

The Nobel Prize in Physics 2006

*The Nobel Prize in Physics for 2006 is awarded to **JOHN C. MATHER** and **GEORGE F. SMOOT** for their discovery of the basic form of the cosmic microwave background radiation as well as its small variations in different directions. The very detailed observations that the Laureates have carried out from the COBE satellite have played a major role in the development of modern cosmology into a precise science.*

From unexpected noise to precision science

The cosmic microwave background radiation was registered for the first time in 1964. Arno Penzias and Robert Wilson (who were awarded the 1978 Nobel Prize in Physics for this discovery) first mistook the radiation for irrelevant noise in their radio receivers (in fact, the cosmic microwave background is part of that “blizzard”-like noise we all receive on our television sets whenever normal transmission is interrupted). However, a theory predicting microwave background had already been developed in the 1940s (by Alpher, Gamow and Herman) and the discovery therefore made an important contribution to the ongoing discussion about the origins of the Universe.

Two competing cosmological theories in particular were on the agenda at this time: either the Universe had been created in an initial Big Bang and then continued to expand, or it had always existed in a Steady State. The Big Bang-scenario actually predicts the existence of microwave background radiation, so the discovery by Penzias and Wilson naturally gave additional credibility to that theory.

The blackbody origin of the Universe

According to the Big Bang-scenario, our Universe developed from a state of intense heat. There are as yet no well-established theories about this primordial condition of the Universe, but immediately afterwards it appears to have been filled with an incredibly intensive radiation. Radiation emitted by such a glowing “body” is distributed between different wavelengths (light colours) in a specific manner, where the shape of the spectrum depends only on the temperature. Without knowing anything about the radiation apart from its temperature it is possible to predict exactly what the spectrum is going to look like. The somewhat contradictory term used to describe this kind of radiation is blackbody radiation. Spectra like these can also be created in a lab, and the German Max Planck – who received the Nobel Prize in Physics for 1918 – was the first to describe their particular shape. Our own sun is in fact a “blackbody”, even though its spectrum is less perfect than that of the cosmic microwave background radiation.

According to the Big Bang scenario, the background radiation gradually cools down as the Universe expands. The original black body shape of the spectrum has however been conserved. At the time when the radiation was emitted, the chaotic mass which was then our Universe was still very hot, around 3000 degrees. The background radiation we measure today has however cooled down significantly, now corresponding to radiation emitted by a body with a tempe-

rature of only 2.7 degrees above absolute zero. This means the wavelengths of the radiation have increased (a rule of thumb for blackbody radiation is that the lower the temperature, the longer the wavelength). That is why the background radiation is now found in the microwave area (visible light has much shorter wavelengths).

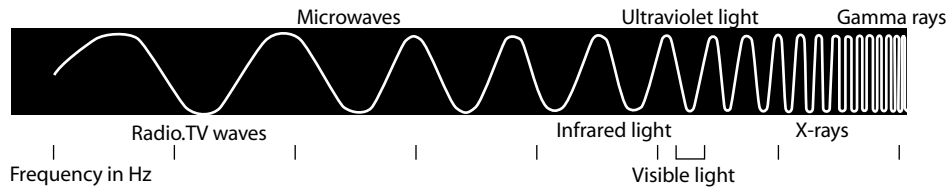


Figure 1

Leaving earth

The first measurements of the cosmic microwave background were made from high mountain summits, rocket probes and balloons. The Earth's atmosphere absorbs much of the radiation, hence the measurements need to be carried out at great altitude. But even at these high altitudes only a small part of the spectrum belonging to the background radiation can actually be measured. A large proportion of the wavelengths included in the spectrum are so efficiently absorbed by air that it is necessary to conduct the measurements outside the Earth's atmosphere. Therefore the first, earthbound measurements (including those made by Penzias and Wilson) never managed to show the blackbody quality of the radiation. This made it difficult to know if the background radiation was really of the type predicted by the Big Bang scenario. In addition, earthbound instruments cannot easily investigate all directions of the Universe, which made it difficult to prove that the radiation was indeed a true background, similar in all directions. Measuring from a satellite solves both these problems – the instruments can be lifted above the atmosphere and measurements can easily be made in all directions.

