CMB @ 50 & NERSC @ 40

The Universe & Computers

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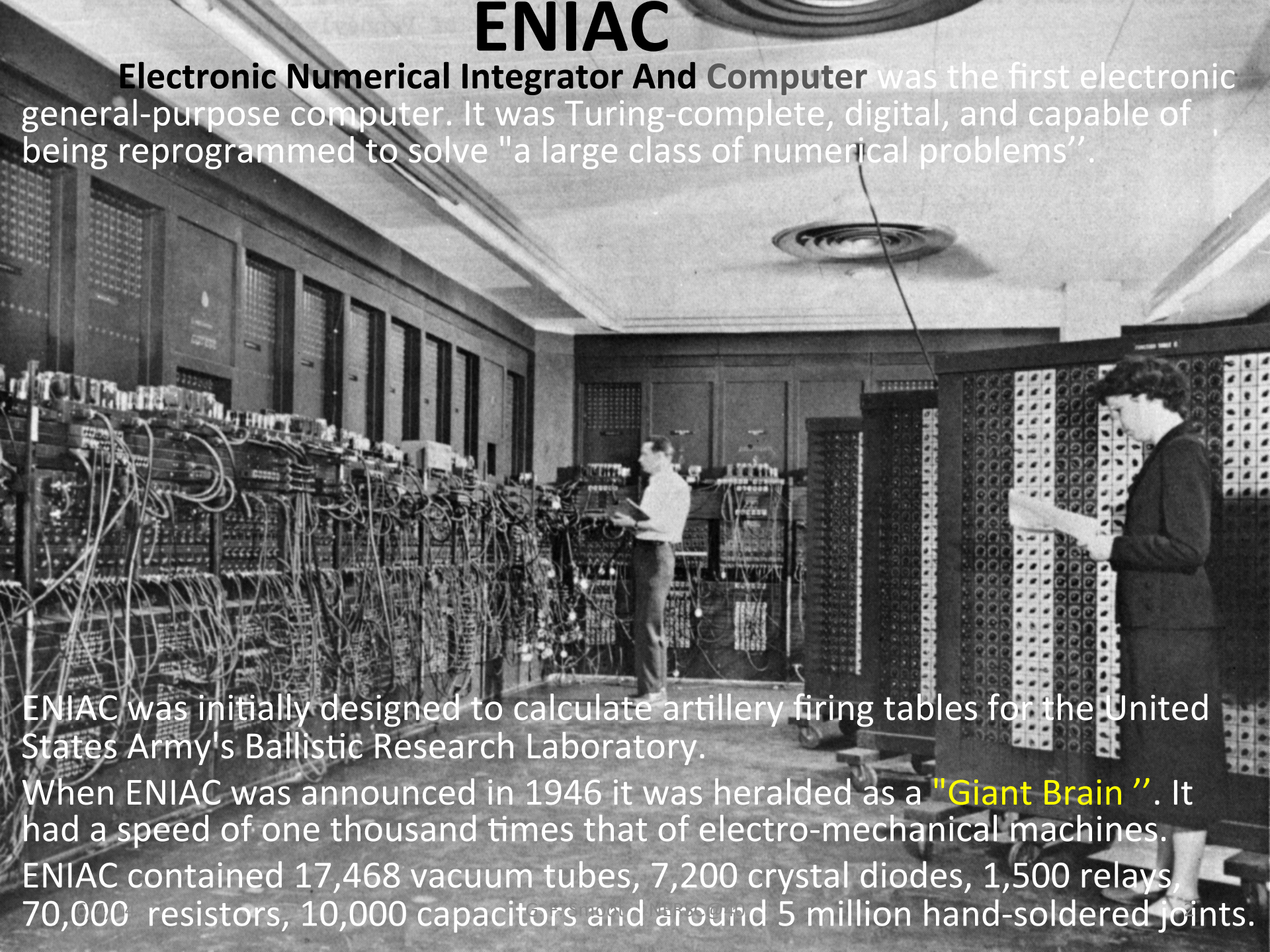
Université Sorbonne Paris Cité / Laboratoire APC
Physics Department; Lawrence Berkeley National Lab
BCCP University of California at Berkeley

ENIAC

Electronic Numerical Integrator And Computer was the first electronic general-purpose computer. It was Turing-complete, digital, and capable of being reprogrammed to solve "a large class of numerical problems''.



ENIAC was initially designed to calculate artillery firing tables for the United States Army's Ballistic Research Laboratory.

When ENIAC was announced in 1946 it was heralded as a "Giant Brain ''. It had a speed of one thousand times that of electro-mechanical machines.

ENIAC contained 17,468 vacuum tubes, 7,200 crystal diodes, 1,500 relays, 70,000 resistors, 10,000 capacitors and around 5 million hand-soldered joints.

Prediction of Cosmic Background Radiation

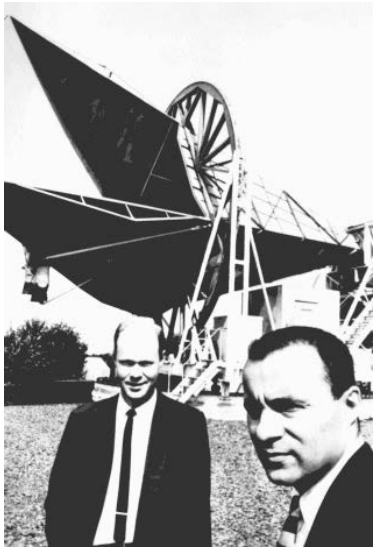
In 1948 George Gamow, Ralph Alpher, & Robert Herman predicted the existence of the cosmic microwave background based on creation of elements in Big Bang.

Alpher and Herman were able to estimate the present temperature of the cosmic microwave background to be 5 K.

Relic Radiation from THE BIG BANG

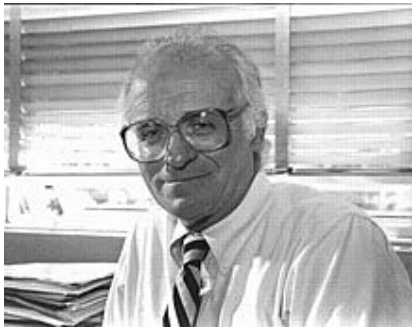
1965 Penzias & Wilson discover isotropic emission at λ=7.35 cm. If a blackbody, T=3±0.5 K. Penzias talks on the phone to Bernie Burke, who heard from Ken Turner about a talk by P.J.E. Peebles (Princeton) who had predicted the universe would be filled with a 5 K radiation.

Discovery of the Cosmic Background Radiation (CBR).



