Physics Nobel Prize 2006

Ghanashyam Date

The Institute of Mathematical Sciences, Chennai

http://www.imsc.res.in

shyam@imsc.res.in

Nov 4, 2006.

Organization of the Talk

Organization of the Talk

- Nobel Laureates and the Citation

Organization of the Talk

- Nobel Laureates and the Citation
- Mile Stones in Cosmic Microwave Background (CMB) Observations

Organization of the Talk

- Nobel Laureates and the Citation
- Mile Stones in Cosmic Microwave Background (CMB) Observations
- Main Properties of CMB

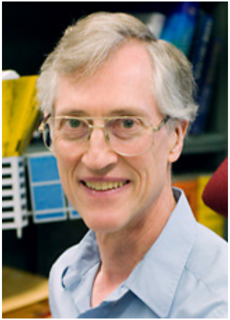
Organization of the Talk

- Nobel Laureates and the Citation
- Mile Stones in Cosmic Microwave Background (CMB) Observations
- Main Properties of CMB
- The Big Bang Model

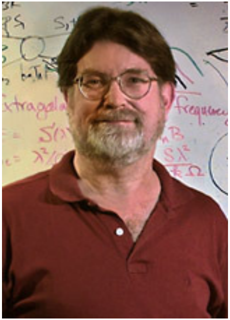
Organization of the Talk

- Nobel Laureates and the Citation
- Mile Stones in Cosmic Microwave Background (CMB) Observations
- Main Properties of CMB
- The Big Bang Model
- Precision Cosmology

The Laureates and The Citation



John C Mather



George F Smoot

For their discovery of black body form and anisotropy of the cosmic microwave background radiation

Mile Stones in CMB Research

Mile Stones in CMB Research

Theoretical Prediction - Gamow (1946) –*forgotten!*

Mile Stones in CMB Research

Theoretical Prediction - Gamow (1946) –*forgotten!*

Accidental Discovery - Penzian-Wilson (1964) – Nobel in 1978.

.

.

Mile Stones in CMB Research

Theoretical Prediction - Gamow (1946) –*forgotten!*

Accidental Discovery - Penzian-Wilson (1964) – Nobel in 1978.

COsmic Background Explorer – conceived in mid 70, launched in 1989 – Nobel in 2006.

.

.

Mile Stones in CMB Research

Theoretical Prediction - Gamow (1946) –*forgotten!*

Accidental Discovery - Penzian-Wilson (1964) – Nobel in 1978.

COsmic Background Explorer – conceived in mid 70, launched in 1989 – Nobel in 2006.

Wilkinson Microwave Anisotropy Probe – launched in 2001 – Precision Cosmology 2003 onwards.

.

Mile Stones in CMB Research

Theoretical Prediction - Gamow (1946) –*forgotten!*

Accidental Discovery - Penzian-Wilson (1964) – Nobel in 1978.

COsmic Background Explorer – conceived in mid 70, launched in 1989 – Nobel in 2006.

Wilkinson Microwave Anisotropy Probe – launched in 2001 – Precision Cosmology 2003 onwards.

Planck Satellite, to be launched in mid 2007, maximum info from CMB.

COBE Experiment

COBE Experiment

Far InfraRed Absolute Spectrophotometer: Measure spectral distribution in the range 0.1 - 10 cm – Mather;

COBE Experiment

Far InfraRed Absolute Spectrophotometer: Measure spectral distribution in the range 0.1 - 10 cm – Mather;

Differential Microwave Radiometer: Measure anisotropies at 3, 6 and 10 mm with angular resolution of 7^0 – Smoot;

COBE Experiment

Far InfraRed Absolute Spectrophotometer: Measure spectral distribution in the range 0.1 - 10 cm – Mather;

Differential Microwave Radiometer: Measure anisotropies at 3, 6 and 10 mm with angular resolution of 7^0 – Smoot;

Diffuse InfraRed Background Experiment: Measure infrared background radiation due to early infrared galaxies and very cold dust – Mike Hauser;

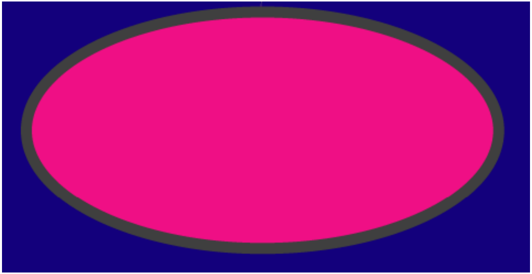
Three Key Properties of CMB

Three Key Properties of CMB

It is Isotropic;

Three Key Properties of CMB

It is Isotropic;



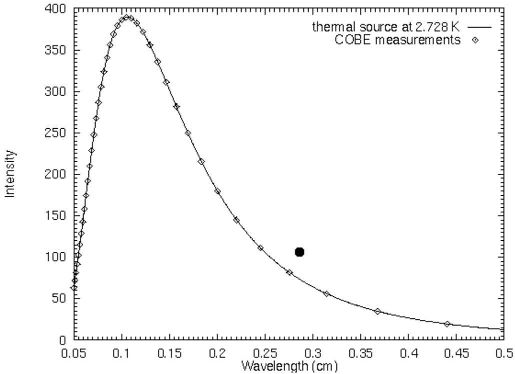
Three Key Properties of CMB . . .

