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the lectures pdfs are available at:

https://www.physics.umd.edu/rgroups/amo/orozco/results/2022/Results22.htm

Correlations in Optics and Quantum Optics; A series of lectures about correlations and coherence 1. November 2022

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BOS.QT

Lesson 2

Tentative list of topics to cover:

- From statistics and linear algebra to power spectral densities
- Historical perspectives and examples in many areas of physics
- Correlation functions in classical optics (field-field; intensity-intensity; field-intensity)
- Correlation functions in quantum examples
- Correlations and conditional dynamics for control
- Correlations in quantum optics of the field and intensity
- Optical Cavity QED
- From Cavity QED to waveguide QED.

History

- Auguste Bravais (1811-63), French, physicist, also worked on metheorology.
- Francis Galton (1822-1911), English, statistician, sociologist, psicologist, proto-genetisist, eugenist.
- Norbert Wiener (1894-1964), United States, mathematician interested in noise.

Correlations for filtering

A data filter.

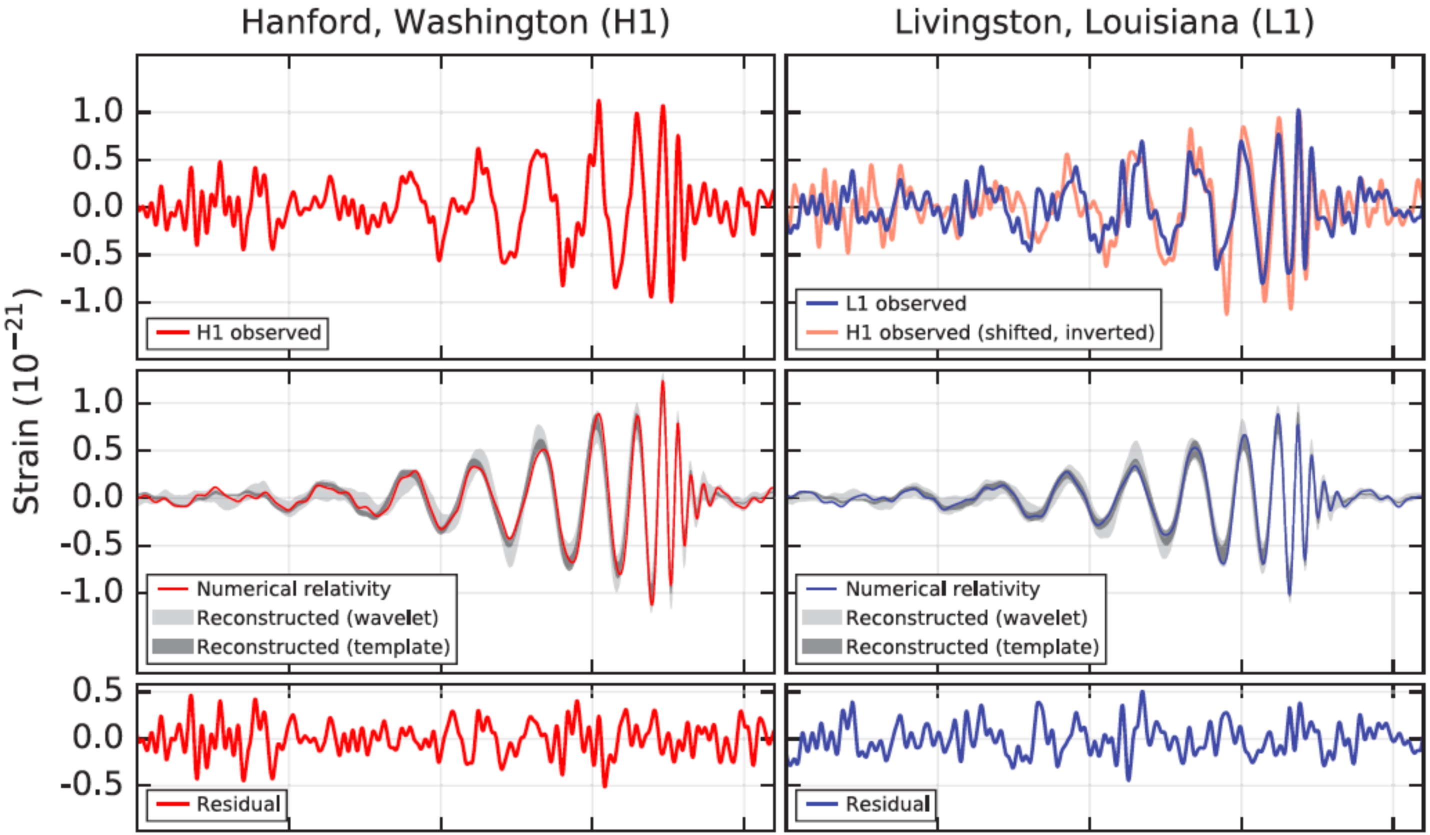
- If the signal is known: take the data vector x_j with length m calculate the internal product with the signal vector s_i of length n, with $n<m$
- Start with $i=j=0$ until $i=n$ y $j=n$ and get C_0
- Move the signal vector over the data by one unit $i=0$ $j=1$ until $i=n$ y $j=n+1$ obtaining C_1, continue this way until you reach C_m
- C(m) will be maximal when the signal and the data coincide. The noise will average down to zero.

These filters can be calculated from basic principles of based on measurements.

Examples:
LIGO
Modern hearing aids

The Wiener–Khinchin-Kolmogorov theorem alows the us to use the power spectral density to calculate the correlation, this is much more effective numerically (n *ln*(n)) instead of n^2

LIGO used correlations to find gravitational waves.



Phys. Rev. Lett. 116, 061102 (2016)

The original experiment of Hanbury Brown, Jennison, and Das Gupta

APPARENT ANGULAR SIZES OF DISCRETE RADIO SOURCES

Observations at Jodrell Bank, Manchester

THE existence of discrete sources of extra-terrestrial radio-frequency radiation is now well established[1,2] and the positions of more than one hundred sources have been published[3-5]. Attempts to identify these sources with any particular class of visual object have so far failed, and the origin of the radiation remains unexplained. One of the fundamental requirements in the study of these sources is a knowledge of their apparent angular size, and although attempts to make this measurement have been made by several observers[1-3], it has proved to be beyond the resolving power of their equipment. The present communication gives a preliminary account of a successful attempt to measure the angular size of the two most intense sources the positions[6] and intensities[4] of which are given in Table 1.

