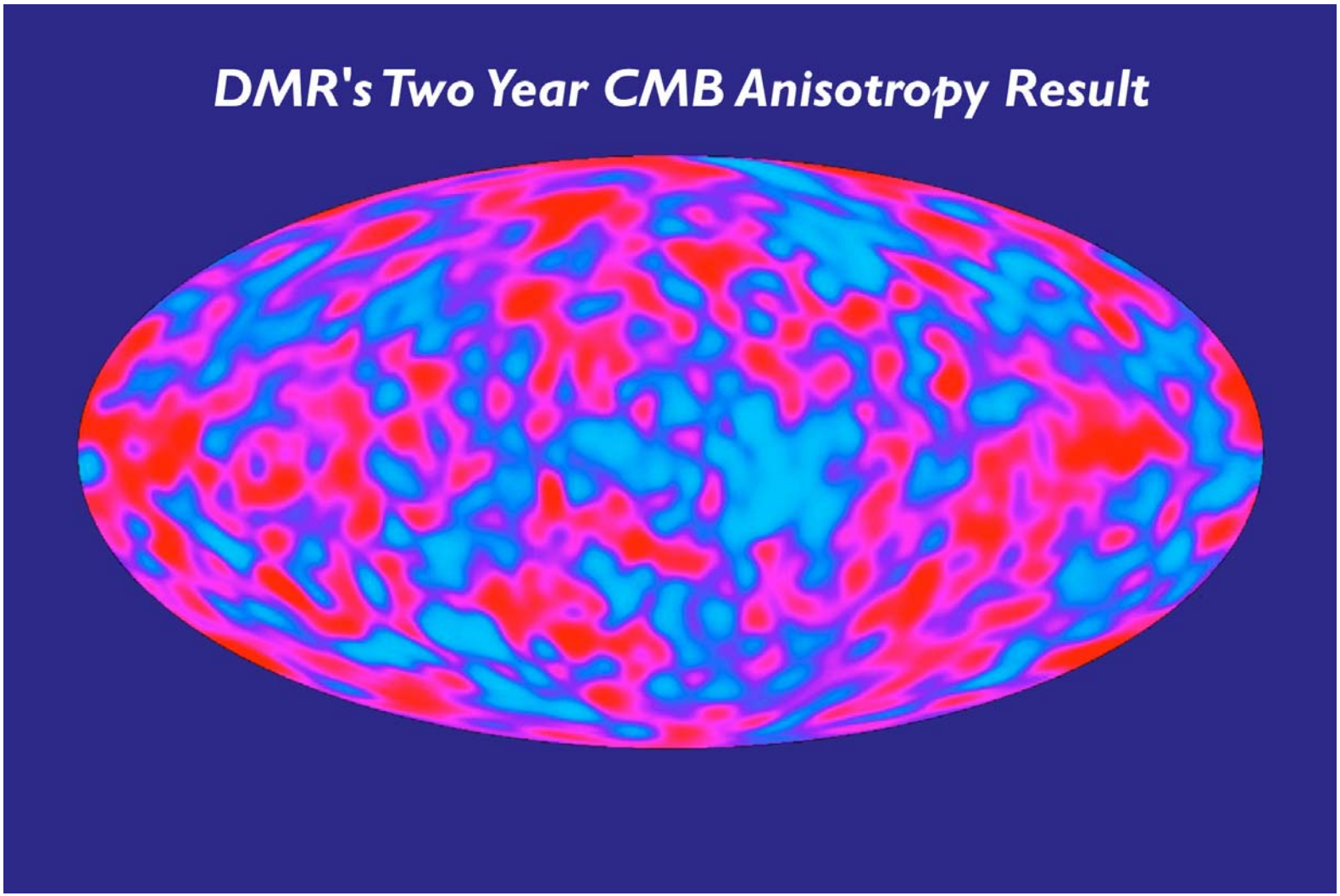
Misc

1. Homework 4 solutions and answers have been posted on the class website yesterday.

2. Today, we are covering material of end of S 26-5, and S 26-6 (Ch. 26)

Fluctuations of the CMB temperature over the entire sky measured by the COBE satellite



the main discovery paper

THE ASTROPHYSICAL JOURNAL, 396:L1–L5, 1992 September 1

STRUCTURE IN THE *COBE*[1] DIFFERENTIAL MICROWAVE RADIOMETER FIRST-YEAR MAPS

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ABSTRACT

The first year of data from the Differential Microwave Radiometers (DMR) on the *Cosmic Backgoround Explorer* (*COBE*) show statistically significant ($>7\ \sigma$) structure that is well described as scale-invariant fluctuations with a Gaussian distribution. The major portion of the observed structure cannot be attributed to known systematic errors in the instrument, artifacts generated in the data processing, or known Galactic emission. The structure is consistent with a thermal spectrum at 31, 53, and 90 GHz as expected for cosmic microwave background anisotropy.

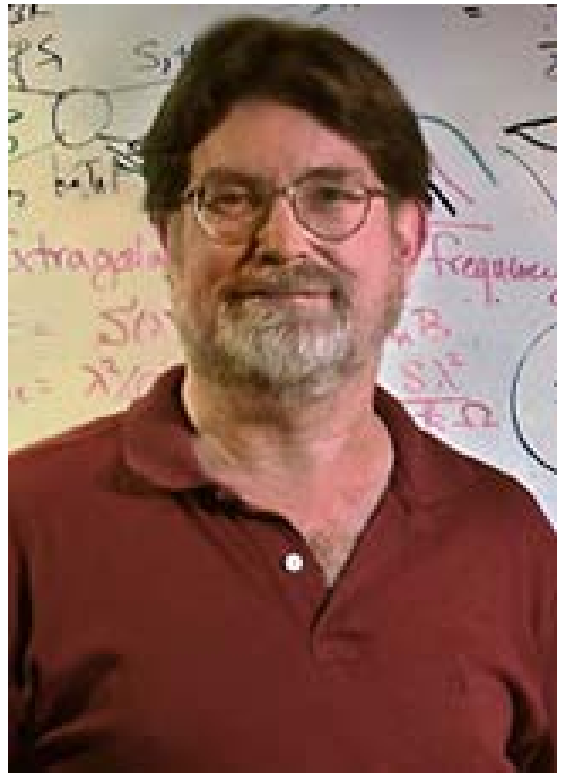
The rms sky variation, smoothed to a total 10° FWHM Gaussian, is $30 \pm 5\ \mu$K ($\Delta T/T = 11 \times 10^{-6}$) for Galactic latitude $|b| > 20°$ data with the dipole anisotropy removed. The rms cosmic quadrupole amplitude is $13 \pm 4\ \mu$K ($\Delta T/T \approx 5 \times 10^{-6}$). The angular autocorrelation of the signal in each radiometer channel and cross-correlation between channels are consistent and give a primordial fluctuation power-law spectrum with index $n = 1.1 \pm 0.5$, and an rms-quadrupole–normalized amplitude of $16 \pm 4\ \mu$K ($\Delta T/T \approx 6 \times 10^{-6}$). These features are in accord with the Harrison-Zel'dovich (scale-invariant, $n = 1$) spectrum predicted by models of inflationary cosmology. The low overall fluctuation amplitude is consistent with theoretical predictions of the minimal level gravitational potential variations that would give rise to the observed present day structure.

Subject headings: cosmic microwave background — cosmology: observations

2006 Nobel Prize in physics

Oct 3, 2005

John Mather
NASA Goddard Space Flight Center



George Smooth
Berkeley

"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

http://nobelprize.org/nobel_prizes/physics/laureates/2006/

Stephan Meyer

U.Chicago Astronomy & Astrophysics Department

member of the COBE science team

received Gruber Cosmology Prize from the International Astronomical Union (IAU) as part of the team in August 2006.

member of the science team of the *WMAP* satellite – the COBE's successor currently in orbit

more details on U.Chicago contribution to COBE instruments and science are at *http://kicp.uchicago.edu*

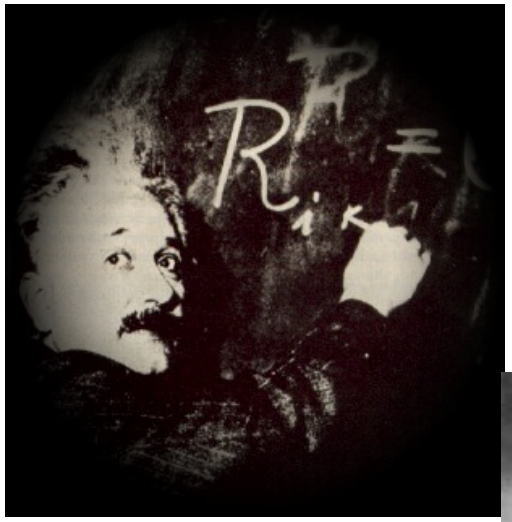
http://www.petergruberfoundation.org/cosmologynews.htm