In 1974 the US Space Administration, NASA, issued an invitation to astronomers and cosmologists to submit proposals for new space-based experiments. This led to the initiation of the COBE-project, the COsmic Background Explorer. **John Mather** was the true driving force behind this gigantic collaboration in which over 1000 individuals (scientists, engineers and others) were involved.

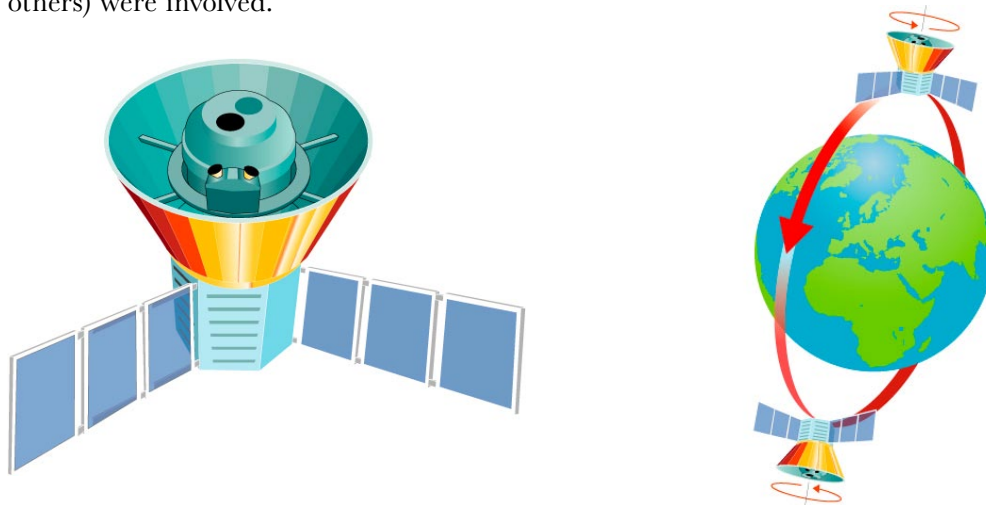


Figure 2. The COBE satellite enabled measurement of the cosmic microwave background in all directions.

John Mather was also in charge of one of the instruments on board, which was used to investigate the blackbody spectrum of the background radiation. **George Smoot** was in charge of the other determinative instrument, which was to look for small variations of the background radiation in different directions.

NASA's original idea was for COBE to be launched into space by one of the space shuttles. However, after the tragic accident in 1986 when the shuttle Challenger exploded with its crew on board, shuttle operations were discontinued for several years. This meant that the future of COBE was in jeopardy. Skilful negotiations finally enabled John Mather and his collaborators to obtain a rocket of their own for COBE, and the satellite was finally launched on November 18, 1989.

The first results arrived after only nine minutes of observations: COBE had registered a perfect blackbody spectrum! When the curve was later shown at a conference in January 1990, it was greeted with standing ovations. The COBE-curve turned out to be one of the most perfect blackbody spectra ever to be measured. (See Fig. 3)

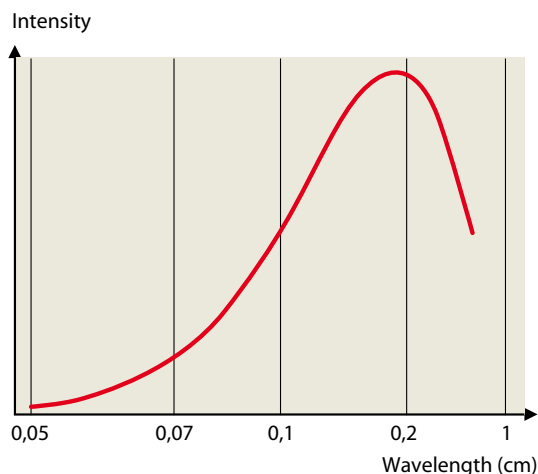


Figure 3. The wavelength distribution of the cosmic microwave background radiation, measured by COBE, corresponds to a perfect blackbody spectrum. The shape of such a spectrum depends only on the temperature of the emitting body. The wavelengths of the microwave background are found in the millimetre range, and this particular spectrum corresponds to a temperature of 2.7 degrees above absolute zero.