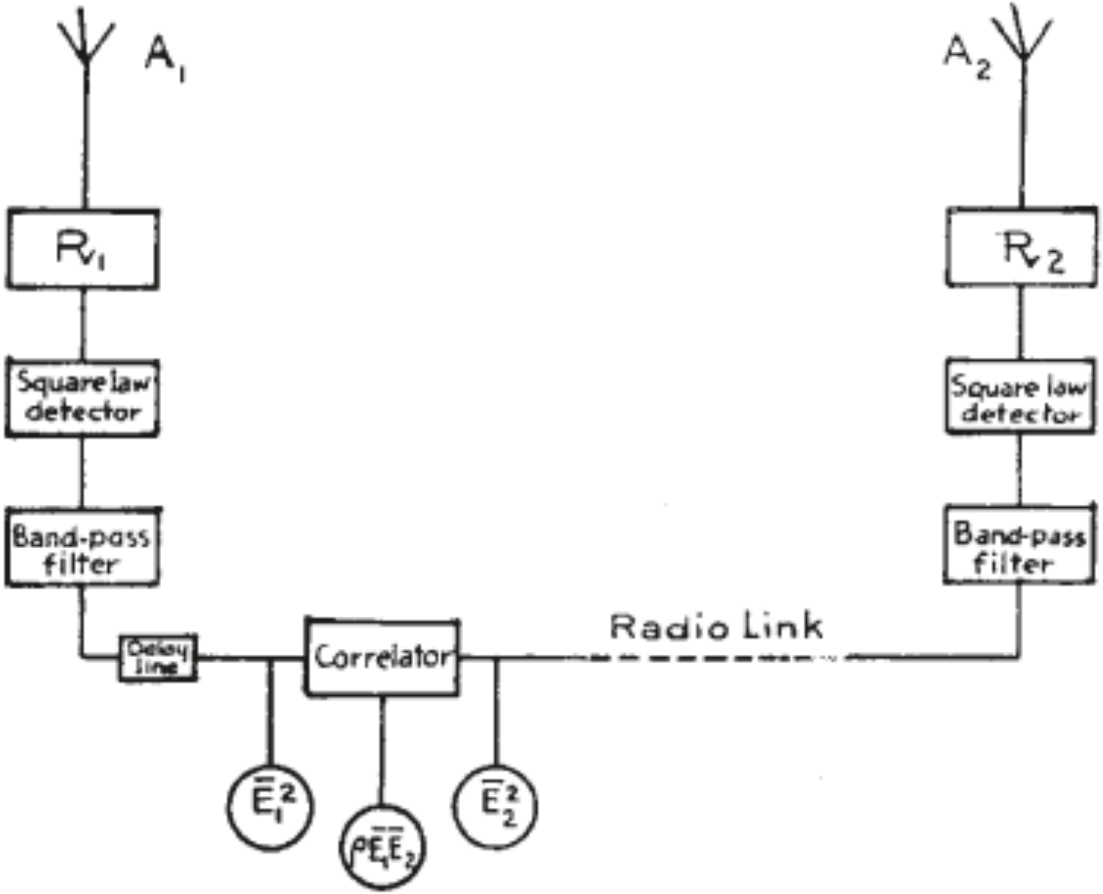
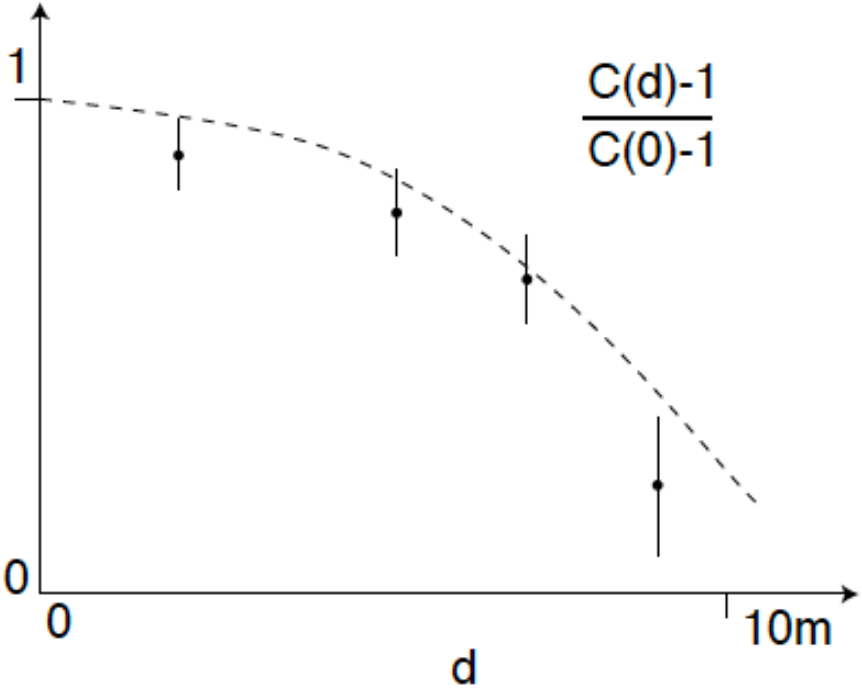


Fig. 1. Schematic diagram of the equipment

Table 2. EXPERIMENTAL RESULTS

Base-line			Cygnus		Cassiopeia	
	Length* (km.)	Bearing†	Correlation coefficient	Angular width of equivalent strip	Correlation coefficient	Angular width of equivalent strip
A	0·30	349·5°	0·99 ± 0·10	< 5′	0·96 ± 0·09	3′ 40″ (< 5′ 50″)
B	2·16	113·0°	0·30 ± 0·03	2′ 10″ ± 4″	0·08 ± 0·02	2′ 55″ ± 10″
C	2·16	235·5°	0·79 ± 0·08	1′ 00″ ± 7″	< 0·01	≮ 3′ 30″
D	3·99	177·0°	0·79 ± 0·07	0′ 34″ ± 8″	0·07 ± 0·01**	



Measurement of the angular diameter of Sirius [15].