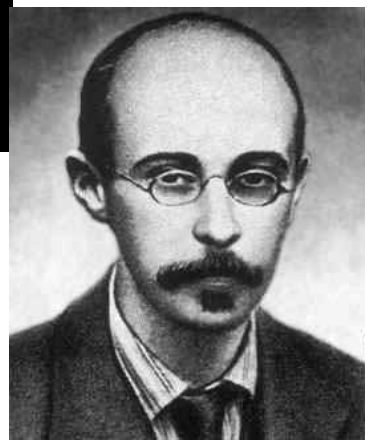
Existence of the CMB and its anisotropy support the main tenets of the Big Bang model

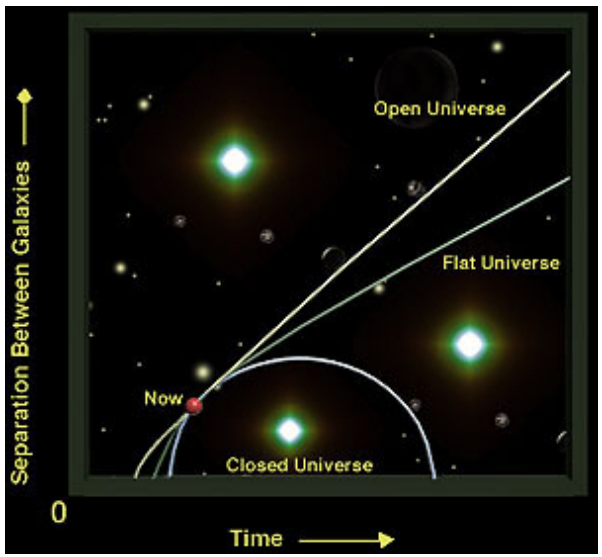
- Dense and hot state of the Universe at early epochs

- Existence of seed fluctuations required for formation of superclusters, clusters, and galaxies (and ultimately, stars and us)

But this is not all… CMB tells us much more about the geometry and contents of our Universe…







$$GEOMETRY = MATTER + ENERGY$$

Einstein's equations can be applied to the Universe as a whole, if one makes assumptions about what stuff contributes to the matter and energy density (r.h.s. of the equations) in the Universe *and* assumes that universe is isotropic and homogeneous (on large scales) – aka the cosmological principle.

Contents of the Universe, defining its global curvature, are all existing components (protons, neutrons, hypothetical dark matter and dark energy) can contribute to gravity and can influence the rate with which the Universe expands.

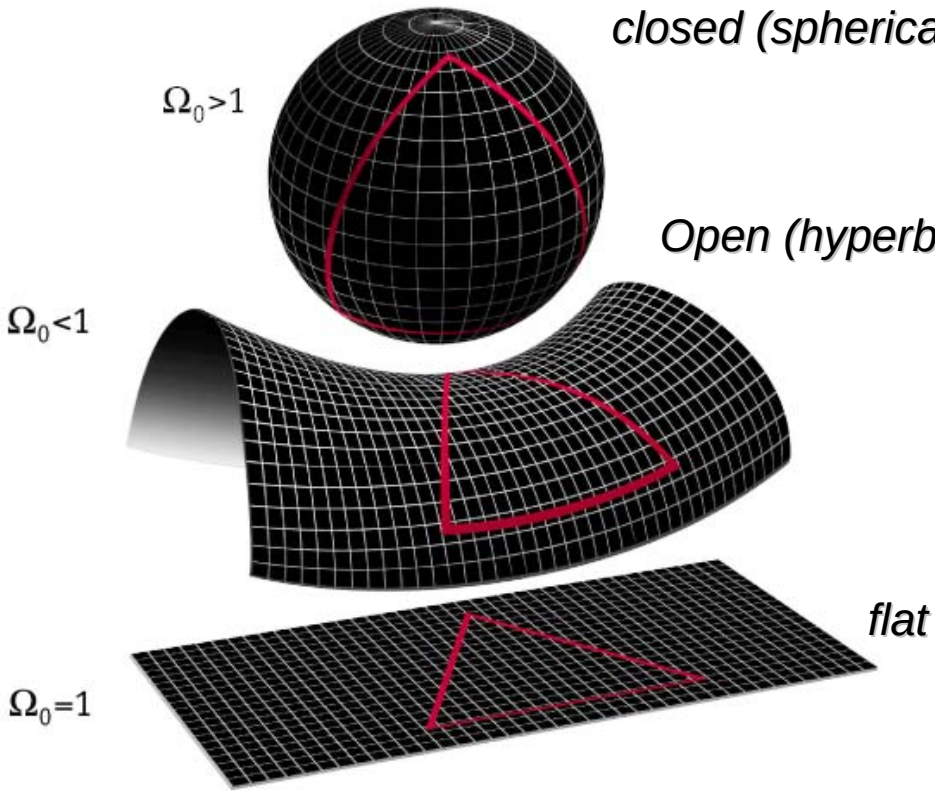
In 1920-22 Alexander Friedmann obtained general solutions to the Einstein's eqiations describing geometry and evolution of space in the Universe

Friedmann equation

shows that matter content and curvature of space in the Universe are linked

$$\Omega_m = \rho_m/\rho_c, \quad \Omega_\Lambda = \rho_\Lambda/\rho_c, \quad \Omega = \Omega_m + \Omega_\Lambda \qquad \rho_c = \frac{3H^2}{8\pi G}$$

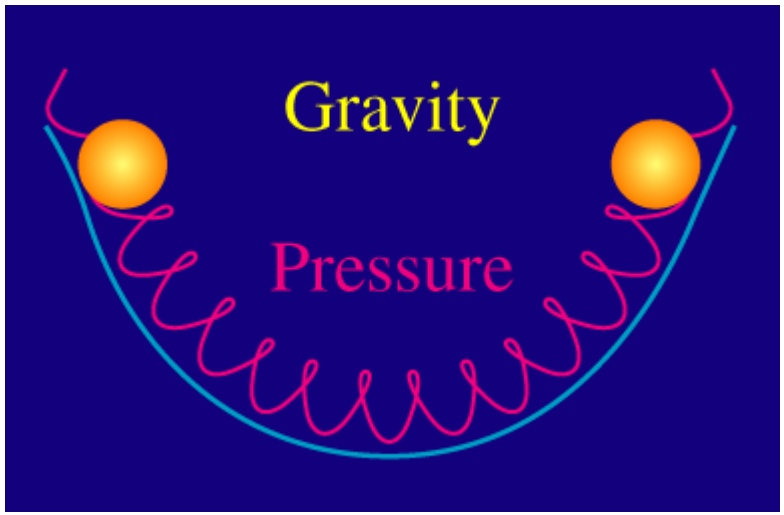
The *current* critical density is approximately 10^{-29} g/cm^3.

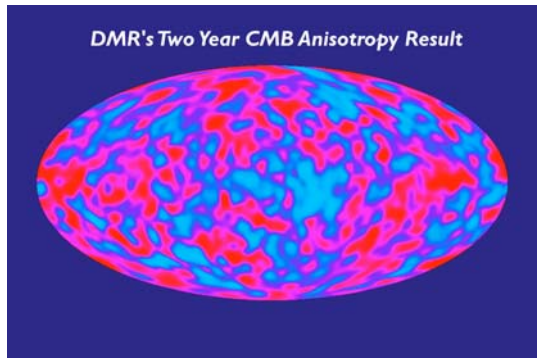


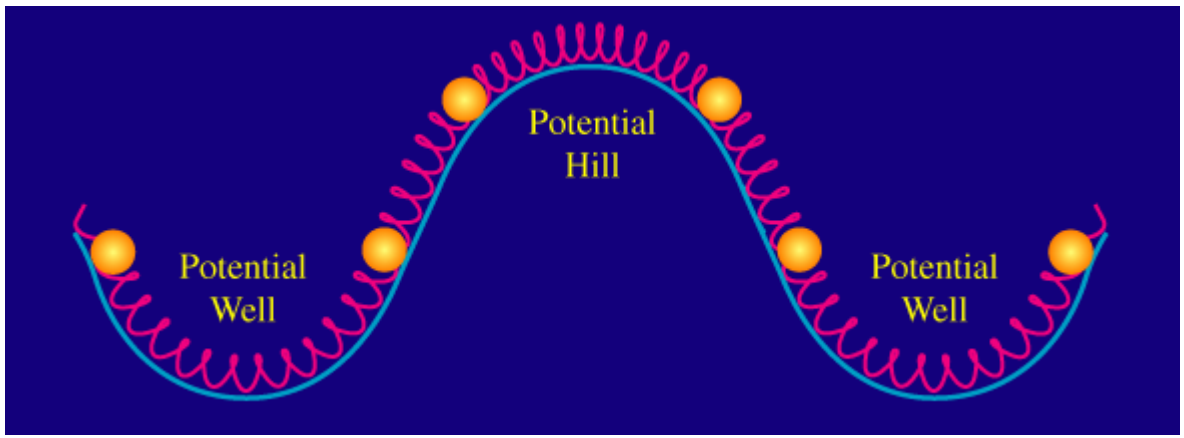
In general, all matter and energy contribute to Omega

the main contributors are matter and cosmological constant (or dark energy)