Arno Penzias & Robert Wilson Nobel Prize (1978)

Jim Peebles

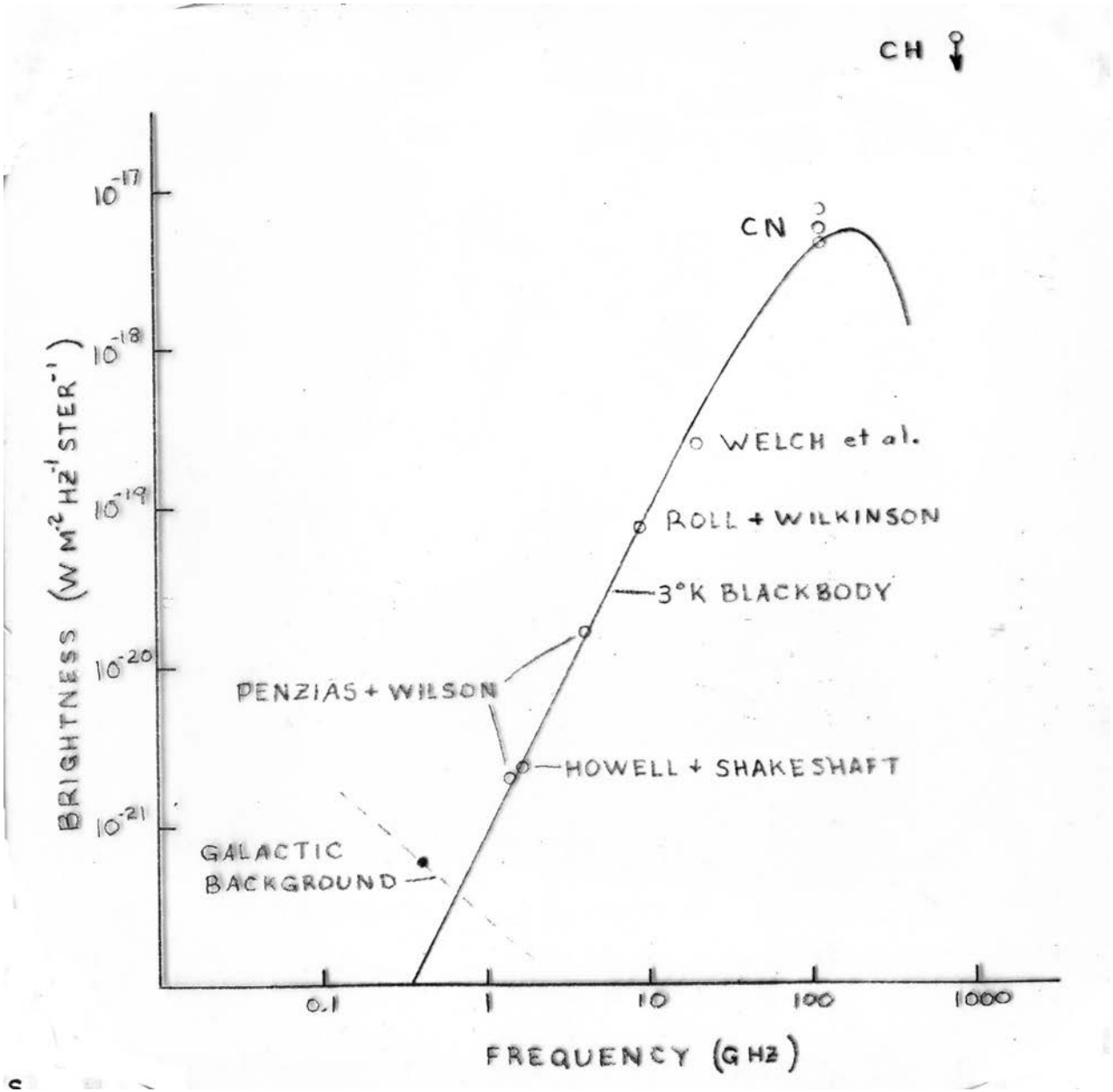


Bernie Burke

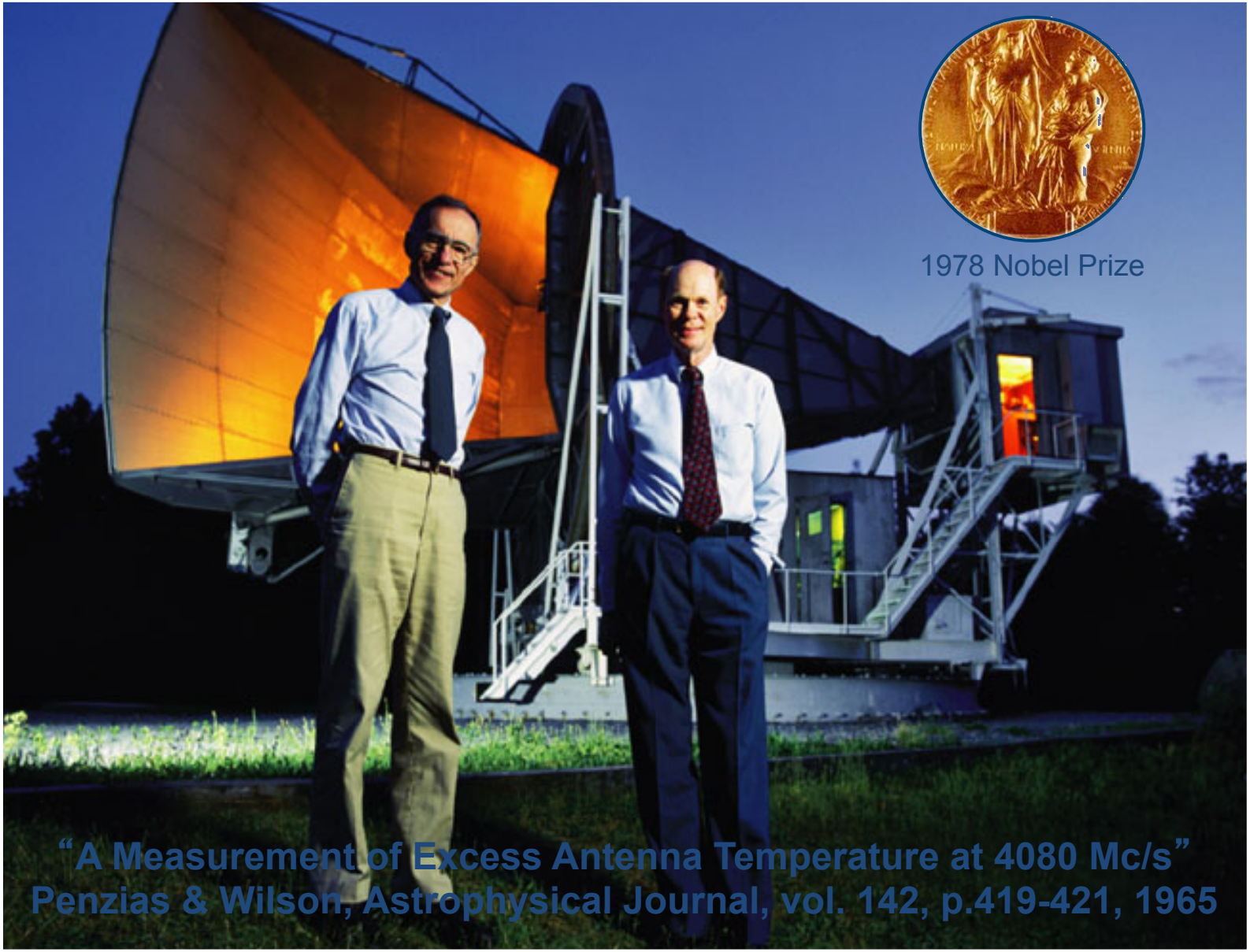
Confirmation

- The first confirmation came quickly from an unexpected source. From 1939 to 1943 Dunham, Adams and McKellar had measured the rotational excitation of CN molecules in diffuse interstellar clouds from their absorption of star light. Herzberg wrote in his standard book on the interstellar medium.
  - "From the intensity ratio of the lines a rotational temperature of 2.3 degrees follows, which of course has only a very restricted meaning."
- The excitation of CN molecules was remembered by 3 separate groups.
  - Burnie Burke told George Field about the measurements. George had written a paper while an assistant professor at Princeton ...
  - Pat Thaddeus asked Nick Wolfe about tests for radiation and Nick remembered the CN.
  - Iosif Shklovsky remembered the CN.
- By the end of the year Wilkinson and Roll had made a measurement at 3-cm wavelength which agreed with P-W.