Correlations in particle physics

VOLUME 3, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1959

PION-PION CORRELATIONS IN ANTIPROTON ANNIHILATION EVENTS*

Gerson Goldhaber, William B. Fowler, Sulamith Goldhaber, T. F. Hoang,
Theodore E. Kalogeropoulos, and Wilson M. Powell
Lawrence Radiation Laboratory and Department of Physics, University of California, Berkeley, California

(Received July 17, 1959)

We have observed angular correlation effects between pions emitted from antiproton annihilation events. This experiment was carried out with a separated antiproton beam[1] of momentum $p_{\overline{p}} = 1.05$ Bev/c. A total of 2500 annihilation events were observed in 20 000 pictures taken with the Lawrence Radiation Laboratory 30-in. propane bubble chamber.

$$\cos\theta_{12} = \vec{p}_1 \cdot \vec{p}_2 / |p_1|\,|p_2| \,.$$

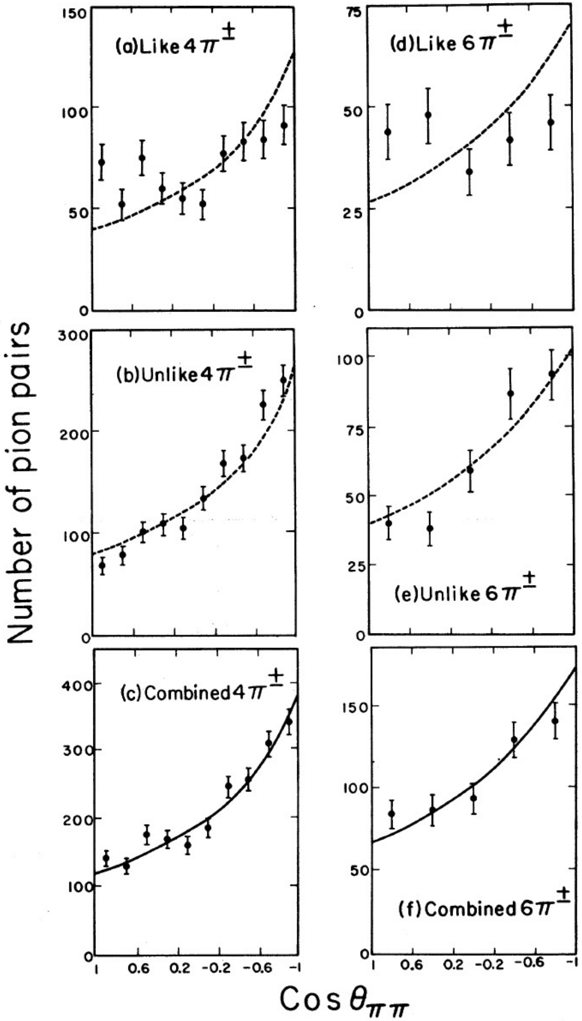


FIG. 1. Distribution of angles between pion pairs as a function of $\cos\theta_{12}$. The curves correspond to

This is the way they now measure the size of the quark-gluon plasma

The physics of Hanbury Brown–Twiss intensity interferometry: from stars to nuclear collisions
Gordon Baym, Acta Phys. Polon. B29 1839,(1998)

arXiv:nucl-th/9804026

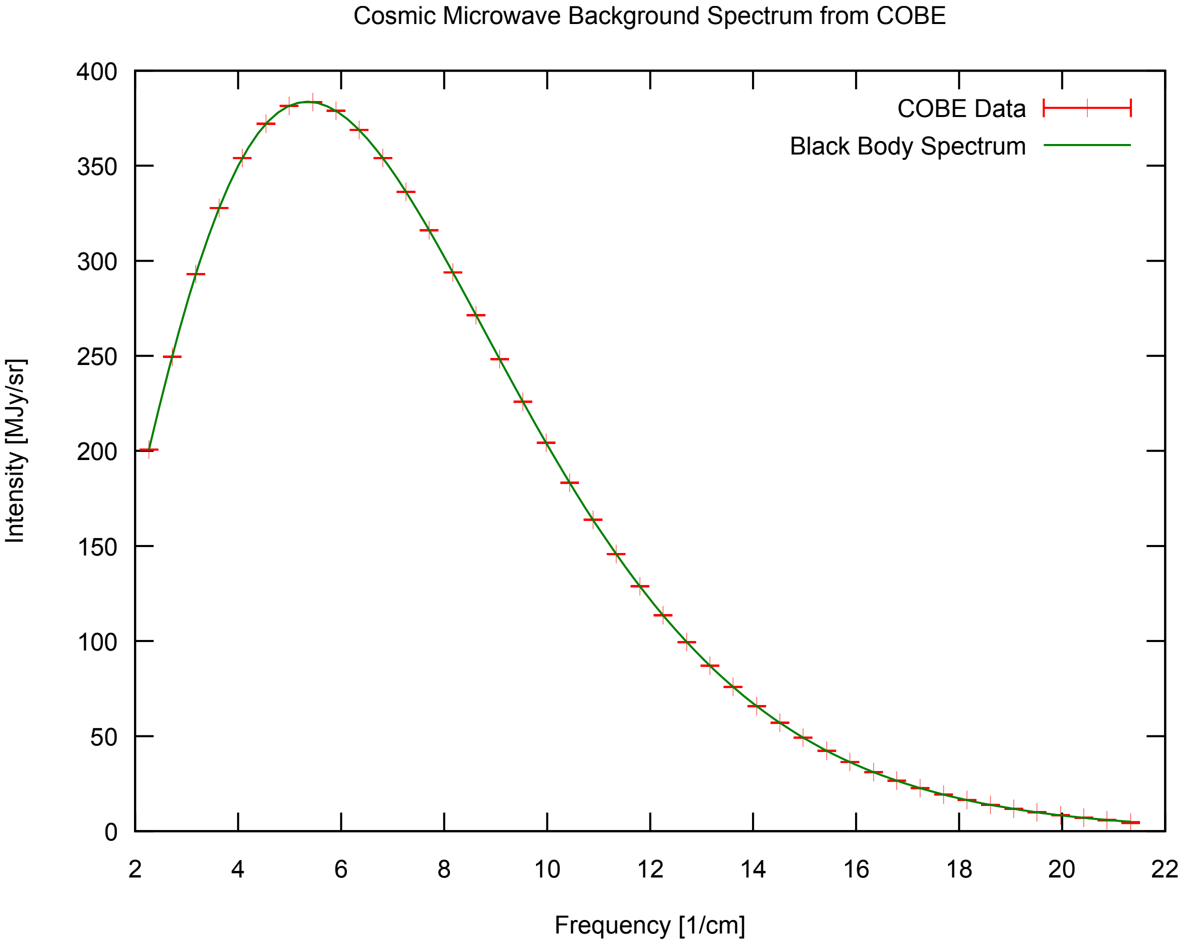
Astrophysics

Arno Penzias and Robert Wilson from Bell Labs discovered the remnants of the Big Bang in 1965. Trying to understand some noise [Cosmic Microwave Background].