"Acoustic" oscillations

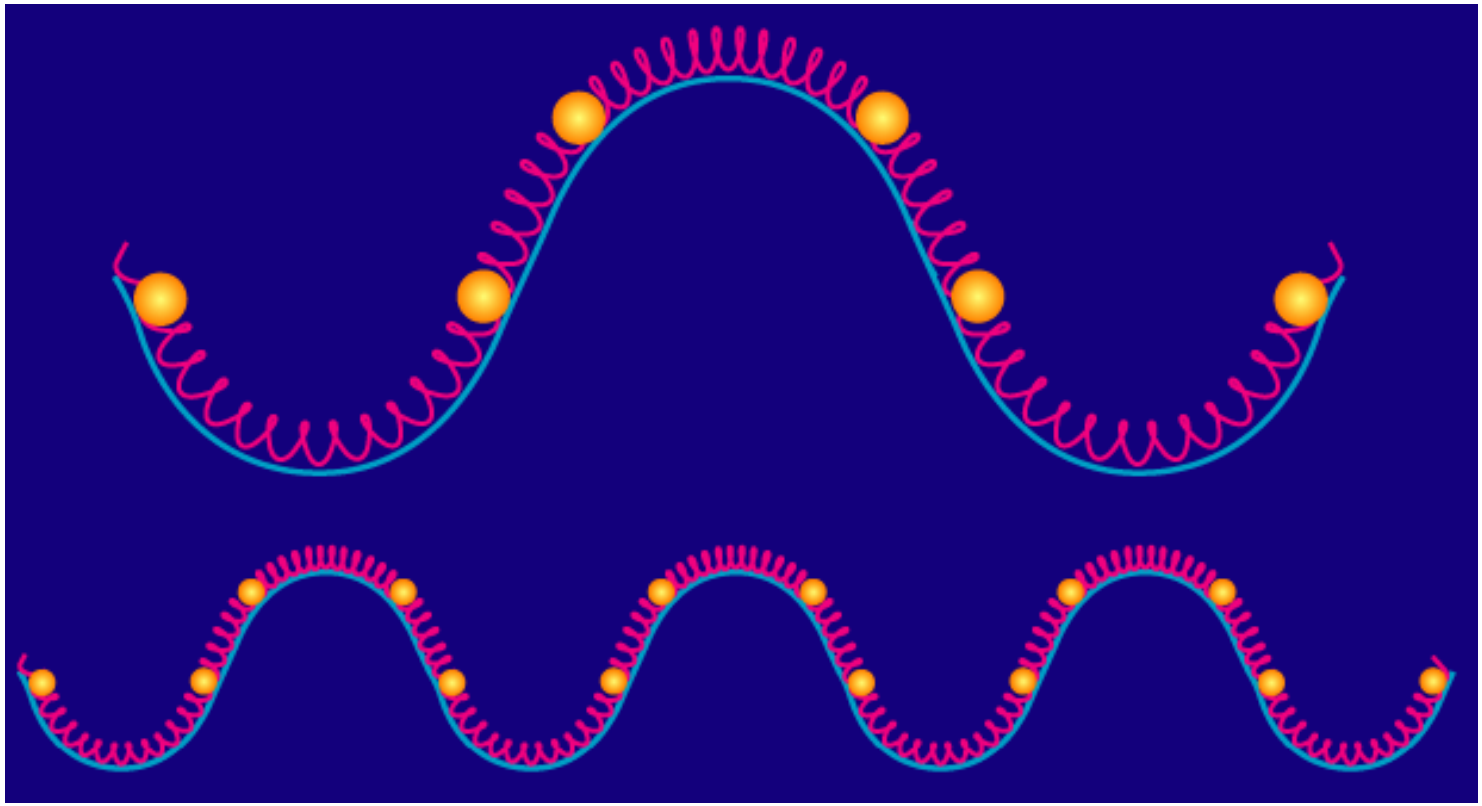






From Wayne Hu's CMB primer:
http://background.uchicago.edu/~whu/intermediate/intermediate.html

"Acoustic" oscillations



Motions of plasma in the primordial universe is controlled by "soundspeed"
Plasma in smaller potential wells can oscillate

From Wayne Hu's CMB primer:
http://background.uchicago.edu/~whu/intermediate/intermediate.html