The birth of galaxies

But this was only a part of COBE's results. The experiment for which George Smoot was responsible was designed to look for small variations of the microwave background in different directions. Minuscule variations in the temperature of the microwave background in different parts of the universe could provide new clues about how galaxies and stars once appeared; why matter in this way had been concentrated to specific localities in the Universe rather than spreading out as a uniform sludge. Tiny variations in temperature could show where matter had started aggregating. Once this process had started, gravitation would take care of the rest: Matter attracts matter, which leads to stars and galaxies forming. Without a starting mechanism however, neither the Milky Way nor the Sun or the Earth would exist.

The theory that tries to explain how the aggregation of matter is initiated deals with quantum mechanical fluctuations in the Universe during the very first moments of expansion. The same type of quantum mechanical fluctuations result in the constant creation and annihilation of particles of matter and antimatter in what we normally think of as empty space. This however is one of those aspects of physics that cannot readily be understood without using mathematics. Let us therefore simply assert that the variations in temperature measured in

today's Universe are thought to be the result of such quantum fluctuations and that according to the Big Bang theory it is also thanks to these that stars, planets, and finally life could develop. Without them, the matter of which we consist would be found instead in a totally different form, spread out uniformly over the Universe.

Visible and dark matter

When the COBE-experiments were planned, it was first thought that the variation in temperature of the microwave background necessary to explain the appearance of galaxies would be about one thousandth of a degree Centigrade. That is small indeed, but things were to prove even worse: While COBE was still being constructed, other researchers reported that the influence of dark matter (a large proportion of the matter in the universe that we cannot see) meant that the variations in temperature to be sought for would rather be in the range of a hundred-thousandth of a degree. The dark matter in itself is in fact an important agent for the aggregation of matter, which means that the variations in temperature necessary to explain the initiation of this process are even smaller than previously believed.

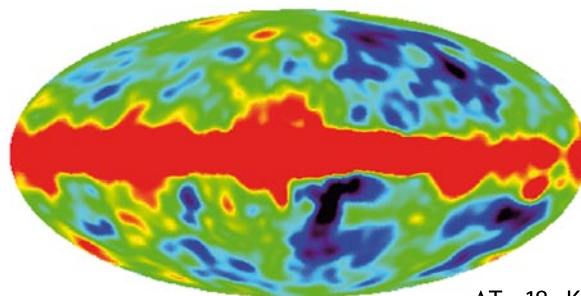
To find such extremely small temperature variations was a great challenge. Even though the instrument was redesigned, the results from COBE became much more uncertain and difficult to interpret than expected. The variations were so small that they were difficult to distinguish from irrelevant noise – so how could one know that they were indeed real? When the results were finally published, in 1992, it turned out however that they could be correlated to ground-based measurements, albeit even more uncertain in themselves than the COBE-measurements. The directions in space in which COBE had registered temperature variations turned out to be exactly the same as those where variations seemed to have been detected from Earth and using balloons.

On April 29, 1992 the English physicist Stephen Hawking said in an interview in *The Times* that the COBE results were “the greatest discovery of the century, if not of all times”.

Speculation becomes precision

On the COBE-satellite the cosmic background radiation was collected in six big funnels, or horns, which constantly swept space in all directions. By using several funnels at once, it was possible to measure in several directions and wavelengths simultaneously, thereby correcting for any temporary disturbances. Each funnel collected radiation from a section of seven degrees of the sky. The temperature of the radiation within this section was then compared to the temperature in the other funnel of a pair, and with the average temperature for the whole sky. In this manner a map of the temperature variations in Space was created (See fig. 4).