Measurements of the CMBR within a Year

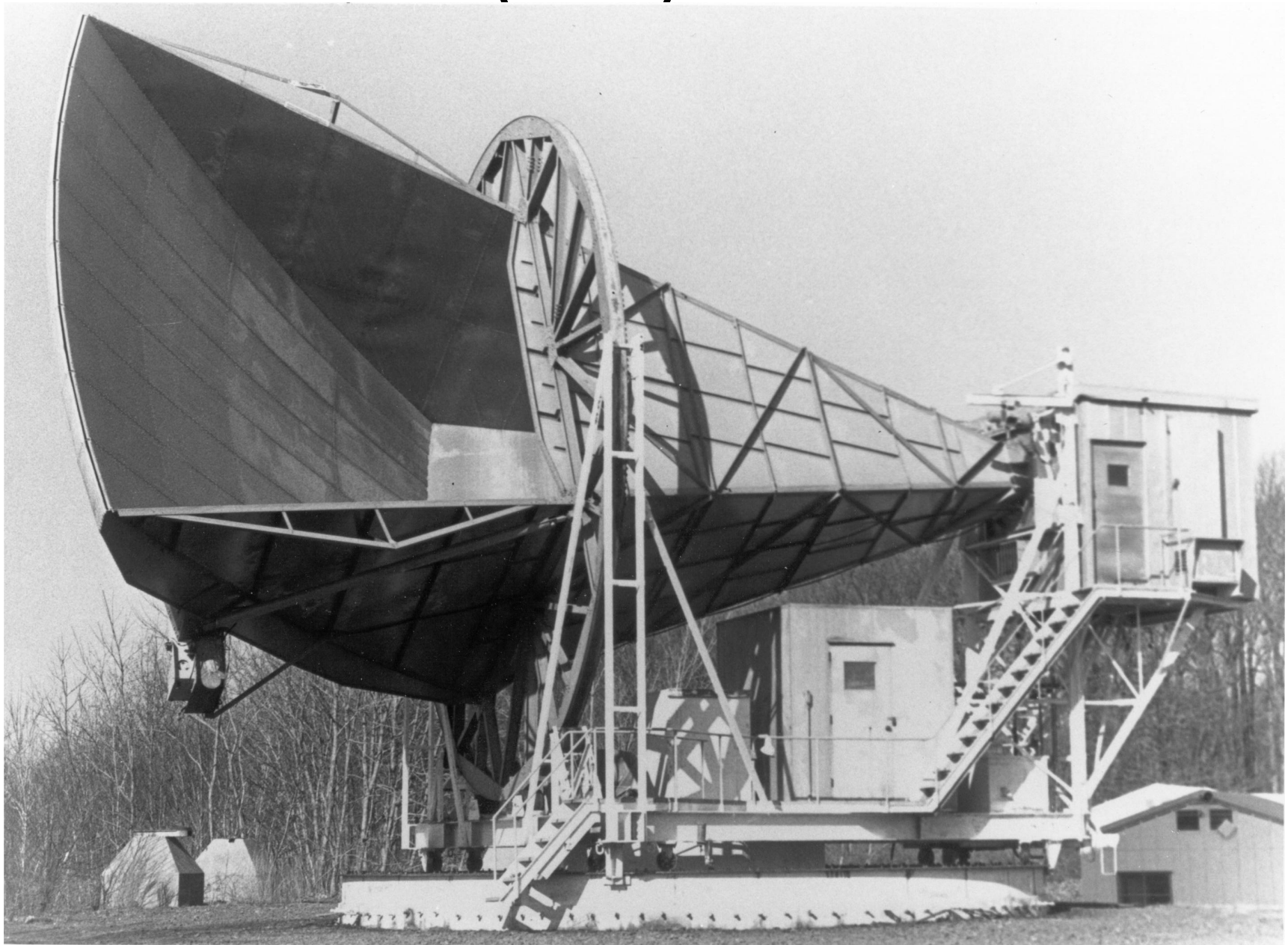


1965: Discovery of the CMB

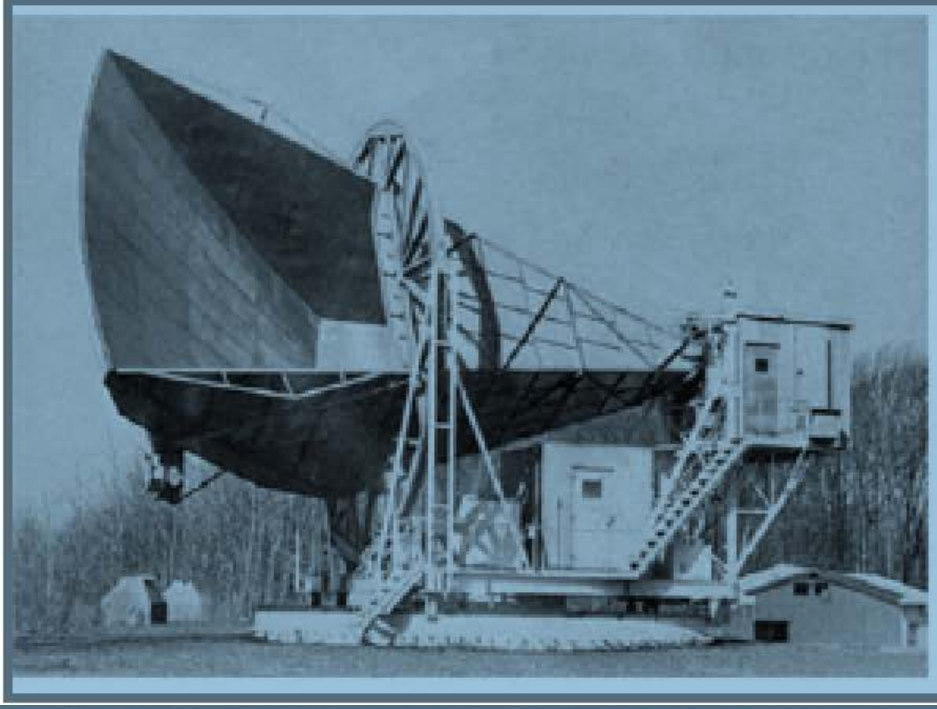


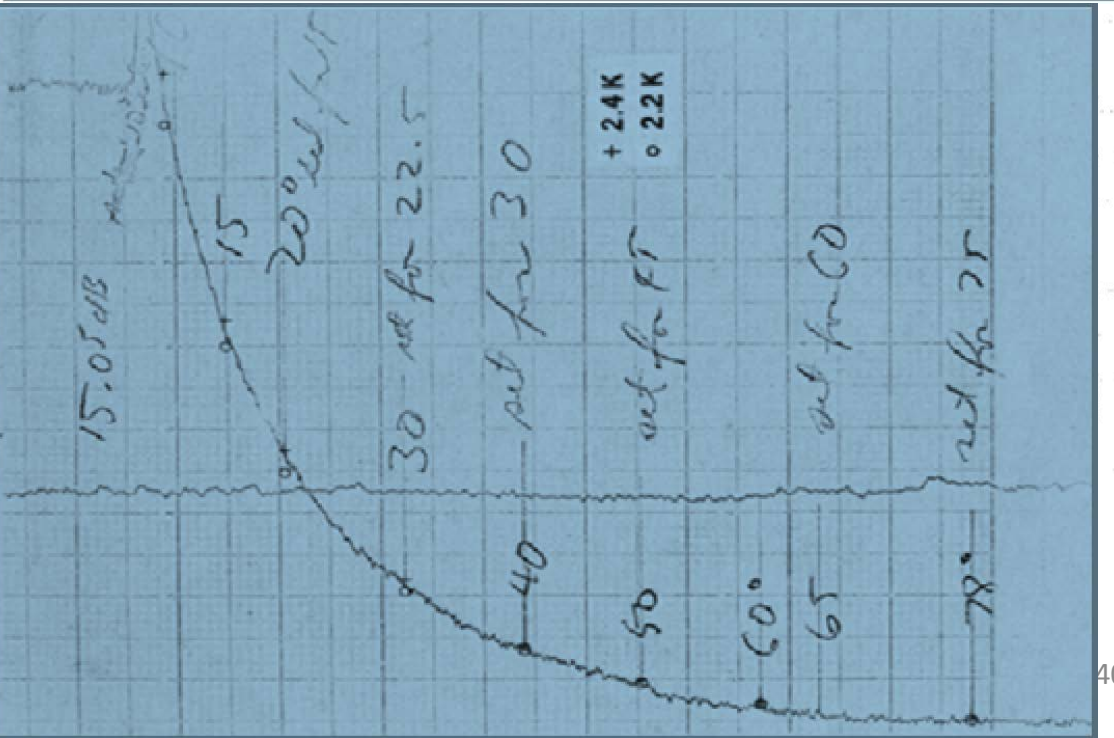
HORN ANTENNA
HAS BEEN DESIGNATED A
NATIONAL HISTORIC LANDMARK
THIS SITE POSSESSES NATIONAL SIGNIFICANCE IN COMMEMORATING THE HISTORY OF THE UNITED STATES OF AMERICA. SCIENTISTS ARNO PENZIAS AND BOB