How is the CMB generated?

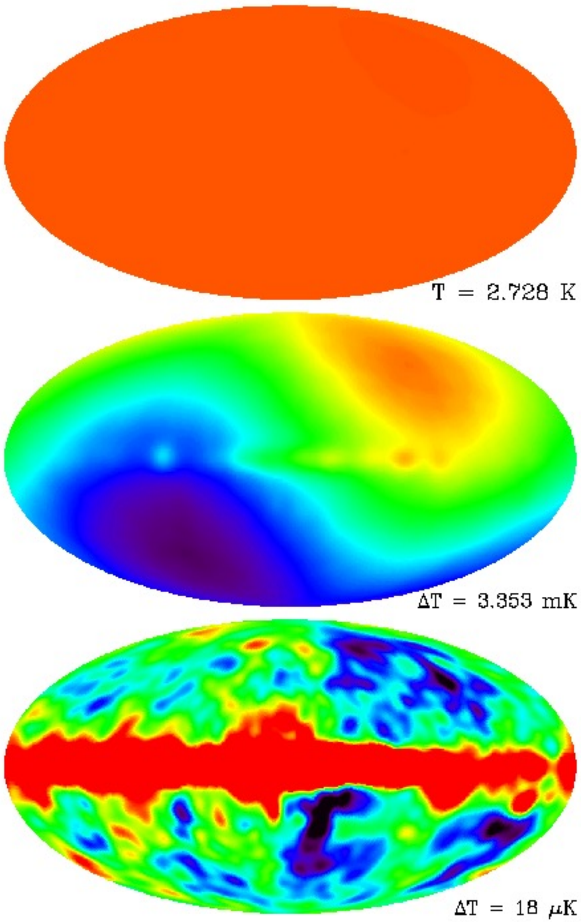
379,000 after the Big Bang, the universe has cooled enough to form neutral atoms y the majortity of the the radiation can now escape.

This radiation is almost uniform but has very small fluctuations ($\partial T/T \sim 10^{-6}$) which come from quantum fluctuations. Gravity plays a very important role. The fluctuations are the seeds for the formation of galaxies, etc.