Three Key Properties of CMB . . .

Its frequency distribution is that of a Black Body Form with Temperature of 2.73^o K;

Three Key Properties of CMB . . .

Its frequency distribution is that of a Black Body Form with Temperature of 2.73^o K;



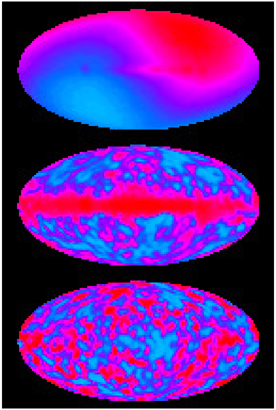
Three Key Properties of CMB . . .

Three Key Properties of CMB ...

There are Anisotropies at the level of 1 part in 10^5.

Three Key Properties of CMB . . .

There are Anisotropies at the level of 1 part in 10^5.



From Physics Today Cover.

Who Established What

Who Established What

The Isotropy was established by Penzias and Wilson;

Who Established What

The Isotropy was established by Penzias and Wilson;

The Black Body Spectrum was established by Mather (COBE);

Who Established What

The Isotropy was established by Penzias and Wilson;

The Black Body Spectrum was established by Mather (COBE);

The Anisotropies were established by Smoot (COBE);

Who Established What

The Isotropy was established by Penzias and Wilson;

The Black Body Spectrum was established by Mather (COBE);

The Anisotropies were established by Smoot (COBE);

The Anisotropies in Polarization were established by the WMAP experiment;

Who Established What

The Isotropy was established by Penzias and Wilson;

The Black Body Spectrum was established by Mather (COBE);

The Anisotropies were established by Smoot (COBE);

The Anisotropies in Polarization were established by the WMAP experiment;

There were other experiments which also contributed to these discoveries but by themselves were inconclusive.

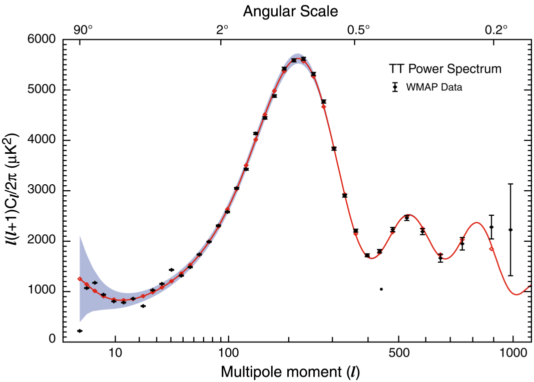
Anisotropy Data

Anisotropy Data

The anisotropy data is usually presented as a graph of CMB power against the multipole moment label:

Anisotropy Data

The anisotropy data is usually presented as a graph of CMB power against the multipole moment label:



Cosmological Theory

Cosmological Theory

Observations: On scales larger than 200 MegaParSecs the universe is Isotropic and Expanding – Hubble $\sim$ 1929;

Cosmological Theory

Observations: On scales larger than 200 MegaParSecs the universe is Isotropic and Expanding – Hubble $\sim$ 1929;

Assumption: On large scales, universe is Homogeneous and Isotropic – The Cosmological Principle;

Cosmological Theory

Observations: On scales larger than 200 MegaParSecs the universe is Isotropic and Expanding – Hubble $\sim$ 1929;

Assumption: On large scales, universe is Homogeneous and Isotropic – The Cosmological Principle;

Theoretical Framework: Space-Time Geometry is Dynamical – Einstein's General Theory of Relativity;

Cosmological Theory

Observations: On scales larger than 200 MegaParSecs the universe is Isotropic and Expanding – Hubble $\sim$ 1929;

Assumption: On large scales, universe is Homogeneous and Isotropic – The Cosmological Principle;

Theoretical Framework: Space-Time Geometry is Dynamical – Einstein's General Theory of Relativity;

Theory: Large scale universe is described in terms of a Scale Factor and a Perfect Fluid – Friedman-Robertson-Walker-Lemaitre;

The Big Bang Model

The Big Bang Model

Main Implication: Universe began from a Singular State of large curvatures, densities and pressures, a finite time ago – Basic Big Bang Model;

The Big Bang Model

Main Implication: Universe began from a Singular State of large curvatures, densities and pressures, a finite time ago – Basic Big Bang Model;

Further Inputs: Matter must have been very hot during the earlier stages. We know the micro-constituents and their interactions. They were probably in approximate Thermal Equilibrium – Hot Big Bang Model;

The Big Bang Model

Main Implication: Universe began from a Singular State of large curvatures, densities and pressures, a finite time ago – Basic Big Bang Model;

Further Inputs: Matter must have been very hot during the earlier stages. We know the micro-constituents and their interactions. They were probably in approximate Thermal Equilibrium – Hot Big Bang Model;

Possibilities: Different constituents could be Cooked during the cooling due to expansion – Origin of Relics as Cosmic Backgrounds – Gamow-Alfer-Herman (1946-49);

Origin of CMB

Origin of CMB

$p + e^- \rightleftharpoons H + \gamma$:

Origin of CMB

$p + e^- \rightleftharpoons H + \gamma$:

Reaction rates depend on energies and densities which decrease due to expansion;

Origin of CMB

$p + e^- \rightleftharpoons H + \gamma$:

Reaction rates depend on energies and densities which decrease due to expansion;

At about 3000^0, photons decouple and constitute the CMBR.