WILSON WITH THE ANTENNA FOUND THE EVIDENCE CONFIRMING THE "BIG BANG" THEORY OF THE CREATION OF THE UNIVERSE, FOREVER CHANGING THE SCIENCE OF COSMOLOGY.
1989
NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

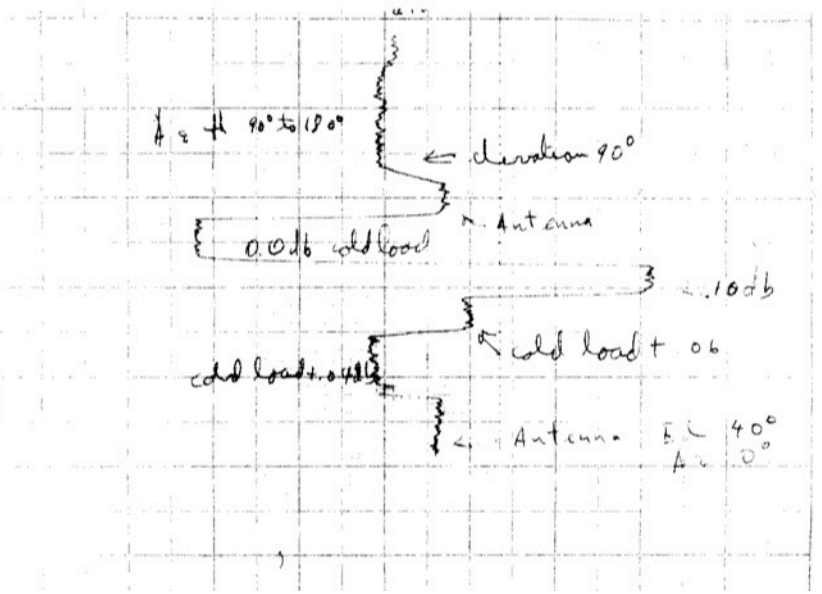
The 20-foot (6-m) Horn Reflector



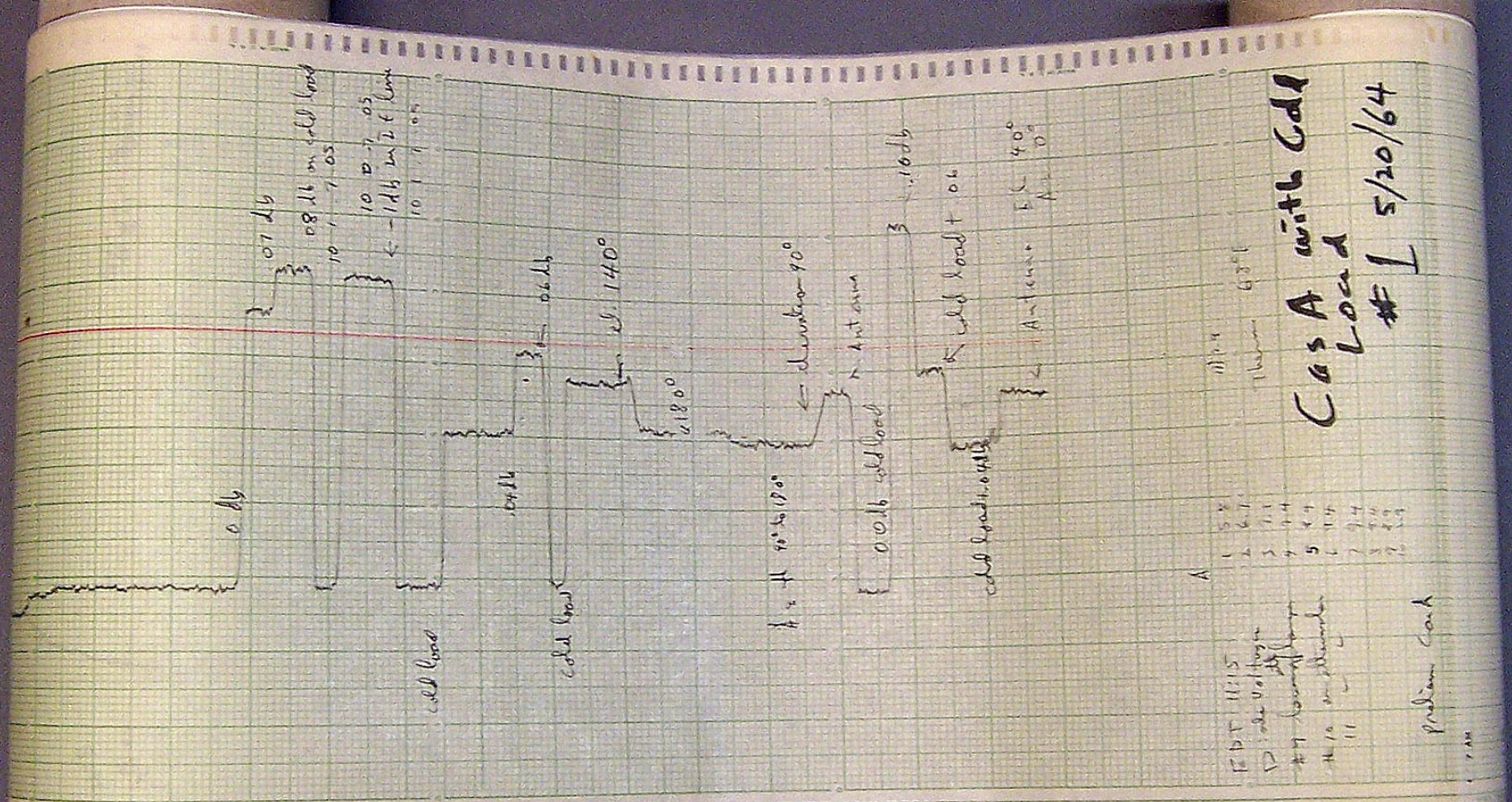
Penzias & Wilson / Bell Labs Receiver at Deutsches Museum