(CMB) John Mather and Gary Hinshaw Scientific Directors

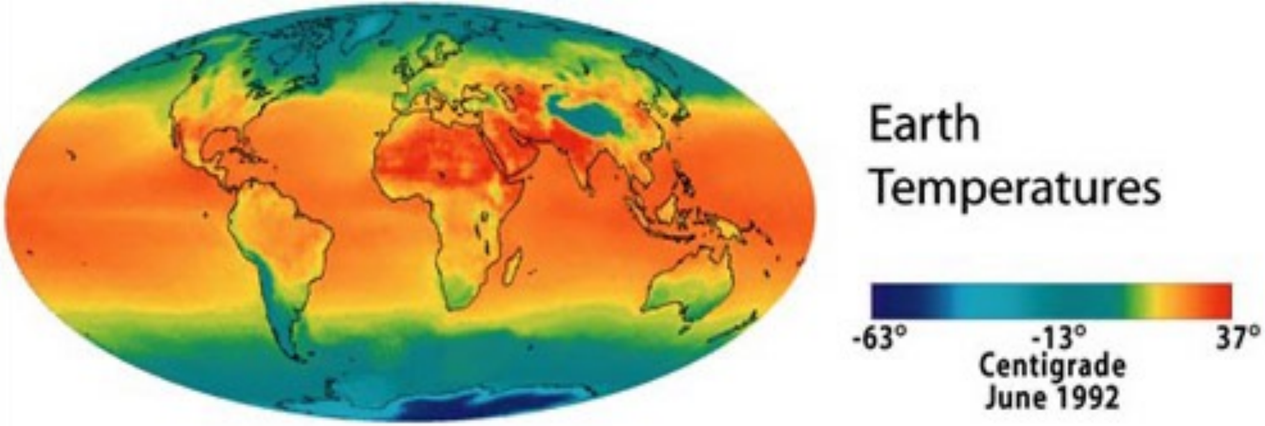
COBE 1992



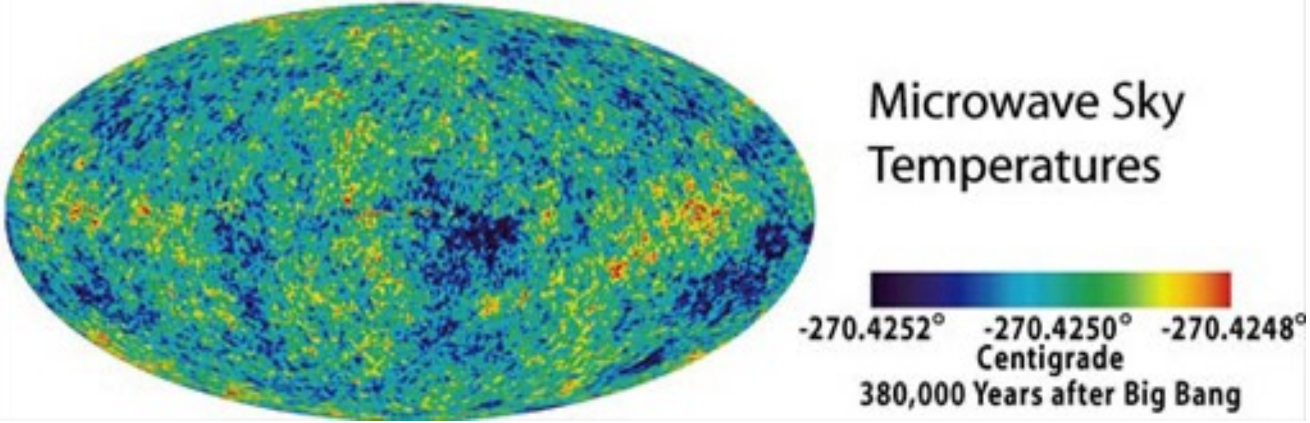
Measurement

Dipole,
from
moving

Remaining
Fluctuations

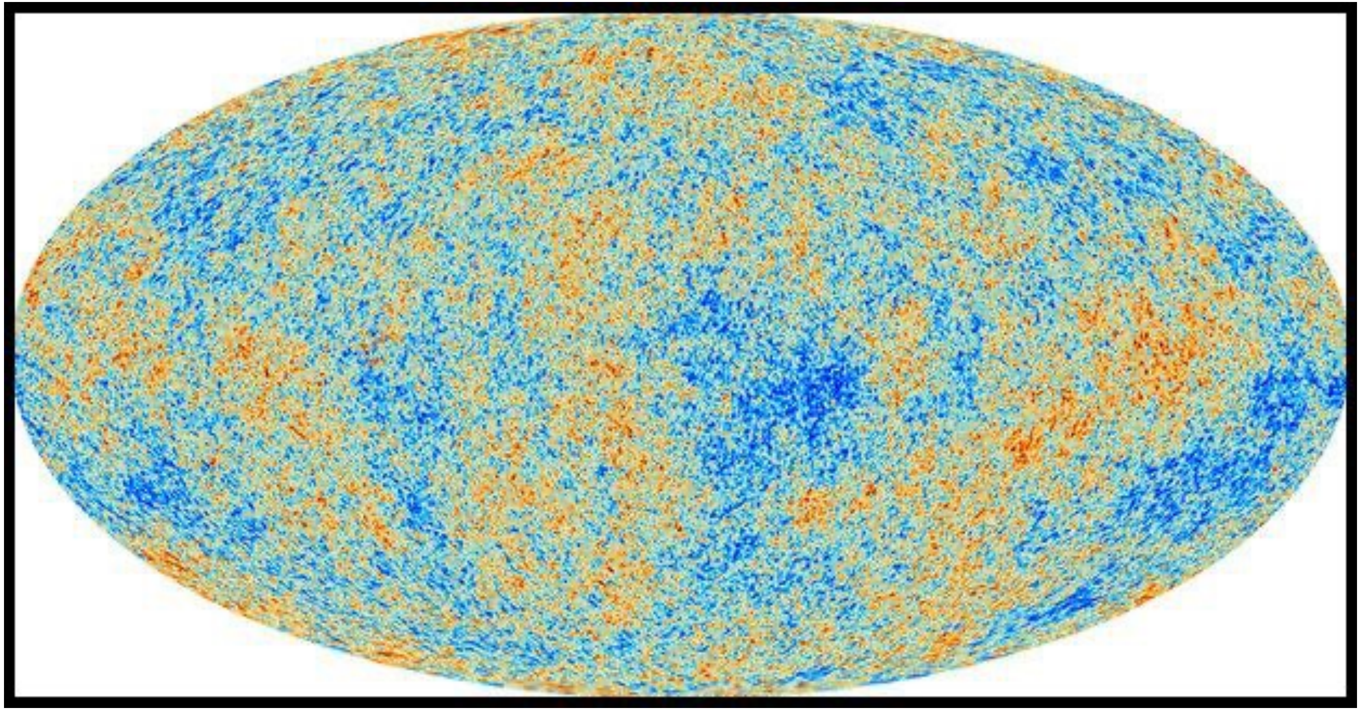


Earth Temperatures



Microwave Sky Temperatures