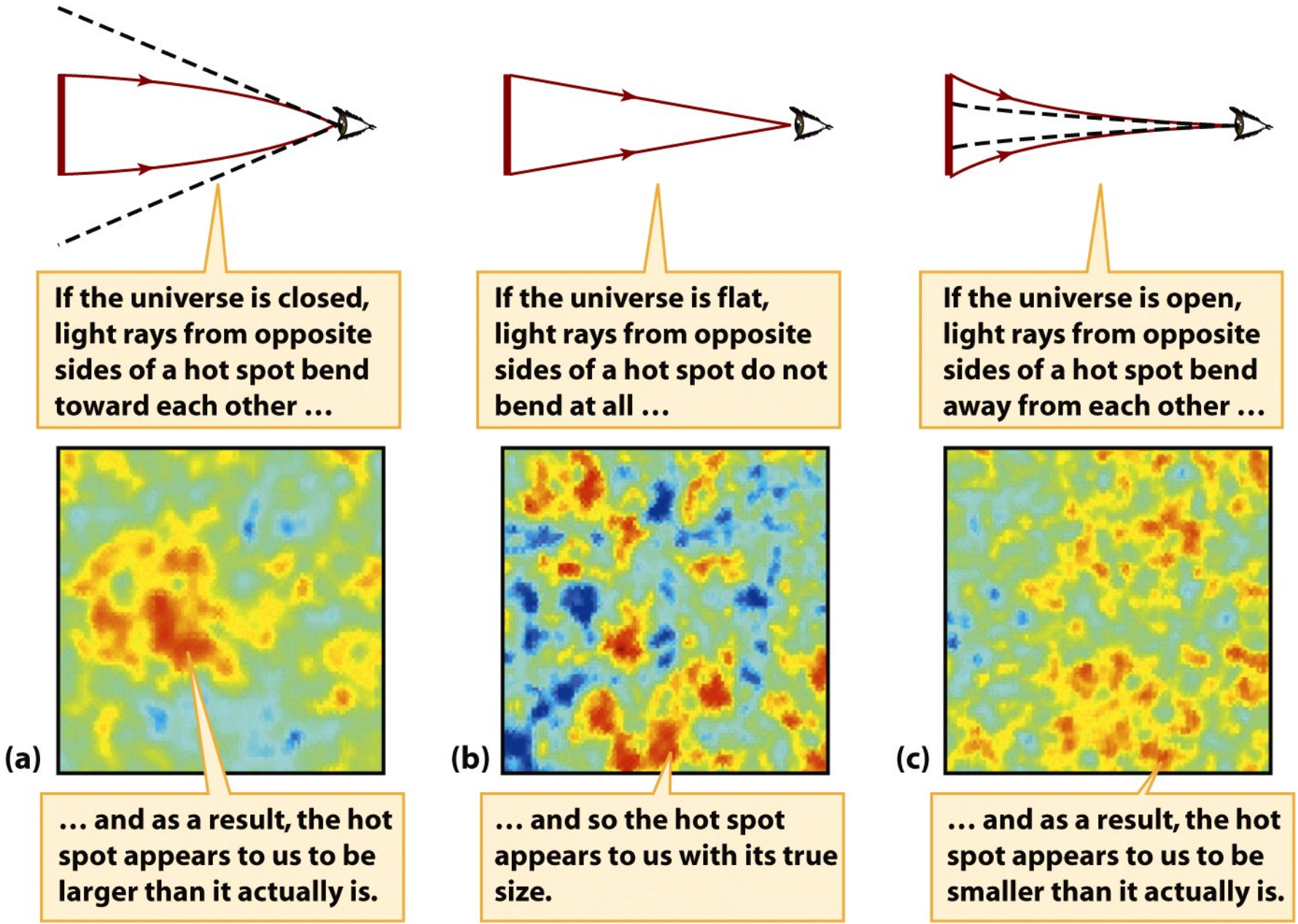
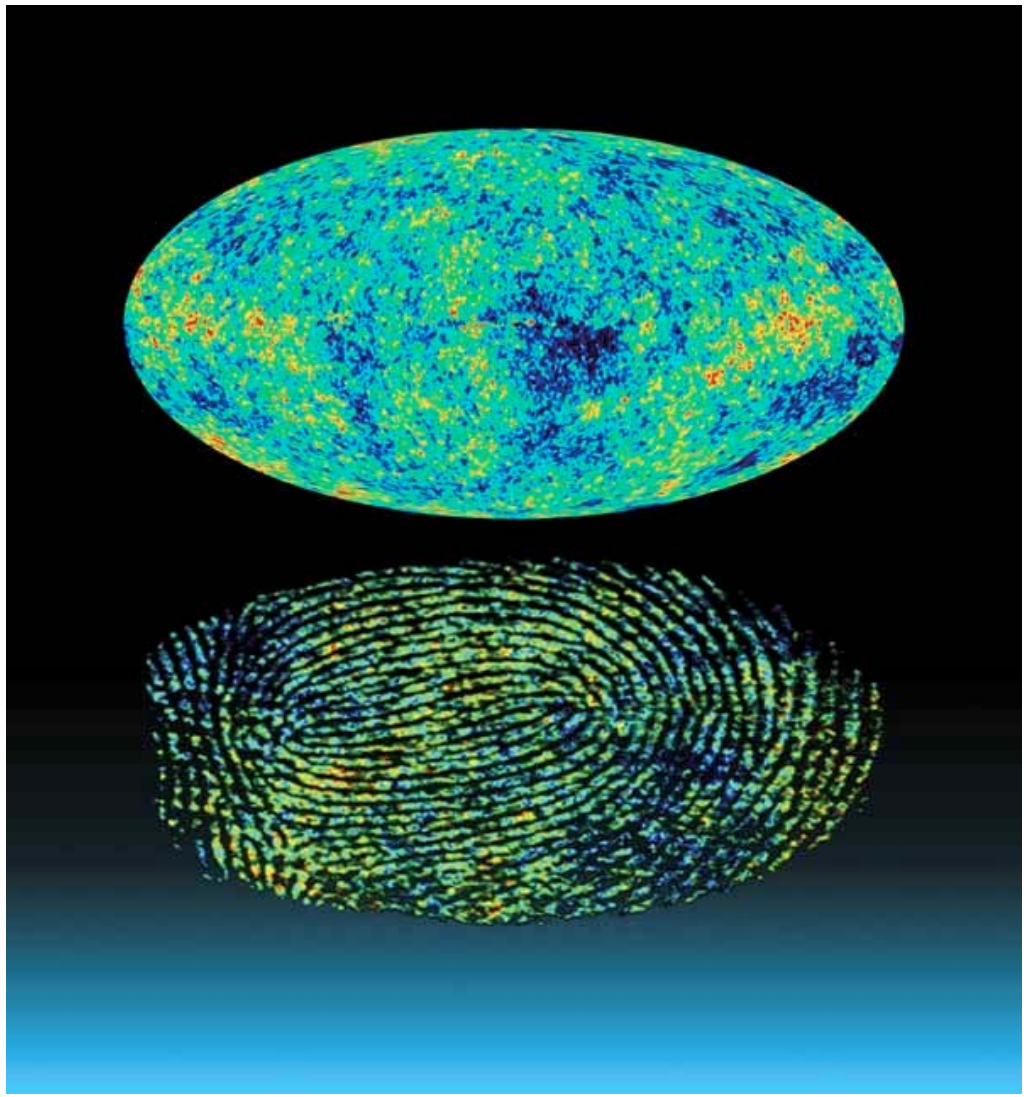
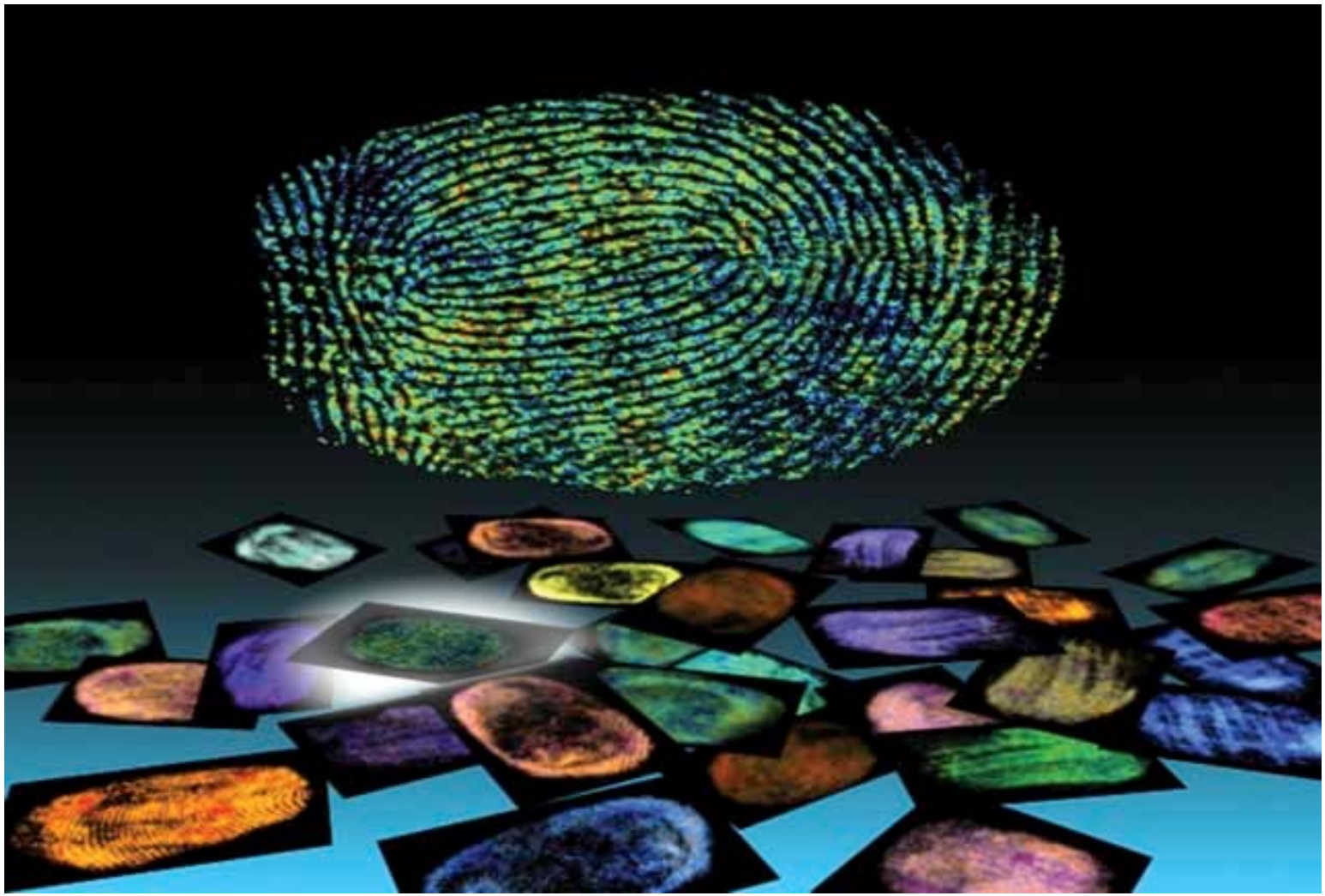