+ 2.4K
o 2.2K
15.05dB
15
20° set for 15
30 set for 22.5
set for 30
set for 45
set for 60
set for 75
40
50
60°
65
78°

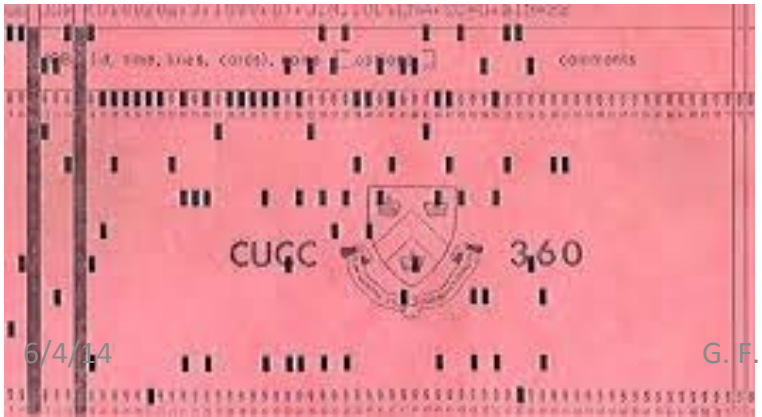

A & H 90° to 180°
elevation 90°
Antenna
0.0db cold load
.10db
cold load + .06
cold load + .04db
Antenna
40°

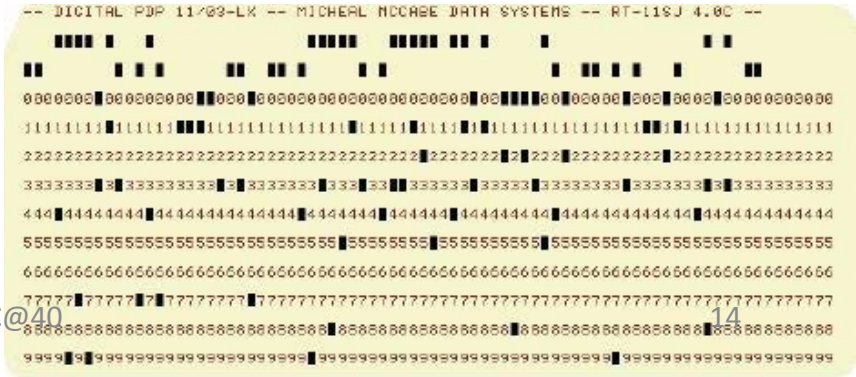
Original Strip Chart of CMB Discovery



50th Anniver
started the w

IBM punch cards





Digitial Equipment Corporation (DEC) PDP-11 (1970)

16-bit minicomputer
small-scale transistor–transistor logic

Real-time operating system with also a small foreground task.

The PDP 11/34 supported up to 256 kB of Unibus memory.

Terminals circa 1970s

DEC LSI-11/23

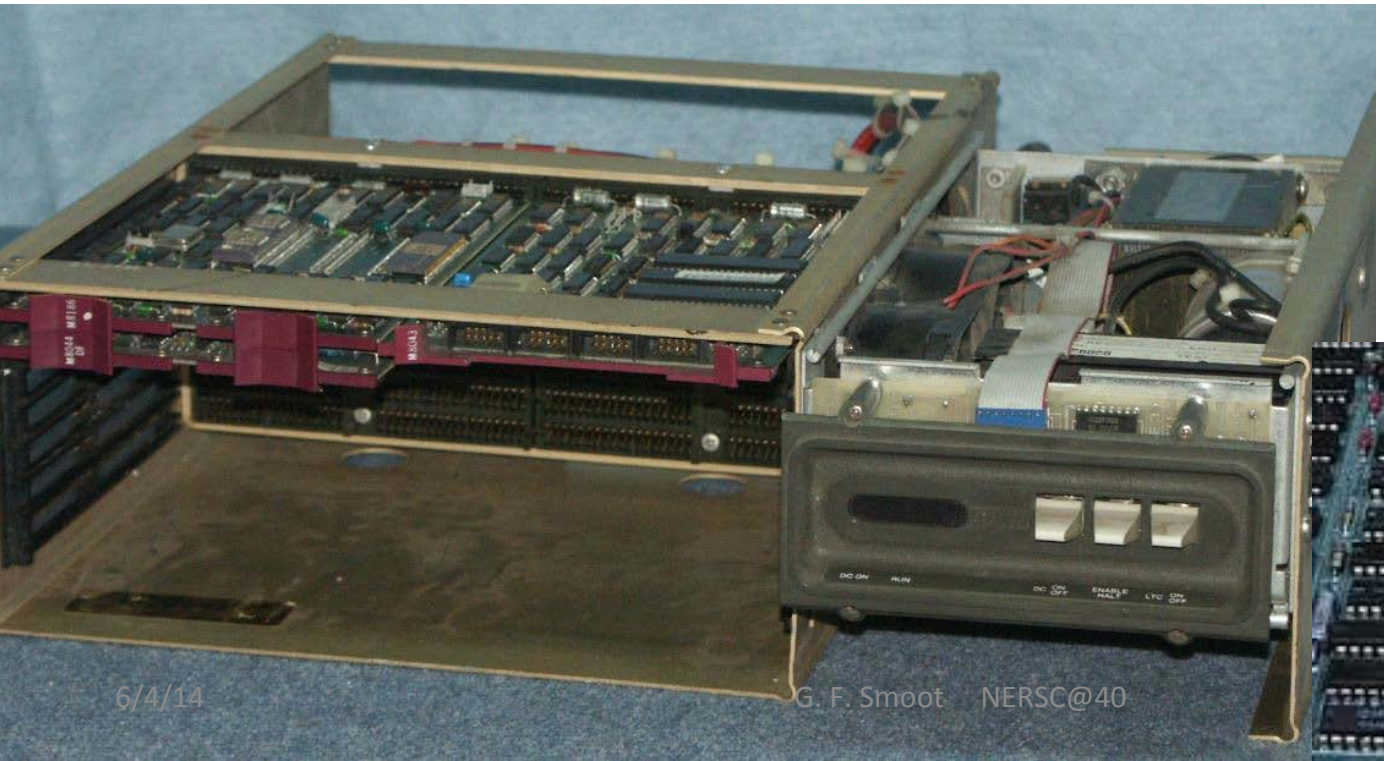
February 1975

The CPU microcode included a debugger: firmware with a direct serial interface (RS-232 or current loop) to terminal. This let the operator do debugging by typing commands and Reading octal numbers, rather than operating switches and reading lights, the typical debugging method at the time. The operator could thus examine and modify the computer's registers, memor and input/output devices, diagnosing and perhaps correcting failures in software and peripherals (unless a failure disabled the microcode itself).