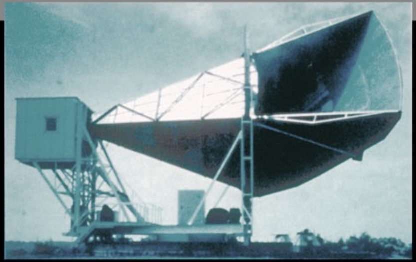
Results from Planck 2013

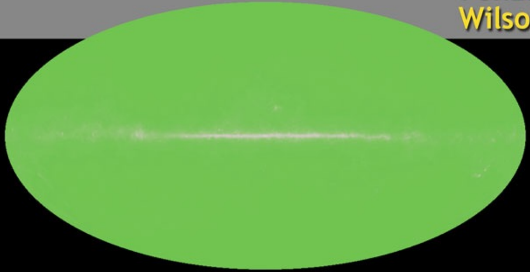


Some 379,000 years after the Big Bang

1965

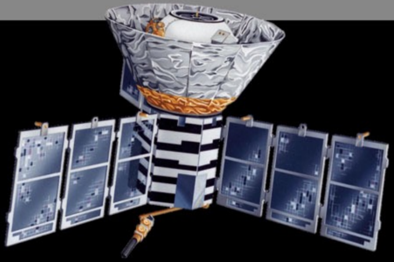
Penzias and Wilson

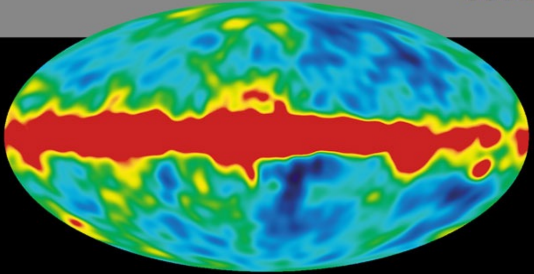




1992

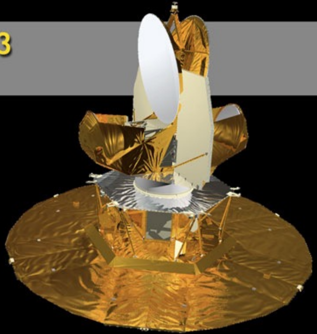
COBE

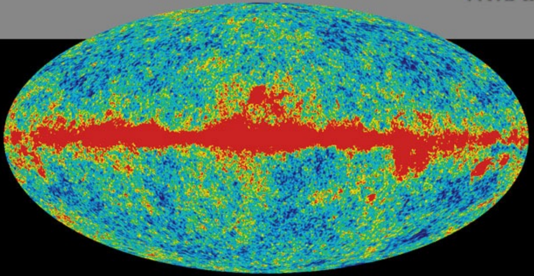