Figure 26-16
Universe, Eighth Edition

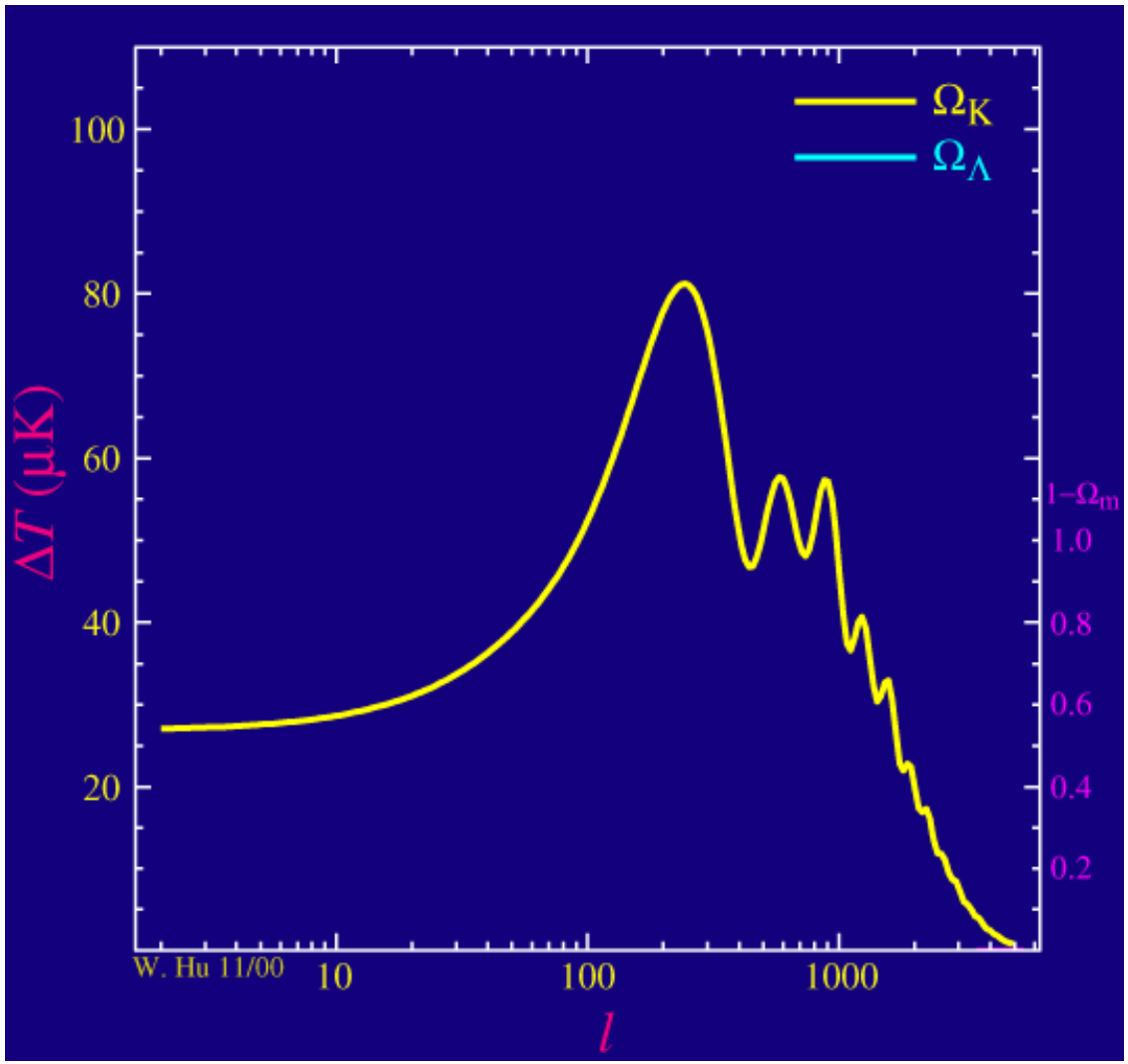
CMB temperature fluctuations as a fingerprint of cosmological model



CMB temperature fluctuations as a fingerprint of cosmological model



In practice, cosmological information is extracted from the statistics of sizes of peaks and minima in the CMB temperature



Angular size of the hot and cold patches

http://background.uchicago.edu/~whu/intermediate/intermediate.html

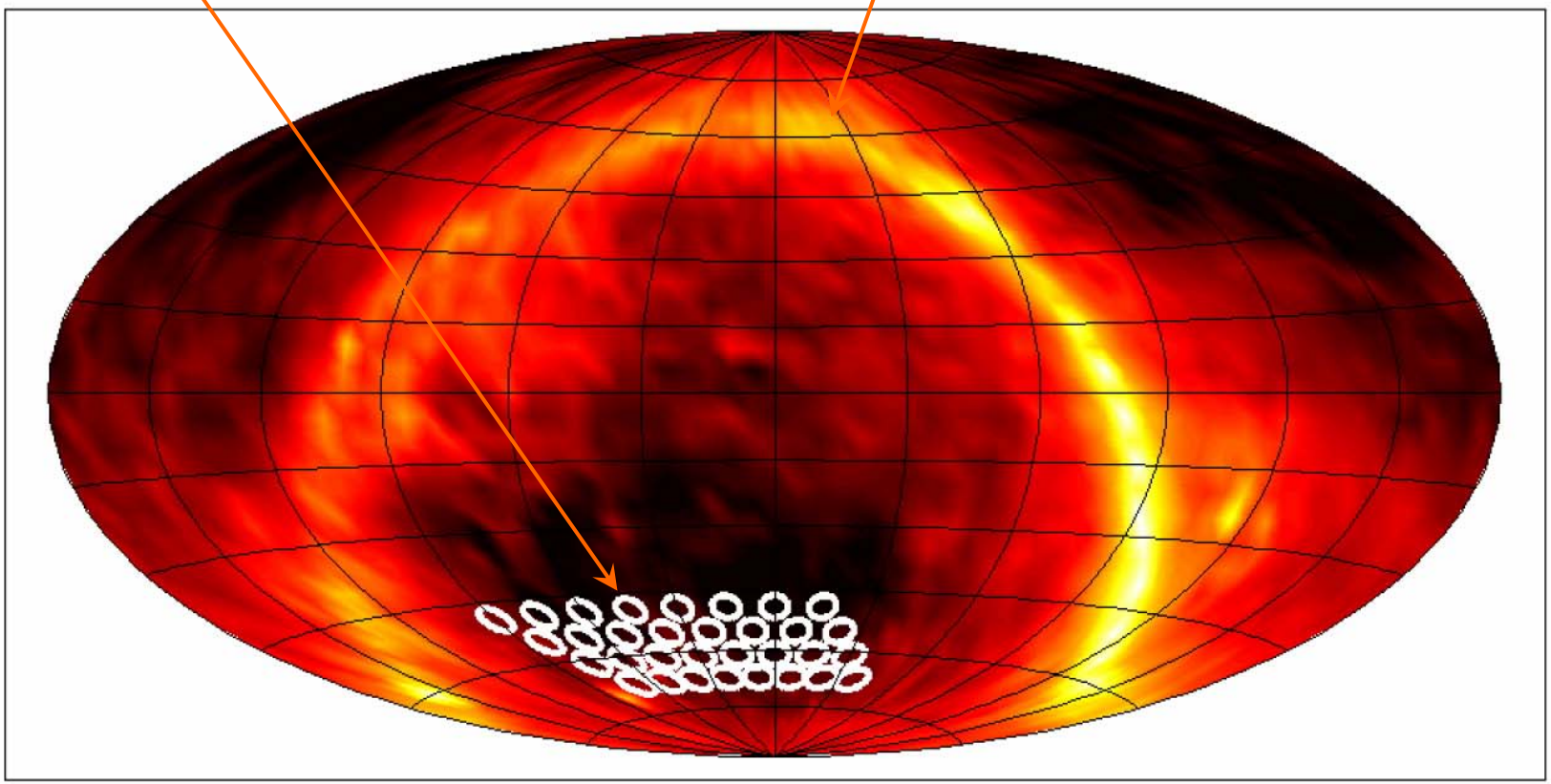
In the late 90s and early 2000s properties of peaks in minima of CMB temperature anisotropies have been studied with ever increasing resolution and accuracy