Figure 4. A sky-map of the temperature variations-measured by COBE. Red corresponds to higher temperature and blue to lower. The variations are minuscule – in the range of a hundred-thousandth of a degree.



Funnels with smaller angles (which offer better resolution) have been used in later measurements like those conducted by the WMAP, Wilkinson Microwave Anisotropy Probe (named after David Wilkinson, who passed away in 2002 and who for a very long time was an important driving force behind the measurements of background radiation and an inspiration also to the COBE-team).

By comparing the variation in the temperature measured within different angles it is also possible to calculate the relationship between the density of visible matter, dark matter, and (in combination with other measurements) the dark energy of the Universe. The word “dark” in this context means that we cannot see and measure this type of matter or energy. That is why measurements of the variations in temperature become particularly important – they offer an opportunity to indirectly determine the density of this type of matter and energy. Because of this, the COBE-project can also be regarded as the starting point for cosmology as a precision science: For the first time cosmological calculations (like those concerning the relationship between dark matter and ordinary, visible matter) could be compared with data from real measurements. This makes modern cosmology a true science (rather than a kind of philosophical speculation, like earlier cosmology).

In this way, the measurements of COBE and WMAP have also provided the basis for calculations concerning the fundamental shape of the Universe. The conclusion seems to be that the Universe is Euclidian – that is, our everyday geometry which tells us that two parallel lines will never cross each other seems to hold even on the cosmological scale. This is an important result since other geometries can be imagined, although they defy our everyday experience.

An interesting idea – that the Universe inflated very rapidly in its early stages – could explain this finding as well as several others made using the new precision measurements.

The COBE-experiment has also initiated several new areas of investigation within both cosmology and particle physics.

New cosmological measurements aim at an even better understanding of what happened the moments before the background radiation was emitted. Studying the microwave background in even more detail is expected to provide new answers.

In particle physics the goal is to understand what constitutes dark matter. This is one of the tasks of the new LHC (Large Hadron Collider) accelerator, which will soon be in use at CERN, the European centre for nuclear research.

LINKS AND FURTHER READING

The Academy's website, www.kva.se, and <http://nobelprize.org> have more information on this year's Prizes, including a web-TV broadcast of the press conference and advanced information mainly intended for the research community.

Scientific articles:

J. Mather et al. 1990 *Astrophys. J (Letter)* 354, 37

G. Smoot et al. 1992 *Astrophys. J (Letter)* 396,1

R.W. Wilson, 1978 *The Cosmic Microwave Background Radiation, Les Prix Nobel*, p. 113

Books:

Mather, J.C. and Boslough, J. 1996: *the very first light* (BasicBooks 1996)

Smoot, G. and Davidson, K. 1993: *Wrinkles in Time* (Little, Brown and Company, London 1993)

Weinberg, S. 1993: *The First Three Minutes*, 2nd edition (BasicBooks 1988&1993)

Link:

Presentation of COBE project at the NASA web site:

<http://lambda.gsfc.nasa.gov/product/cobe/>

.....

THE LAUREATES

JOHN C. MATHER

Astrophysics Science Division
NASA Goddard Space Flight
Center
Code 665, Observational Cosmol-
ogy
Greenbelt, MD 20771,
USA

[http://universe.gsfc.nasa.gov/staff/
CVs/John.Mather/](http://universe.gsfc.nasa.gov/staff/CVs/John.Mather/)

US citizen. Born 1946 (60). PhD in physics in 1974 from the University of California at Berkeley, CA, USA. Senior Astrophysicist at NASA's Goddard Space Flight Center, Greenbelt, MD, USA.

GEORGE F. SMOOT

Lawrence Berkeley National Laboratory,
1 Cyclotron Road,
Berkeley, CA 94720
USA

<http://aether.lbl.gov/>

US citizen. Born 1945 (61) in Yukon, FL, USA. PhD in Physics in 1970 from MIT, Cambridge, MA, USA. Professor of Physics at the University of California, Berkeley, CA, USA.