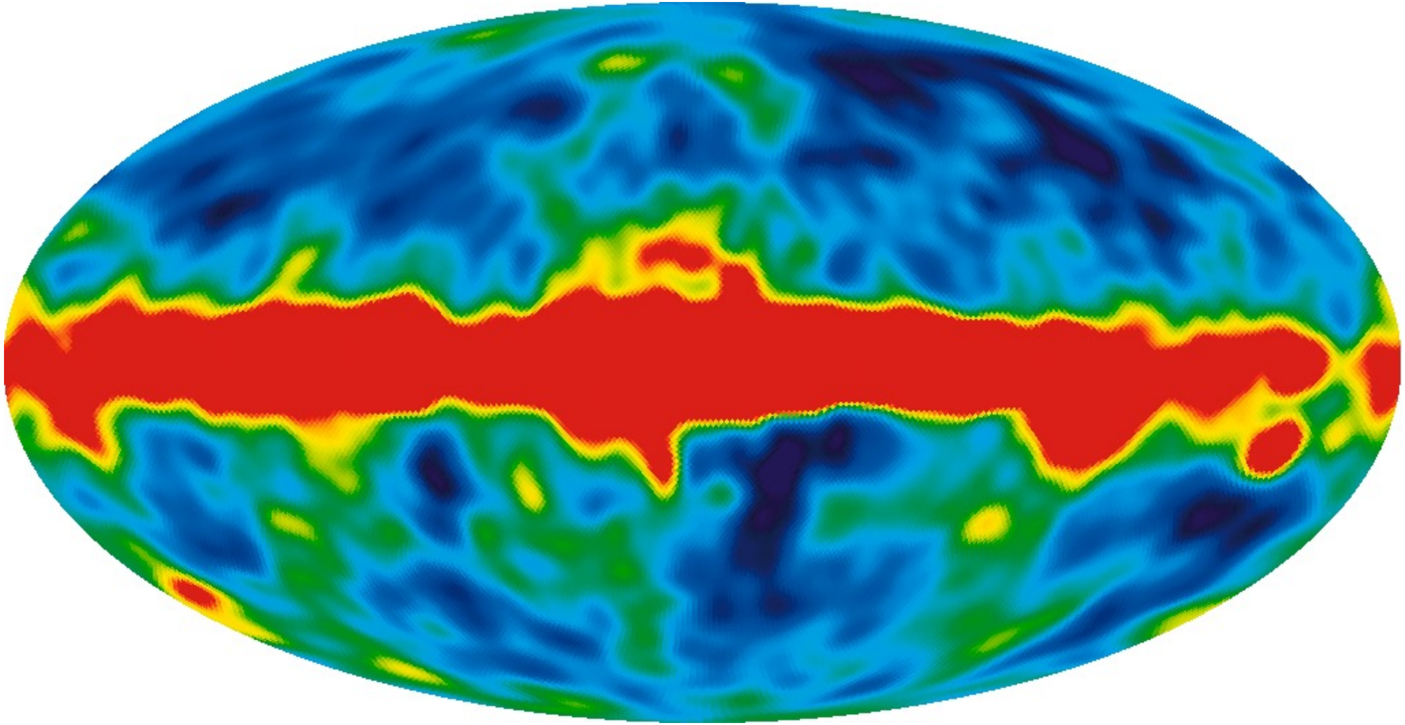


2003

WMAP

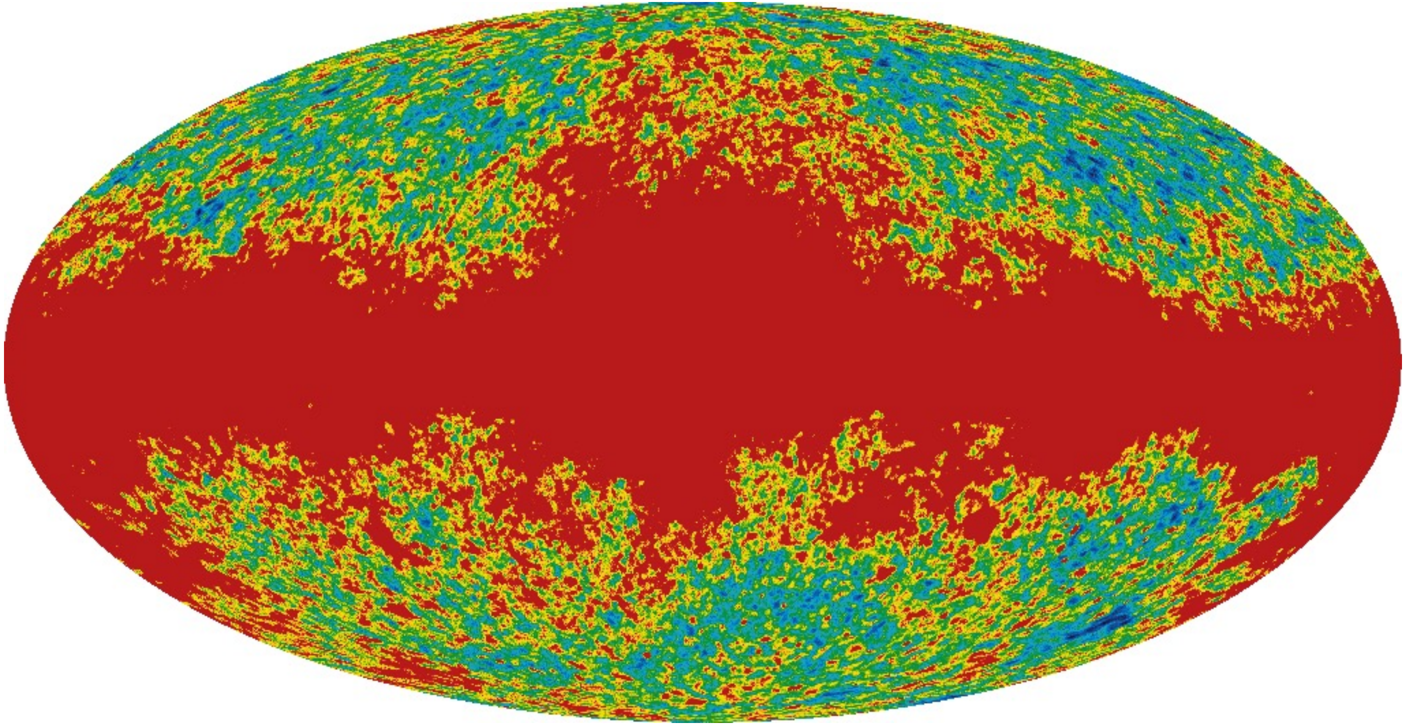




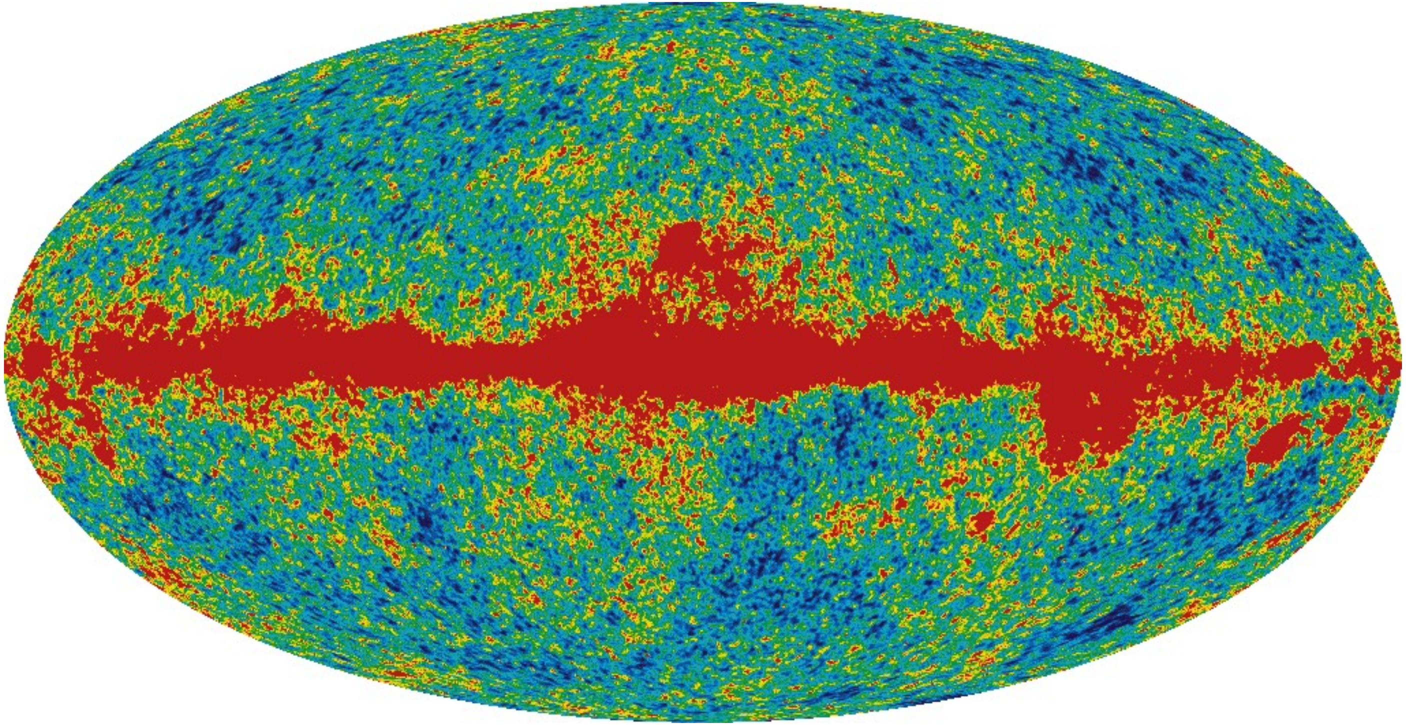


COBE launched in 1989 4 year result: resolution 7 degrees ans 100 μ-Kelvin.

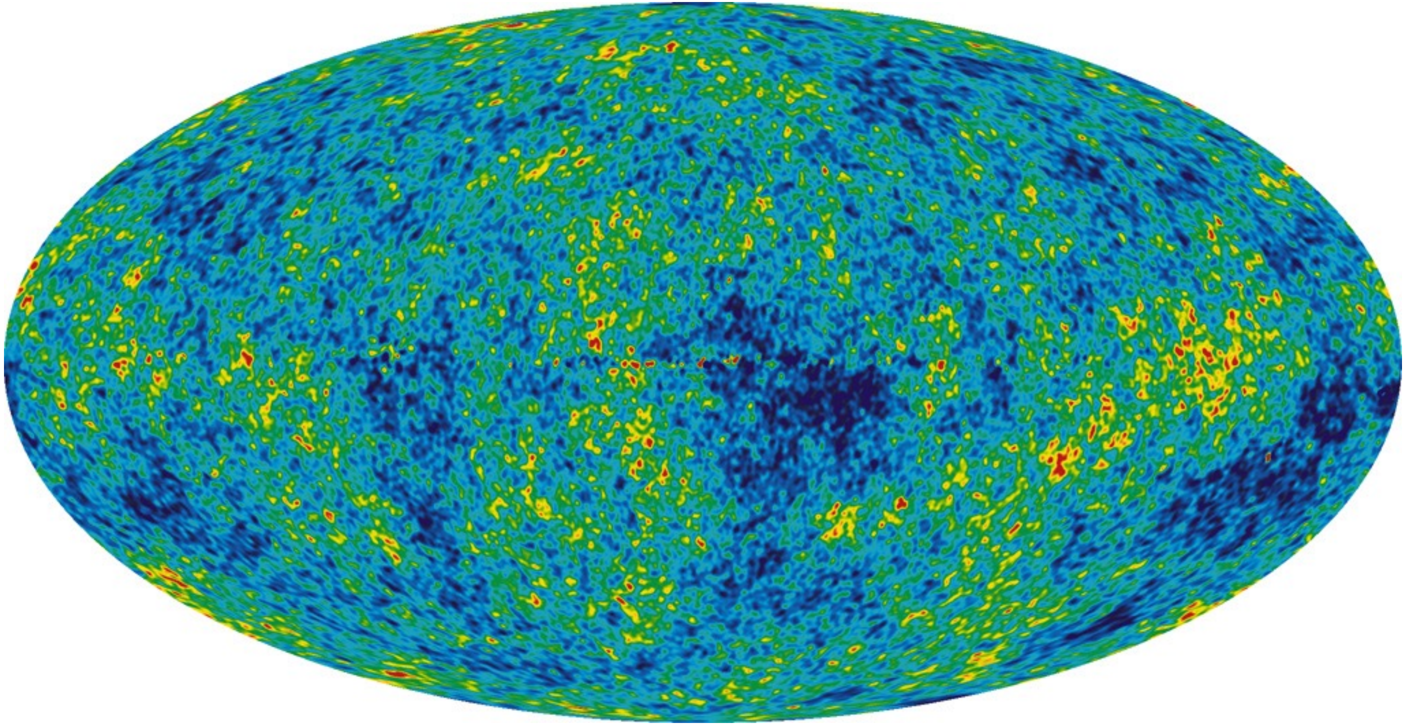
2006 Nobel for George Smoot and John Mather