The operator could also specify from which disk to boot.

PDP-11/23 — Second generation of LSI. Early units supported only 248 kB of memory.

LSI 11/73 supported up to 4 MB of memory



COBE DMR 31.4 GHz (9-mm) Lab Breadboard

Spectrum : My Posse at White Mtn.

South Pole | Steve Levin | John Gibson | Bill Vinje | Giovanni de Amici | Marc Bensadoun | Michele Limon | George Smoot | Marco Bersanelli

DEC VAX (Virtual Address eXtension)
32 bit instructions

DEC Alpha Cluster

LBL CDC 7600

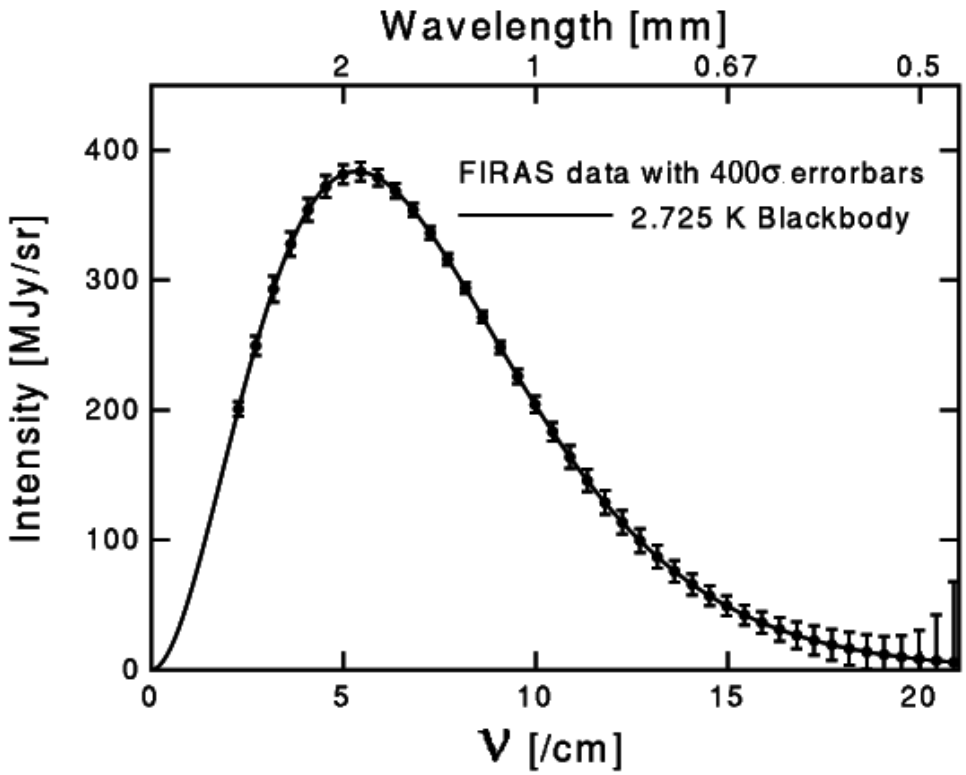
The People's Printer & Card Reader (mid – 1970's)