U.Chicago's DASI experiment, led by Prof. John Carlstrom

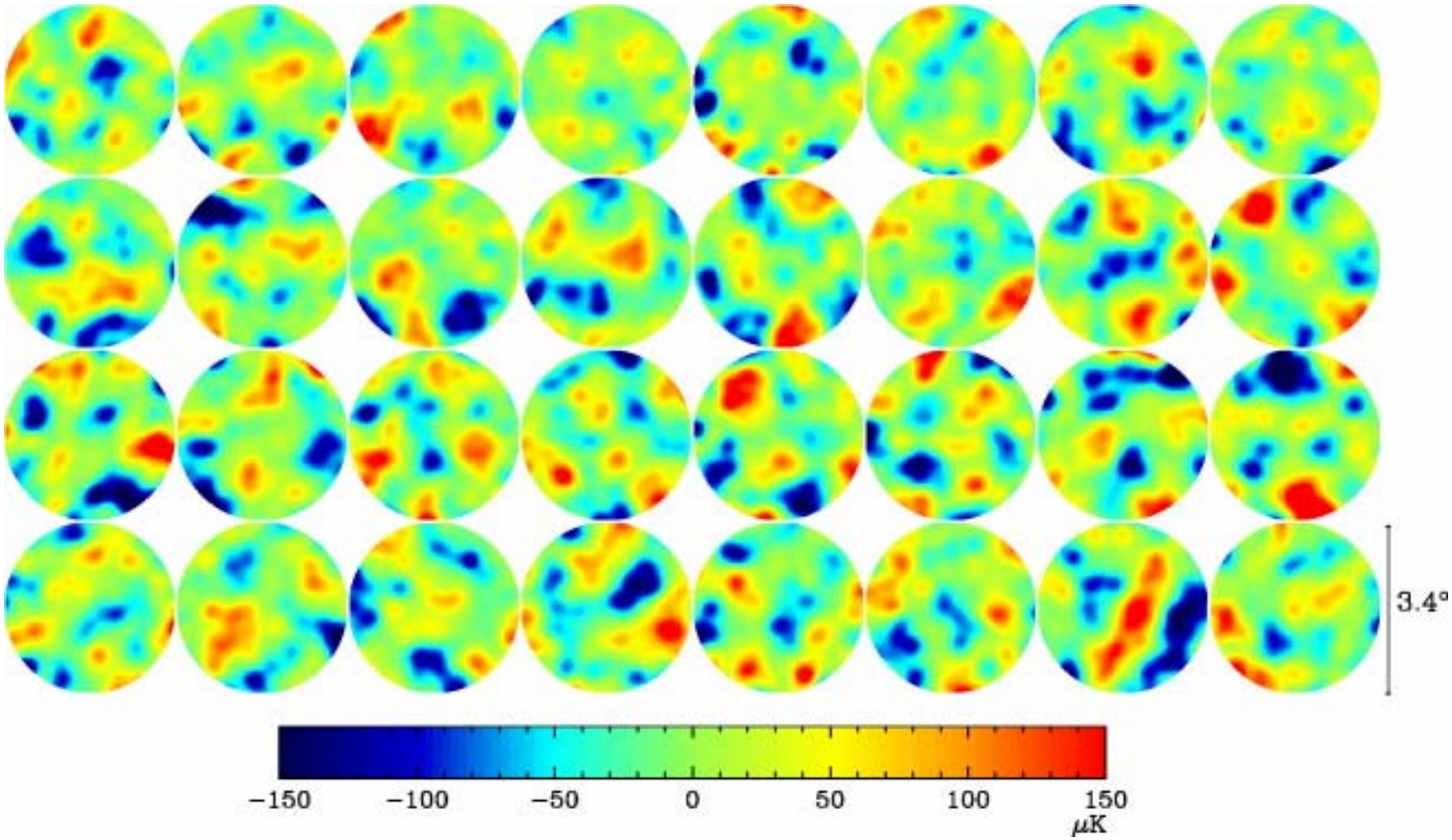
Fields on the sky observed by DASI: selected to be "dark" in infrared emissions from our Milky Way

sky fields observed by DASI – some of the "darkest" on the sky

shades of red – radio emission from the Milky Way



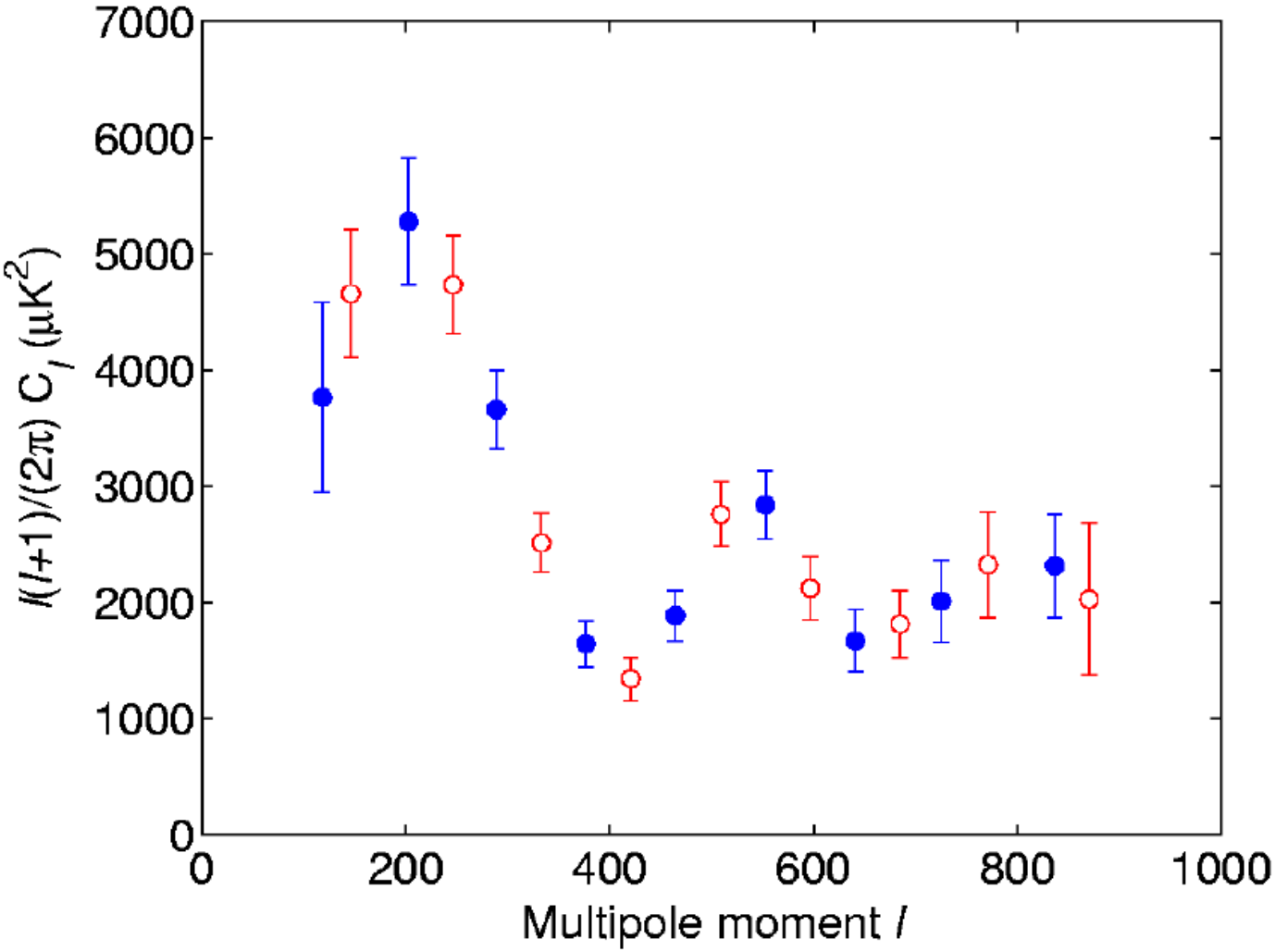
Fluctuations of the CMB temperature measured by DASI in its observed fields



scale of temperature fluctuations in micro-Kelvin = one millionth of a degree Kelvin