Origin of CMB

$p + e^- \rightleftharpoons H + \gamma$:

Reaction rates depend on energies and densities which decrease due to expansion;

At about 3000^0, photons decouple and constitute the CMBR.

The spectrum is of Black Body form if decoupling is very sharp OR Scale factor $\times$ Temperature is constant even before decoupling;

Origin of CMB

$p + e^- \rightleftharpoons H + \gamma$:

Reaction rates depend on energies and densities which decrease due to expansion;

At about 3000^0, photons decouple and constitute the CMBR.

The spectrum is of Black Body form if decoupling is very sharp OR Scale factor $\times$ Temperature is constant even before decoupling;

If deuterium is also due to cooking process, then the second assumption is holds.

Anisotropies

Anisotropies

Universe is Inhomogeneous and anisotropic on smaller scales!

If matter and radiation were in thermal equilibrium before CMB, then Seeds of these structures should be imprinted in CMB. COBE showed their existence.

Anisotropies

Universe is Inhomogeneous and anisotropic on smaller scales!
If matter and radiation were in thermal equilibrium before CMB, then Seeds of these structures should be imprinted in CMB. COBE showed their existence.

Primordial inhomogeneities in Density are the seeds of structures (Galaxies). What are their amplitudes and distributions?

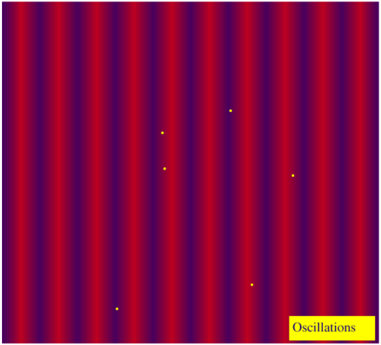
Anisotropies

Universe is Inhomogeneous and anisotropic on smaller scales! If matter and radiation were in thermal equilibrium before CMB, then Seeds of these structures should be imprinted in CMB. COBE showed their existence.

Primordial inhomogeneities in Density are the seeds of structures (Galaxies). What are their amplitudes and distributions?

Fluctuations of certain scales cause standing wave patterns in the tightly coupled plasma (before CMB generation). These induce Primary Anisotropies in CMB and are manifested as a series of Acoustic Peaks in the power spectrum shown before.

Inhomogeneities $\longrightarrow$ Anisotropies



From: http://background.uchicago.edu/∼whu/

Precision Cosmology

Precision Cosmology

The Locations of the peaks, the Amplitudes and the Shapes are all sensitive to the parameters of a cosmological model such as topology, Hubble parameter, densities of various constituents etc.

Precision Cosmology

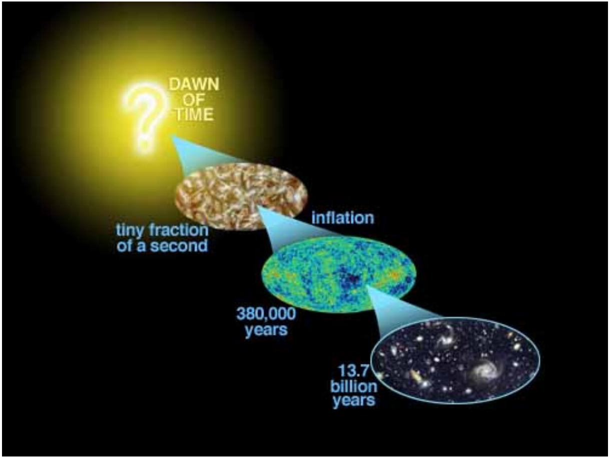
The Locations of the peaks, the Amplitudes and the Shapes are all sensitive to the parameters of a cosmological model such as topology, Hubble parameter, densities of various constituents etc.

Precise determination of the power spectrum of CMB anisotropies thus constrains these parameters – Precision Cosmology!

A Sample of Results from WMAP

Temperature	2.725 ± 0.001^0K
Age of the universe	$13.73^{+0.16}_{-0.15}$ Gyr
Geometry	Flat, Density $= \sim 10^{-29}$ g cm^{-3}
Matter	$23.7 \pm 3.4\%$
Dark Energy	$76.3 \pm 3.4\%$
...	...

. . . And Here is a Picture



. . . Further Reading

- G. Smoot and K. Davidson, *Wrinkles in Time*, William Morrow and Company, New York, 1993;
  This is an interesting account of the efforts of the COBE team and the discovery of anisotropies in the CMB.
- Here are some informative web-sites on the CMB:
  http://background.uchicago.edu/~whu/;
  http://map.gsfs.nasa.gov/

Thank You