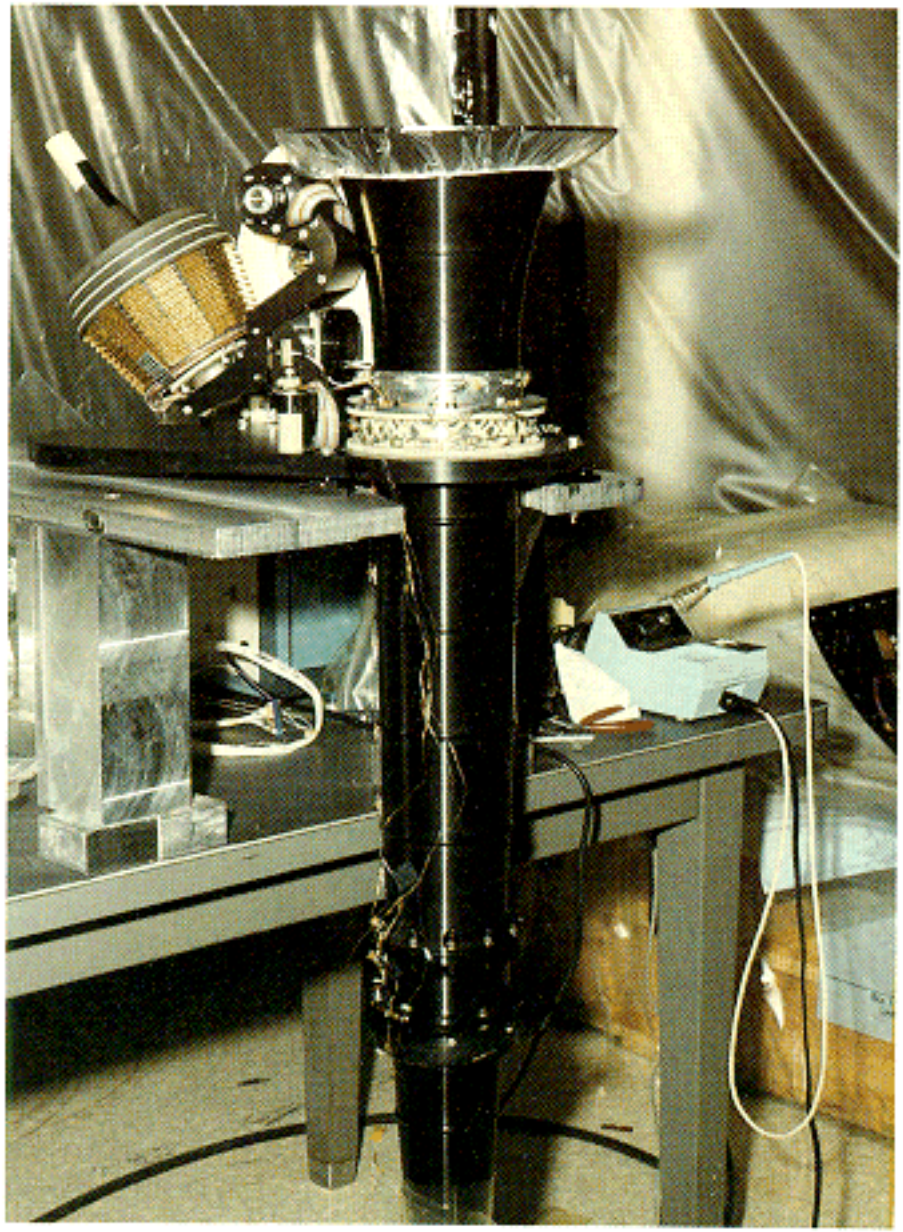
CONTROL DATA 166 Line Printer

CONTROL DATA 405 Card Reader

FIRAS Horn & Ext. Calibrator

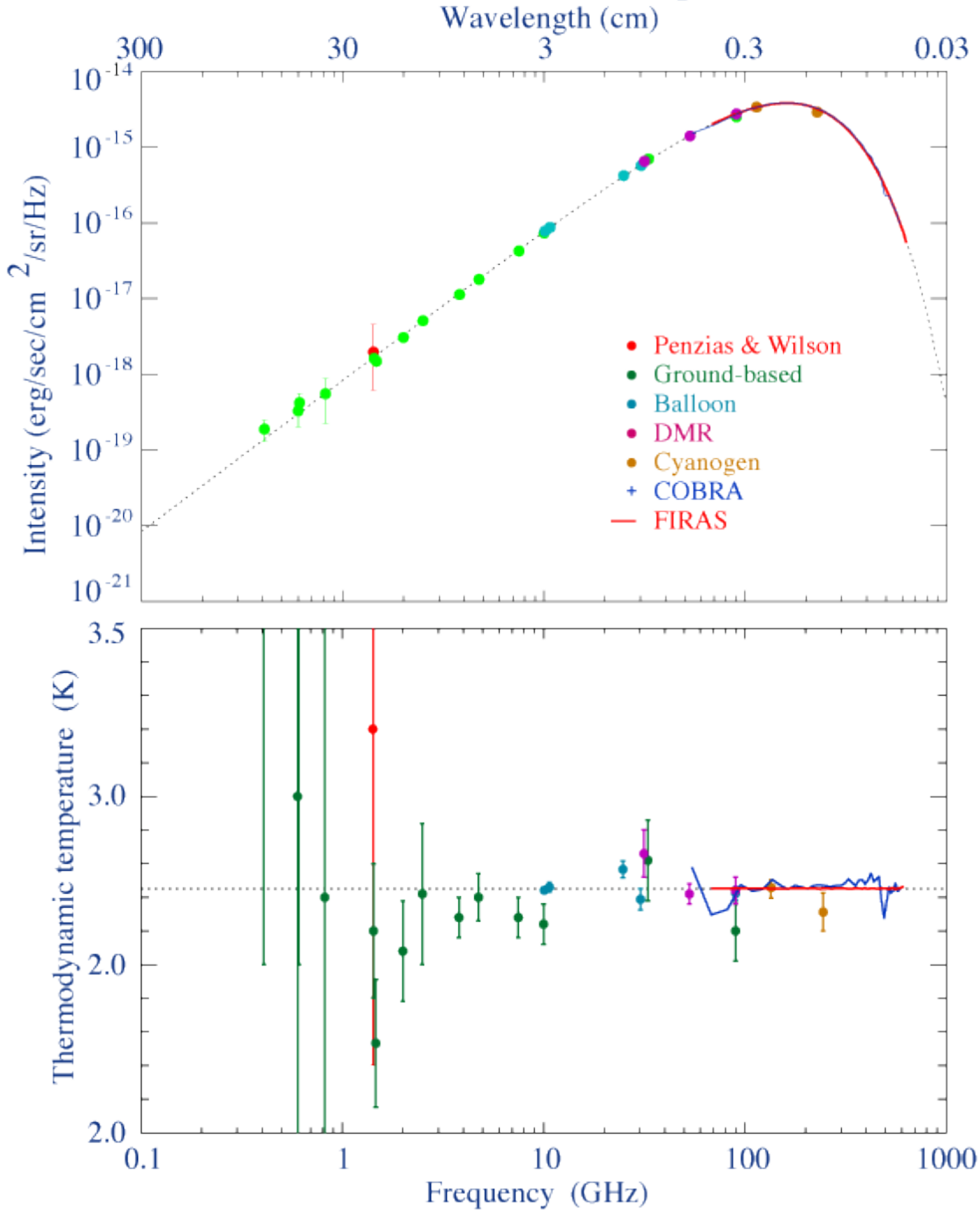
COBE Spectrum of the Universe
-first 7 minutes of data
-Jan 1990 AAS meeting