from John Carlstrom's press release talk in Washington DC in 2001

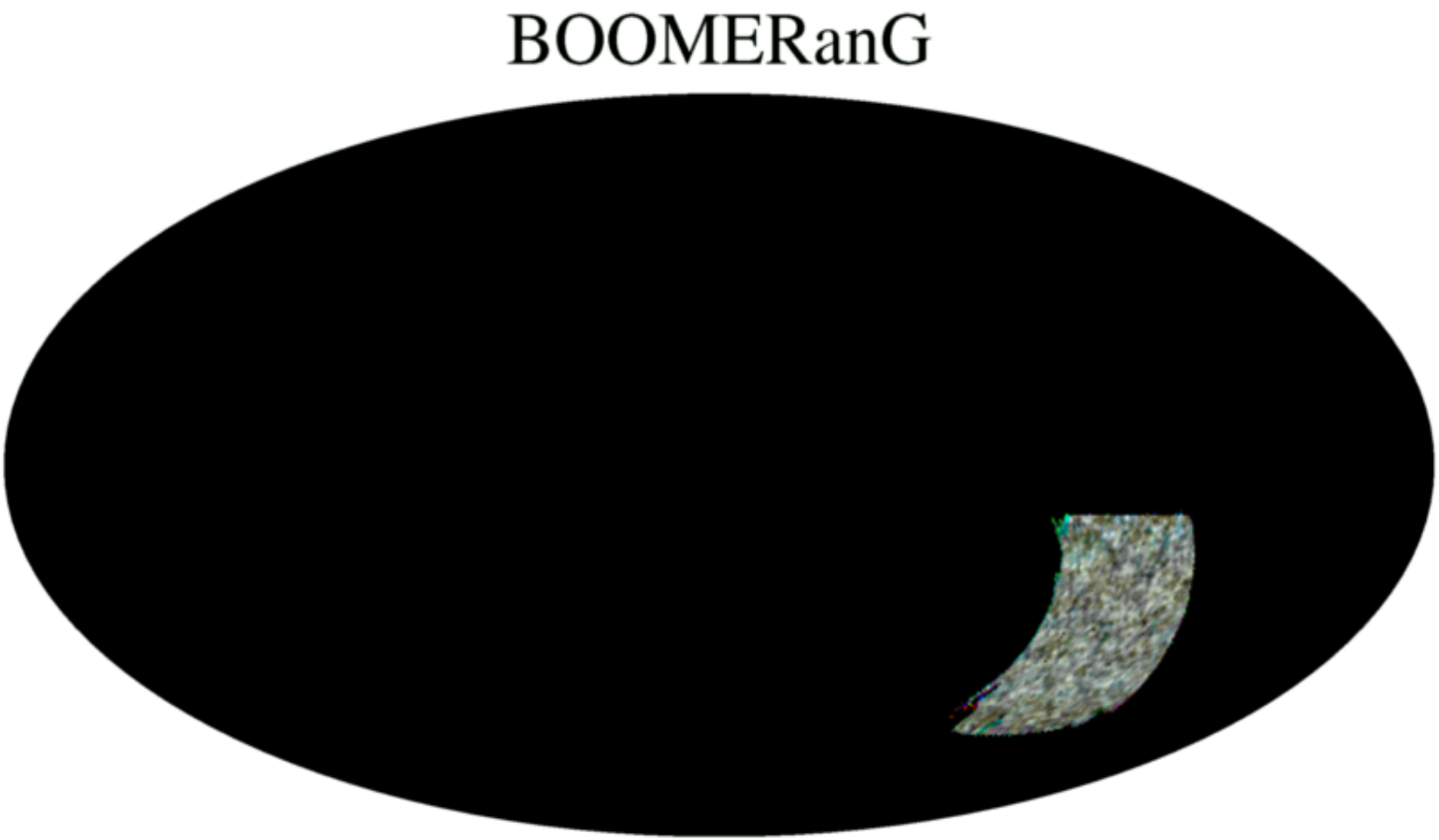
DASI power spectrum

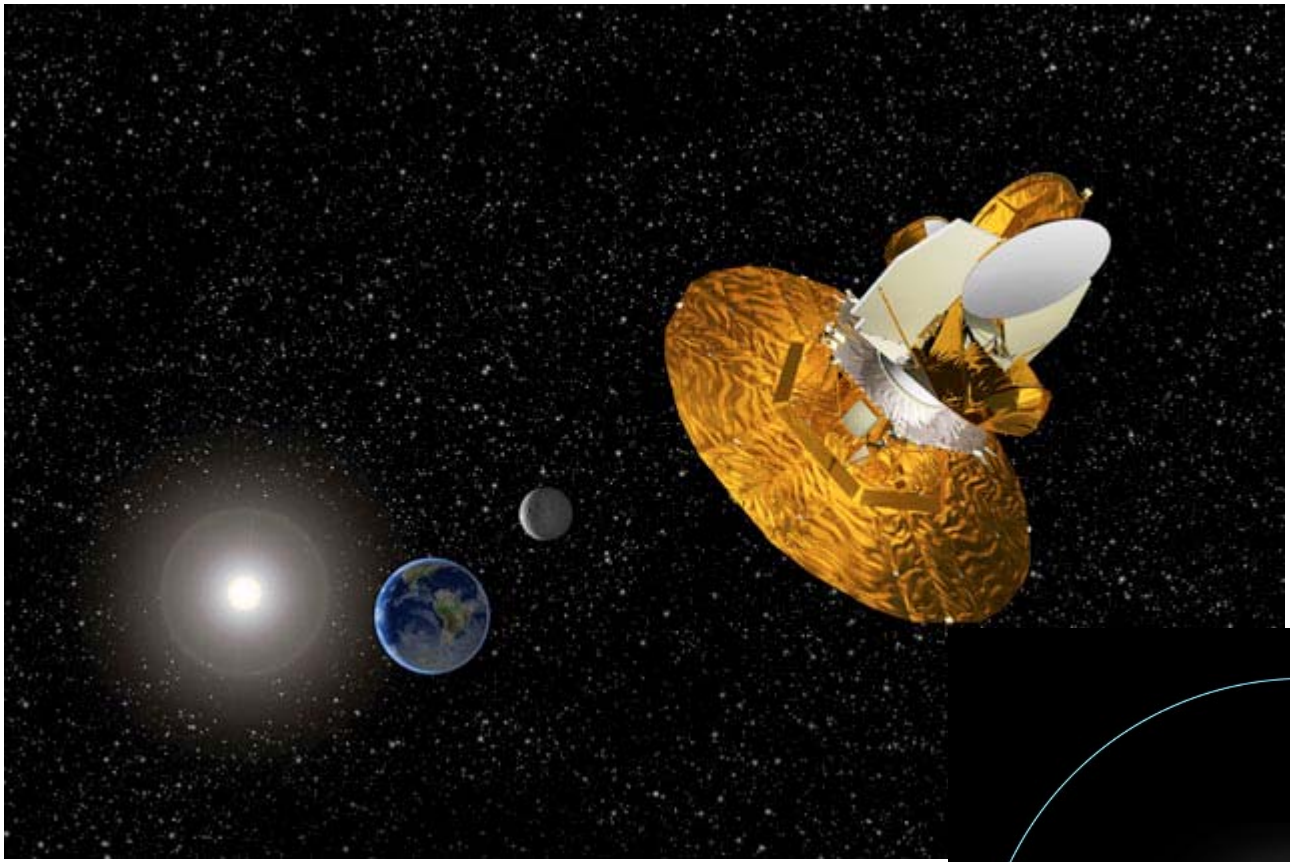


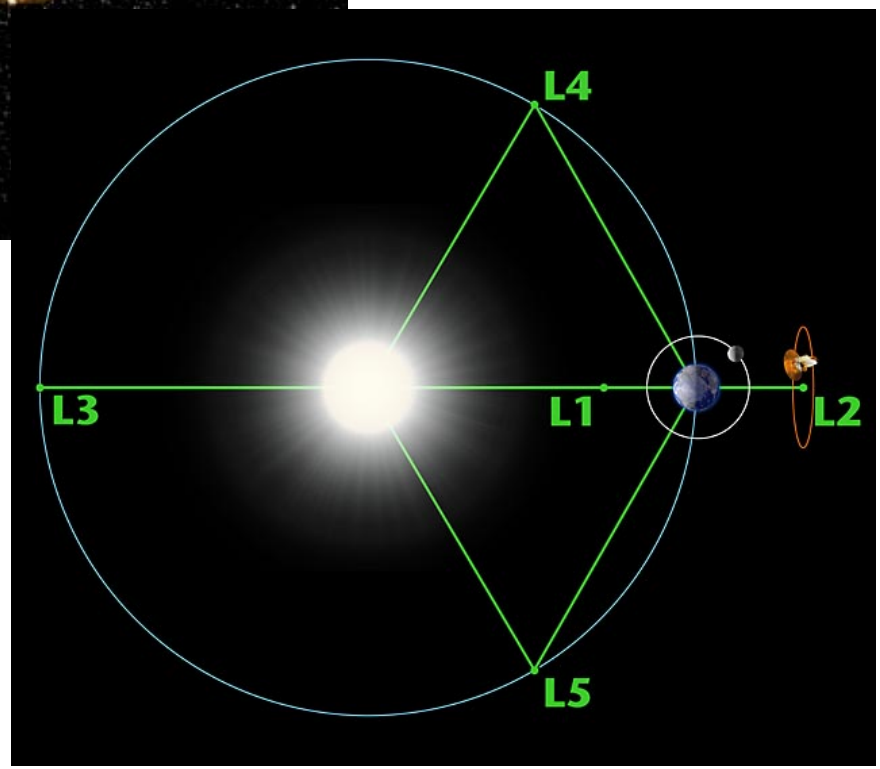
BOOMERanG

Balloon Observations Of Millimetric Extragalactic Radiation and Geophysics

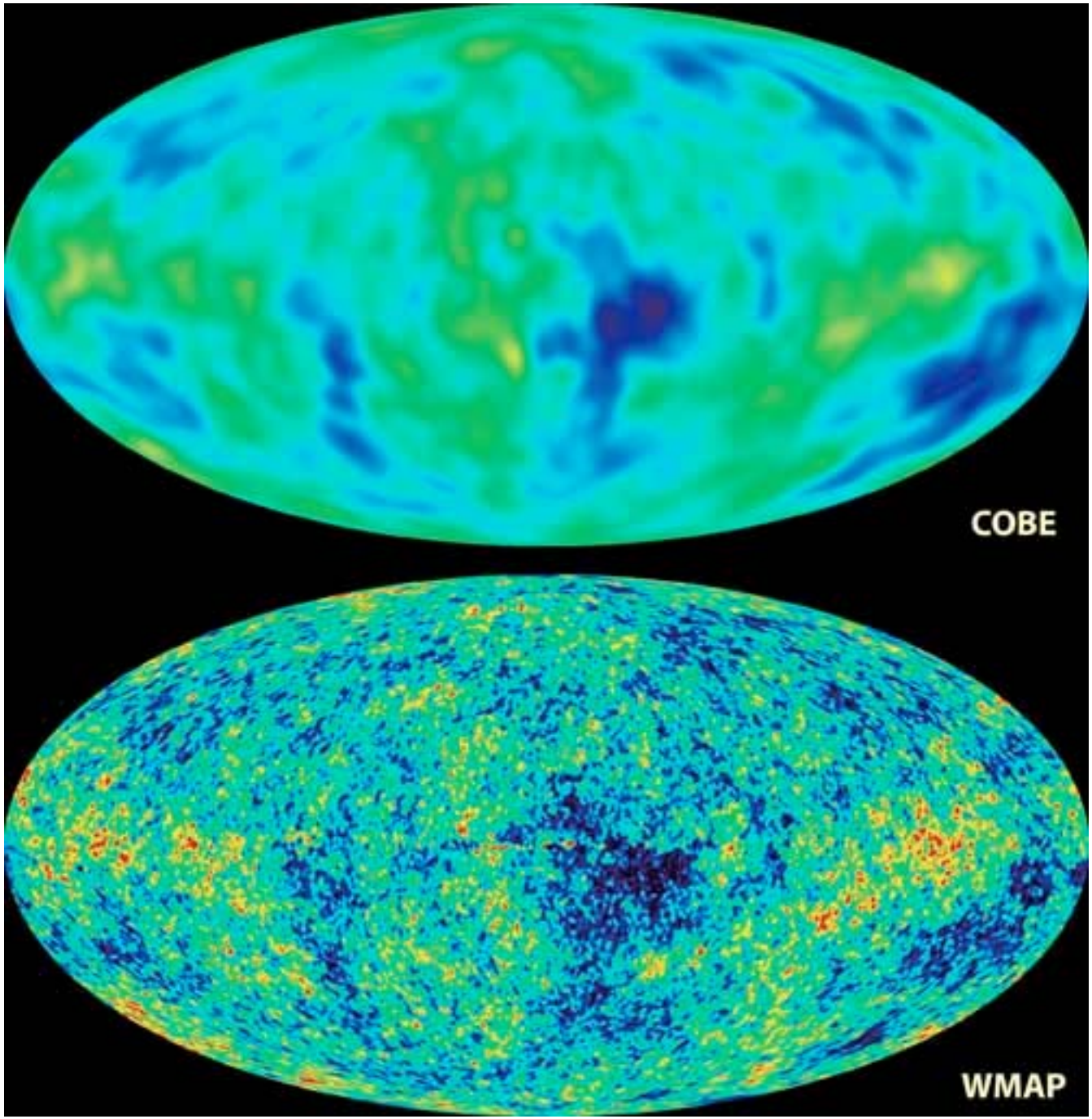
Small Sky Coverage





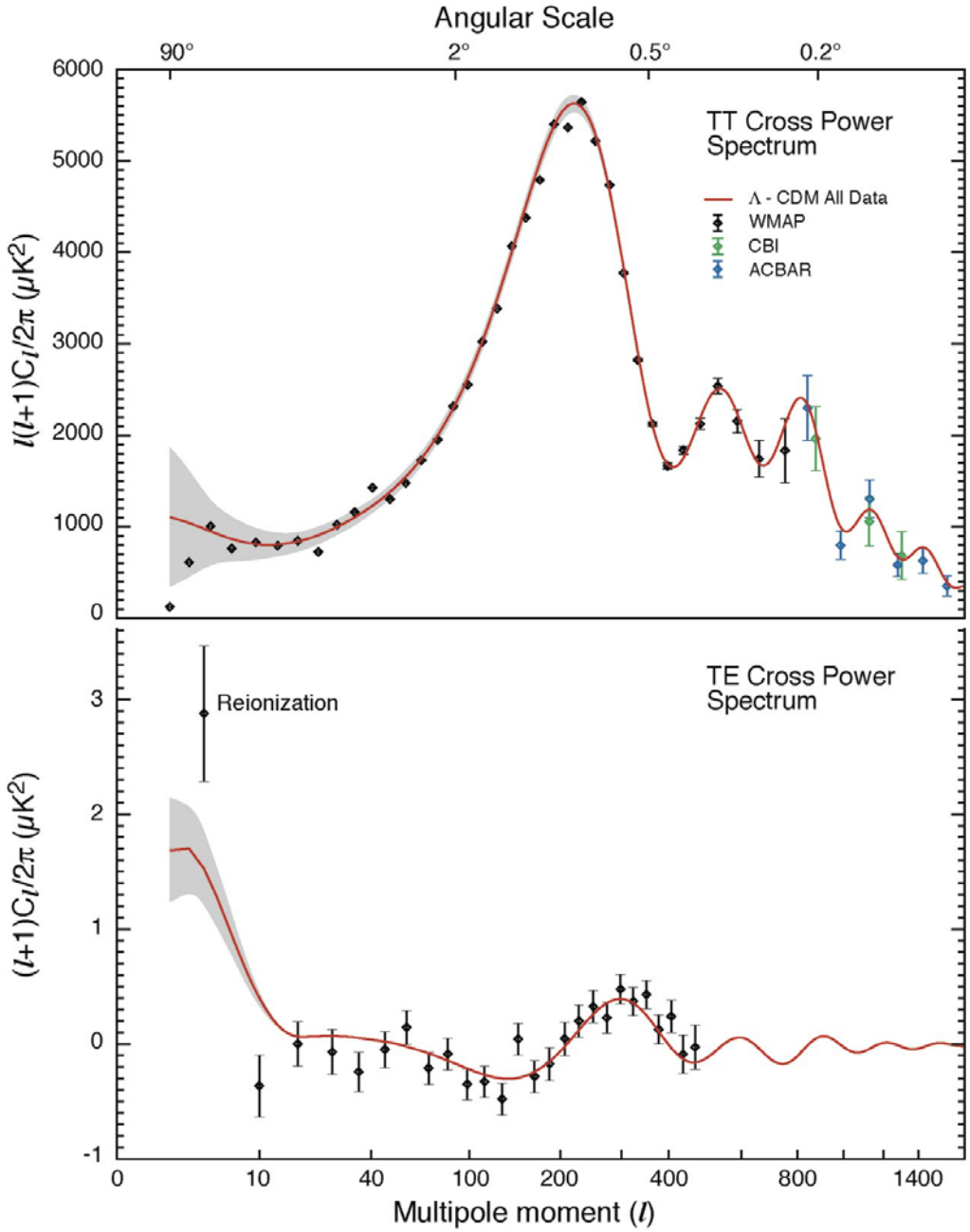


Wilkinson Microwave Anisotropy Probe (WMAP) launched in 2001



COBE detected Anisotropies in the CMB temperature

modern experiments can measure them with much higher angular resolution and sensitivity



Modern measurements of the CMB temperature fluctuation spectrum

Precision cosmology from CMB + some helpers...

parameter	*WMAP value*	*what is it?*
Ω_{total}	1.02 +/- 0.02	total density
Ω_{Λ}	0.73 +/- 0.04	dark energy density
Ω_{matter}	0.27 +/- 0.04	matter density
Ω_{baryon}	0.044 +/- 0.004	baryon density
H_o	71 +/- 4 km/s/Mpc	Hubble constant
t_o	13.7 +/- 0.2 Gyr (billion years)	age of the universe

FUTURE

Q/U Imaging Experiment (QUIET) – experiment to measure polarization of the CMB with new sensitive detectors from JPL

http://quiet.uchicago.edu/

Mount of the CBI experiment in ATACAMA desert in Chile

Bruce Winstein is leading the effort in Chicago

The South Pole Telescope (SPT)

http://spt.uchicago.edu/

- a 10-m single dish radio telescope assembled a year ago at the South Pole.

- Will attempt to measure polarization of the CMB induced by the gravity waves during the period of inflation in the first instance after the Big Bang among other things…