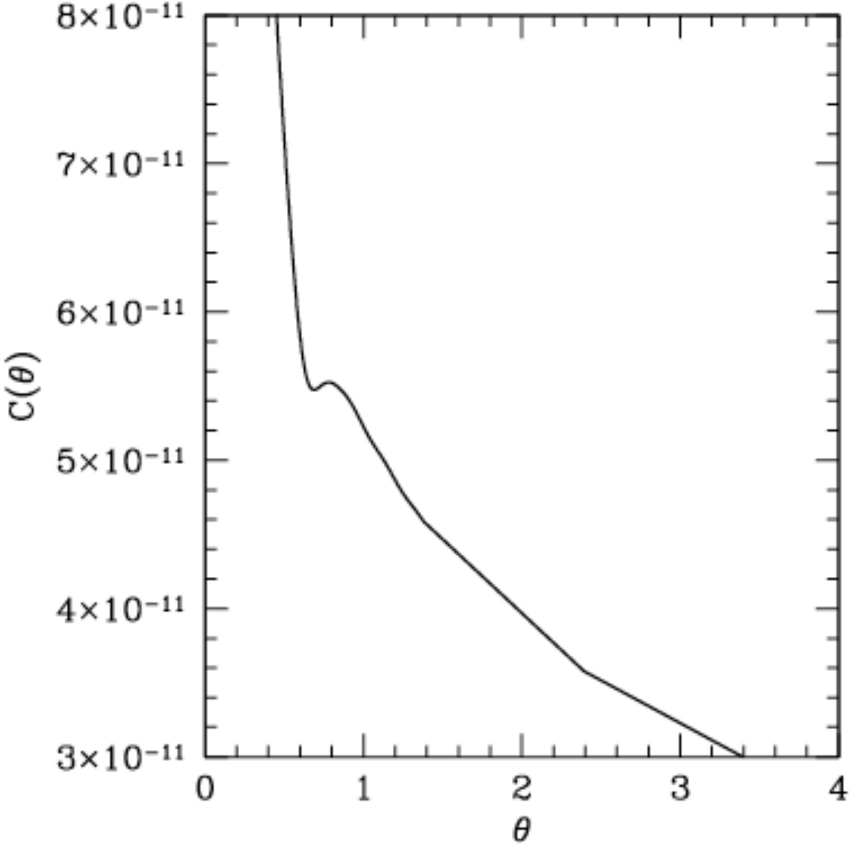
5 years WMAP band K (20 to 30 GHz)



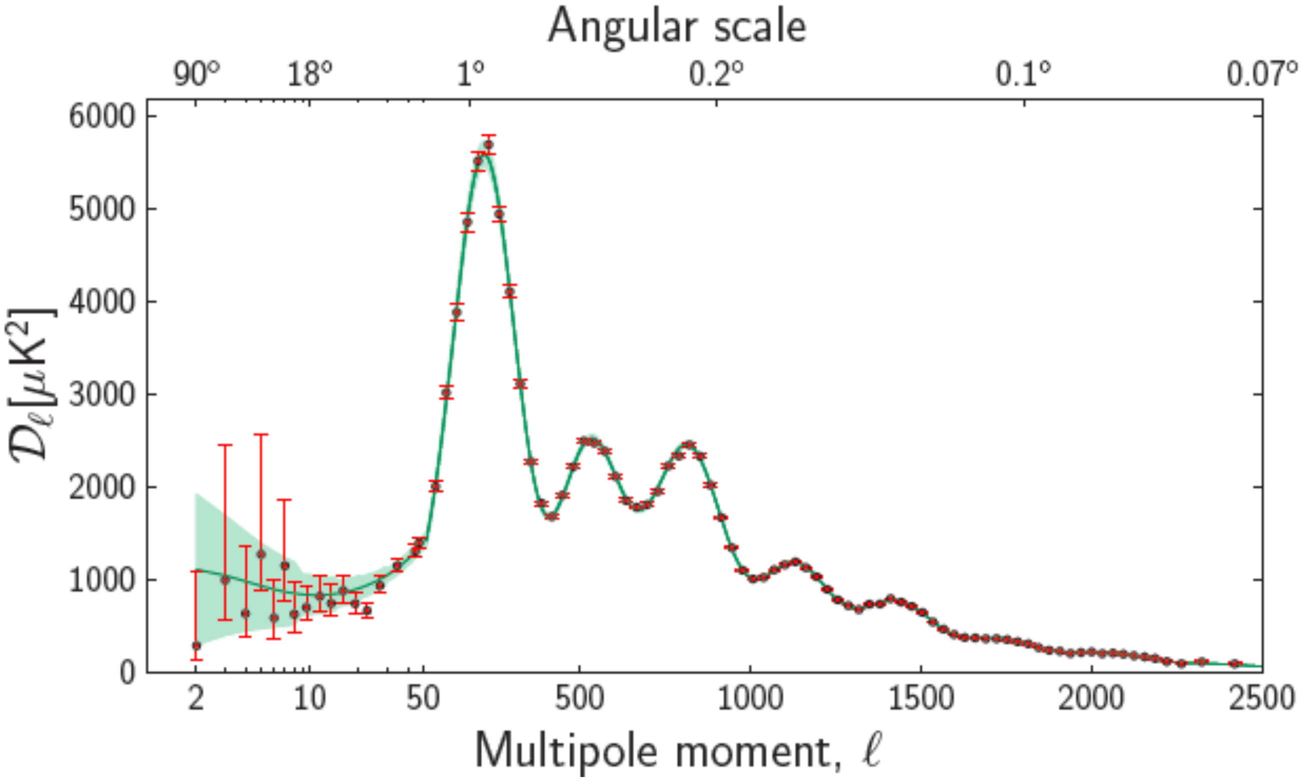
Band Q 33 to 50 GHz (6 mm)



Fluctuations on the WMAP
5 years (subtracting the milky way) 200 µ-Kelvin



Correlation function of the fluctuations on the CMB showing the acoustinc sound horizon. ArXive 1506.01907



Power sepectrum (Planck) of the fluctuations in CMB as a function of multipole moment *l* and angle. ArXive 1506.01907, James Pebbles Nobel Prize 2019

What do those fluctiations tell us?

- The matter distribution was very uniform in the early universe, but it had to have fluctuations to generate the structures that we see Today (galaxies, etc.)

- These fluctuations in the density affected the temperature of the emitted photons in each region: In a dense region, the photons had to overcome a larger gravitational potential, so they should have acquired a larger red shift cooling them.

Later oscillations (acoustic sound horizon) are not possible with the existing baryonic matter. They are related with non baryonic dark matter.

Thanks