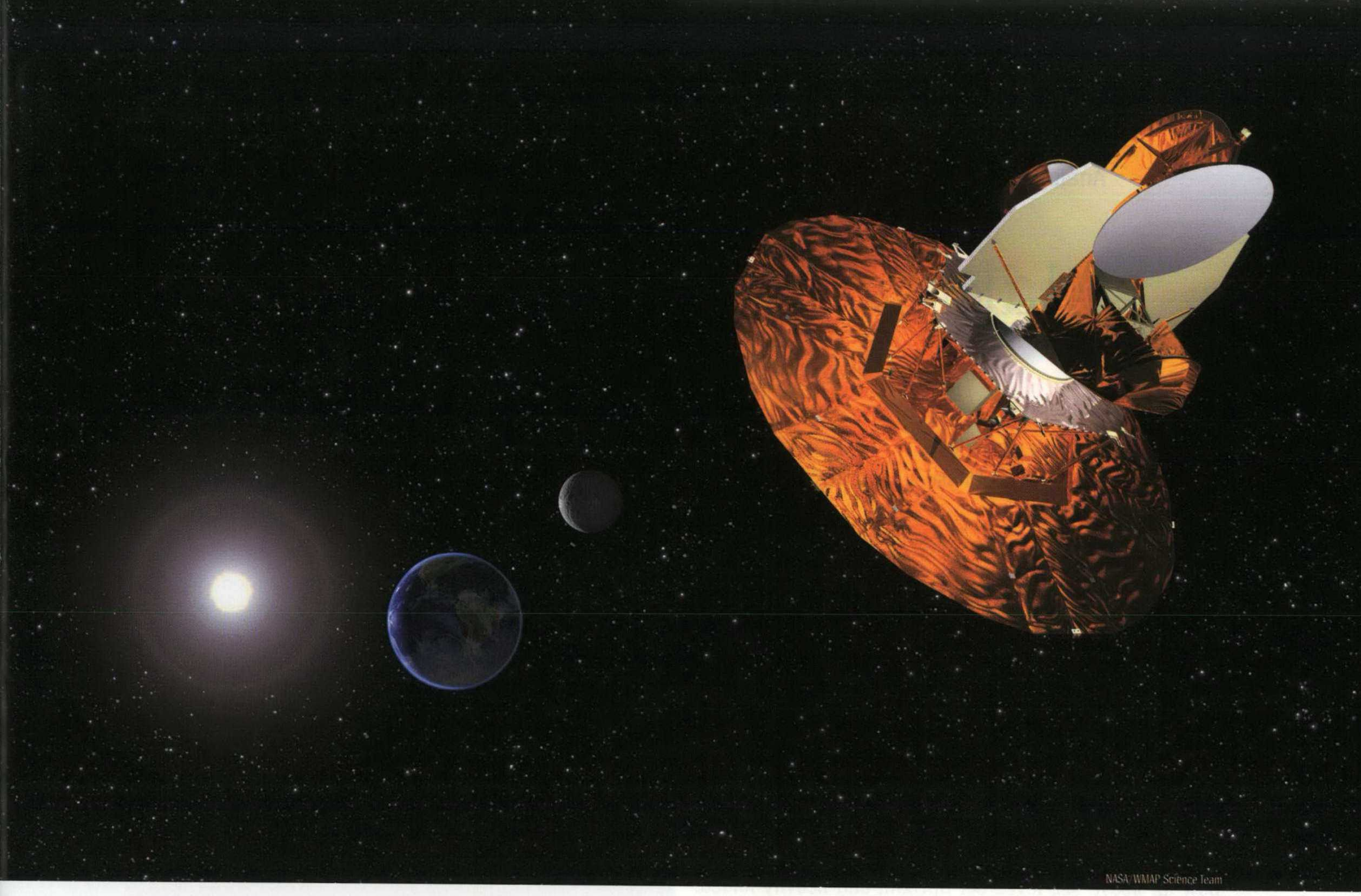
## Cold sky

Penzias and Wilson only ascertained the basic properties of such radiation: its approximate thermal nature and its isotropy - i.e. the fact that radiation of approximately more or less the same intensity reaches us from every direction. In other words, every place in the sky is just as warm (or rather: just as cold!). The map of the sky then observed in the centimeter wavelengths did not evidence any details, as if this photo of the nascent Universe had been taken with a poor camera, using not very sensitive film.

Astronomers spent a quarter of a century trying to tease out details from that photo. And with good reason: such details represent nothing else than a picture of the Universe's oldest structures, or more precisely protostructures - denser or thinner primordial areas within the cosmic plasma, back in the epoch when even galaxies and galaxy clusters had yet to form. These denser areas would later give rise, through gravitational instability, to all the objects in the Universe. Identifying temperature fluctuations in the background radiation would therefore substantiate the hypothesis that cosmic structures were created by gravitational instability. However, Earth-based observations are very difficult and the fluctuations


NASA/WMAP Science Team

**The map of the cosmic microwave background radiation reveals the primordial distribution of hotter and denser areas vs. cooler and emptier areas in the Universe**




**The WMAP probe has measured the temperature of the whole sky to a precision of 20 μK within each pixel of 0.3°. These measurements have enabled us to precisely identify the Universe's age (13.7 billion years) and composition**

sought are very small, representing only one hundred thousandth of a degree.

## Satellite mission

The Earth itself and its atmosphere are very strong sources of microwave radiation, making it hard to catch the signal coming from space. The maximum of the background radiation falls in the infrared range. For many years the Earth's atmosphere prevented researchers from conclusively confirming the thermal nature of that radiation, but things changed with the COBE satellite mission. Data gathered by this probe in the early 1990s led to the publication of the first microwave-range map of the sky illustrating irregularities in temperature distribution. This provided an amazing confirmation of the Big Bang theory and the theory of structure formation (e.g. galaxy formation) in the Universe. At the same time, the thermal nature of the radiation was confirmed with great precision, signaling that we understand correctly the physical processes that have occurred during the evolution of the Cosmos, over the past 14 billion years. The Universe has proven to be the most perfect "black body" we know of, structures really did emerge as a consequence of gravitational instability, and the Cosmos has indeed been subject to steady expansion for nearly 14 billion years. The discovery of the microwave background radiation's anisotropy plus the confirmation of its thermal nature won the 2006 Nobel Prize in physics.

Cosmology is now experiencing a golden age. The first maps of fluctuations in the microwave background radiation, with a resolution of 7 angular degrees, were published just 15 years ago, but now the Wilkinson Microwave Anisotropy Probe (WMAP) satellite operating in orbit is providing maps with a resolution of around 10 angular minutes and also measuring the linear polarization of the microwave background radiation. The European Space Agency plans to launch the Planck probe in 2008, with even greater sensitivity, even better resolution, and the ability to measure circular polarization. Such polarization would have been imparted to the photons by the background of gravitational waves derived from the epoch of "cosmic inflation" or super-fast expansion during the first minute fractions of a second of the Universe's existence; its discovery would offer the first evidence that inflation did take place and enable us to identify at what moment (at what energies) it did. If microwave background radiation photons are found to exhibit circular polarization, we can likely expect a third Nobel Prize to be awarded for the study of this intriguing memento from the Universe's early evolution. ■

**Further reading:**

http://map.gsfc.nasa.gov

http://nobelprize.org/nobel_prizes/physics/laureates/2006/smoot-lecture.html

http://www.wiw.pl/astronomia/1106-kosmologia.asp