CMB Anisotropy Observations

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Outline

- **History of the CMB discovery**
- **CMB anisotropy**
- **Observations**
- **Overview of results and future goals**

References

http://nedwww.ipac.caltech.edu/level5/Kosowsky2/frames.html

http://background.uchicago.edu

What is Cosmic Microwave Background

- Thermal radiation with T_{BB}=2.7 K from entire sky
- Temperature variations $\Delta T/T \sim 10^{-5}$
- No deviations from the BB shape have been detected yet

There should be temperature and polarization fluctuations, which reflect small density and velocity variations in the early Universe

The goal: to constrain the overall properties of the Universe

The reasons: the physical processes at that time were very simple

CMB discovery history

Theoretical prediction: Alpher & Herman (1948) as a by-product of the theory of nucleosynthesis in the early Universe

(5K background with no suggestion of its detectability)

Recognized discovery: A.Penzias & R.Wilson (1965) **Nobel Prize**

Earlier probable detections

1940: A. McKellar (Canada), CN molecules in the ISM at an equilibrium T ~ 2.3 K

1955: E. Le Roux (France), isotropic emission at l=33 cm (all-sky survey) with T=3±2 K

1957: T. Shmaonov (USSR), independent of direction signal at l=3.2 cm with T=4±3 K

Finally: Doroshkevich & Novikov (1964) emphasized the detectability of a microwave blackbody as a basic test of Gamow's Hot Big Bang model

Search for the CMB temperature fluctuations

Initial theoretical estimates (1960's): $\Delta T/T \sim 10^{-2}$ - no detection

Later: $\Delta T/T < 10^{-3}$ - baryonic density fluctuations are not responsible for the structures visible today (e.g., galaxies) → dark matter

Finally (1992): COBE satellite detected fluctuations at a level of $\Delta T/T \sim$ a few of 10^{-5}, which is consistent with the structure formation in inflation-motivated Cold Dark Matter cosmological models

COBE measured temperature ripples at angular scales from 10° to 90°

http://background.uchicago.edu/~whu/beginners/introduction.html

The COBE results were soon confirmed by numerous ground-based and balloon measurements, stimulating the intense theoretical and observational interest in the CMB over the past decade.

Little bit of data analysis technique

http://background.uchicago.edu/~whu/araa/node4.html

Completed missions

Balloon-born **A**nisotropy **M**easurement

(1995-1999)

has a liquid-helium cooled Fourier spectrometer (COBRA), which is capable of identifying non-CMB signals

First flight in 1995 over Texas at an altitude of 41.5 km

5 spectral channels at frequencies 3.7-8.5 cm^{-1}

Observed 2 regions of the sky: 0.7° separated by 3.6 °

Measured $\Delta T/T = 3.1\ 10^{-5}$

Completed missions

South Pole (1993-1994)

Multichannel intensity measurements at ν=26-45 GHz

FWHM = 1°-1.7 ° , coverage 20 ° x 1 °, ΔT=41.2μK for l=68

Cosmic Anisotropy Telescope (1996-2000)

First interferometer to measure fluctuations in the CMB

Frequency range: 13-17 GHz, FWHM ~ 2 °

Temperature sensitivity per pixel in 300^h is 35μK

Showed that the rise of fluctuation power towards scales ~1° were matched by a decline at smaller angles, thus showing the existence of the long-predicted acoustic peak in the CMB power spectrum

http://www.mrao.cam.ac.uk/telescopes/cat

Ongoing missions

Very Small Array (since 2000, Tenerife)

A 14-element radio interferometer operating at ν=26-35 GHz with a resolution of 0.5°

Temperature sensitivity per pixel in 300^h is 7μK

http://www.mrao.cam.ac.uk/telescopes/vsa/index.html

TopHat (2000, South Pole)

A spinning telescope with a bolometer array

Operates from a balloon for 2 weeks

It will map a 48° disk of the sky every day

5 spectral bands from 0.5 to 2 mm, resolution ~0.3 °

http://topweb.gsfc.nasa.gov/

Ongoing missions

Cosmic Background Imager (2000-)

Location: Northern Chile, altitude 5100m

Interferometer with 13 antennas (90cm diameter each)

Resolution: 4′ (*l* up to 3500), Frequency range: 26-36 GHz

The first set of data confirmed what was found at lower *l*:

$\Omega_{\mathbf{total}} \sim 1$, $\Omega_{L} \sim 0.7$, $\Omega_{\mathbf{b}} \sim 0.05$

http://astro.caltech.edu/~tjp/CBI/pictures/cbi-frontview.html

Future missions

Planck Surveyor (ESA, 2003)

1.5-m telescope, 8° field of view

Low Frequency Instrument- 56 detectors (radio receivers at 20 K) split into 4 channels at 30, 44, 70, & 100 GHz

Angular resolution – 10′-33′, ΔT= 4-12 μK

High Frequency Instrument- bolometer array at 0.1 K split into 5 channels from 100 to 857 GHz

Angular resolution – 5′-10′, ΔT/T = (1.7-6670) 10^{-6}

The goal performances exceed requirements

Future missions

Planck Surveyor

Objective: produce full sky maps in 9 channels

Scientific goal: measure CMB anisotropies at all angular scales larger than 10′ with an accuracy set by small scale fluctuations of the foreground emission

http://astro.estec.esa.nl/SA-general/Projects/Planck/science/performance/perf_top.html

Overview of results and future goals

- The CMB temperature anisotropy has been measured at *l* up to a few 10^3

- No CMB polarization has been detected yet

- Future missions need to map the entire sky with a higher resolution and sensitivity
- Theoretical predictions need to be refined
- New data analysis techniques need to be applied