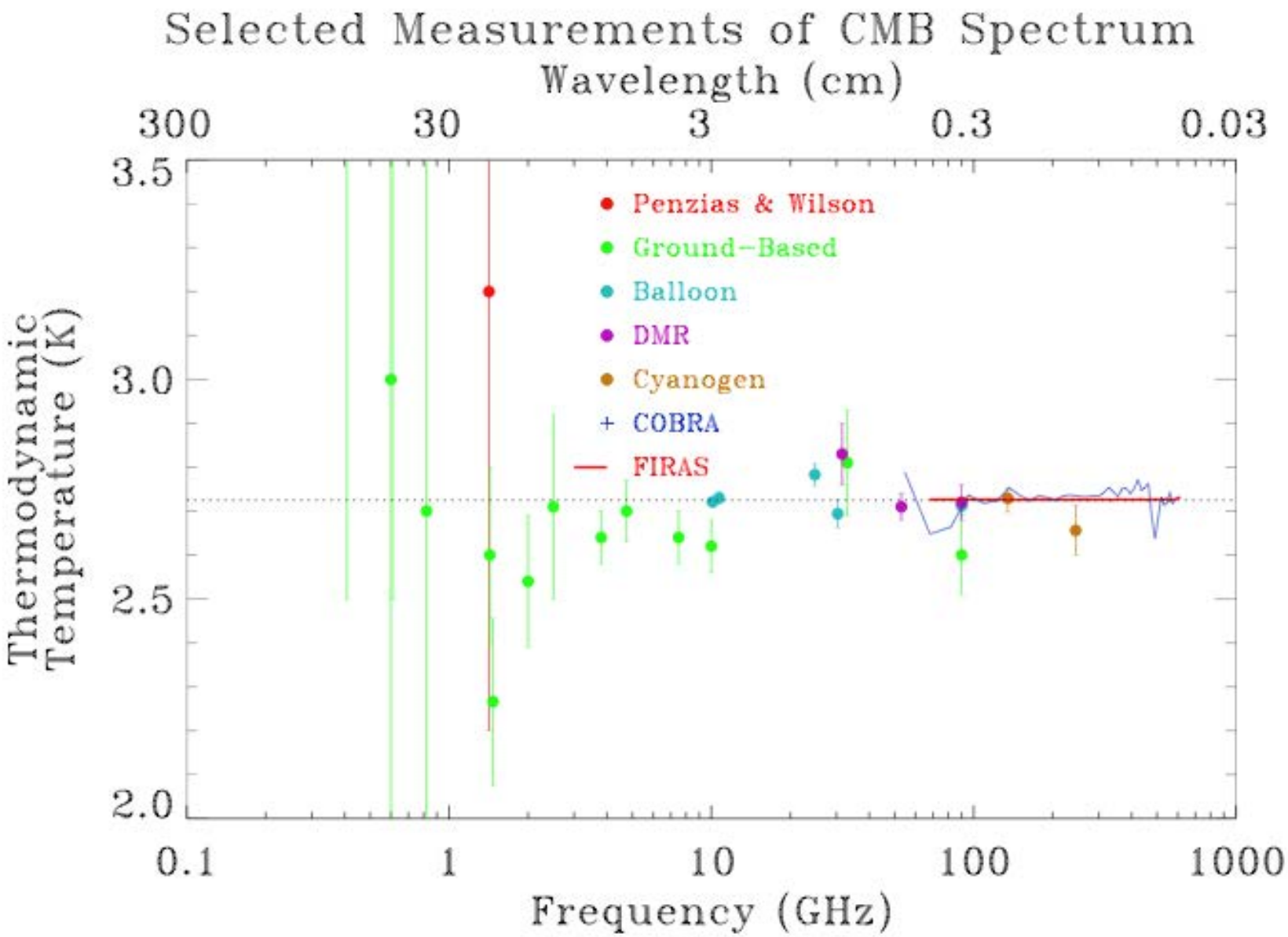




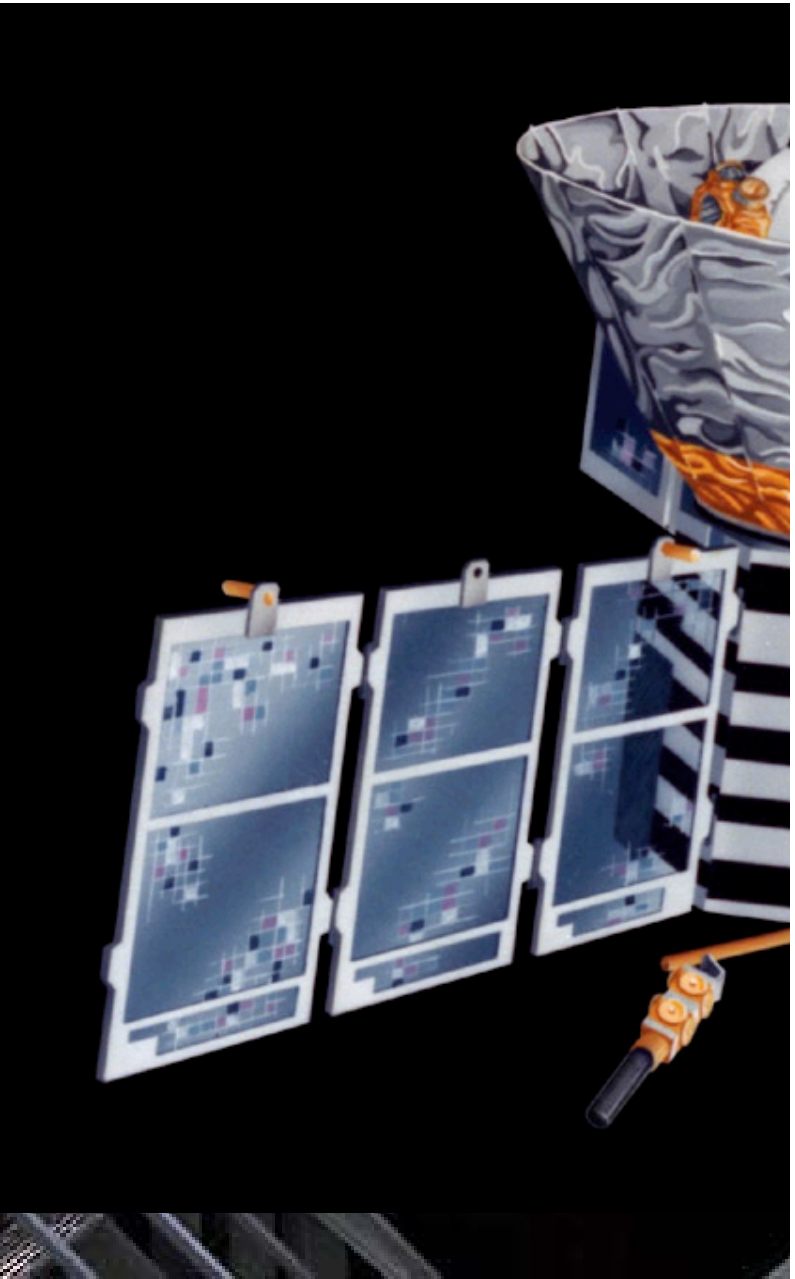
Horn antenna with movable calibrator. Protective plastic covers will be removed.

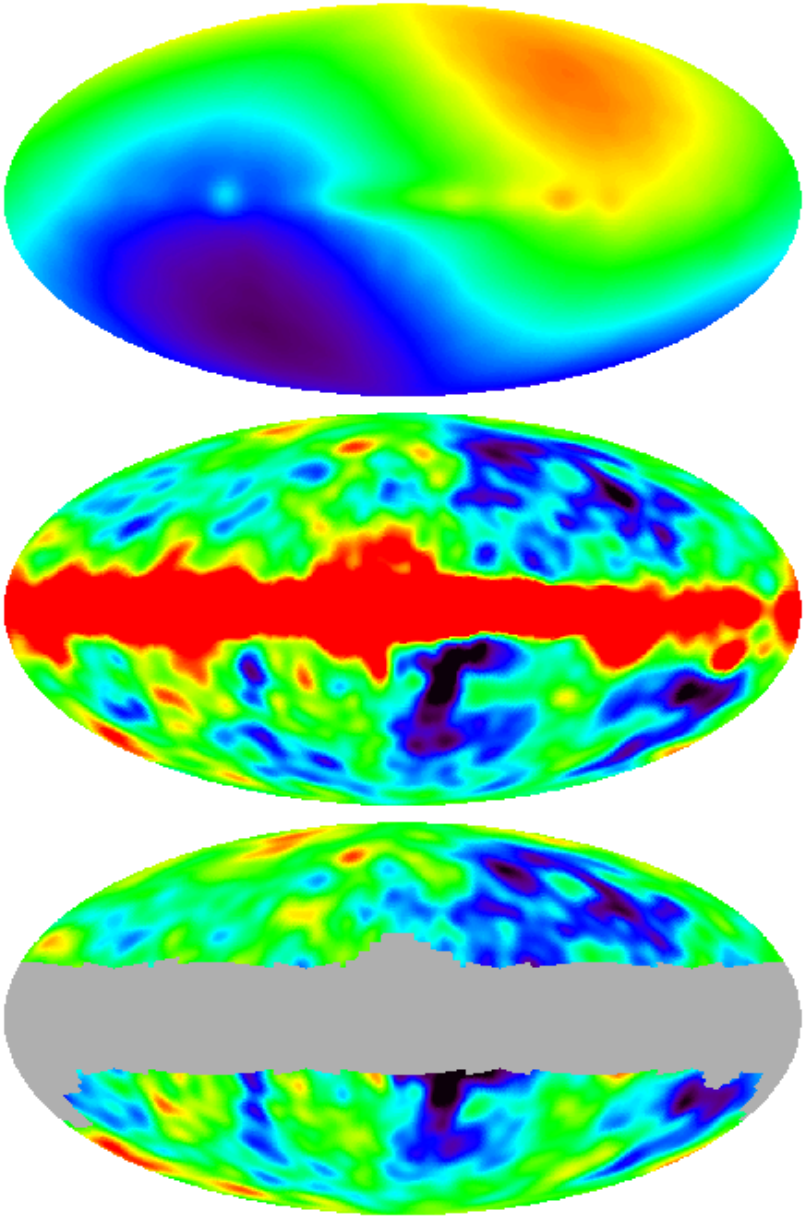
Measurements of CMB Spectrum

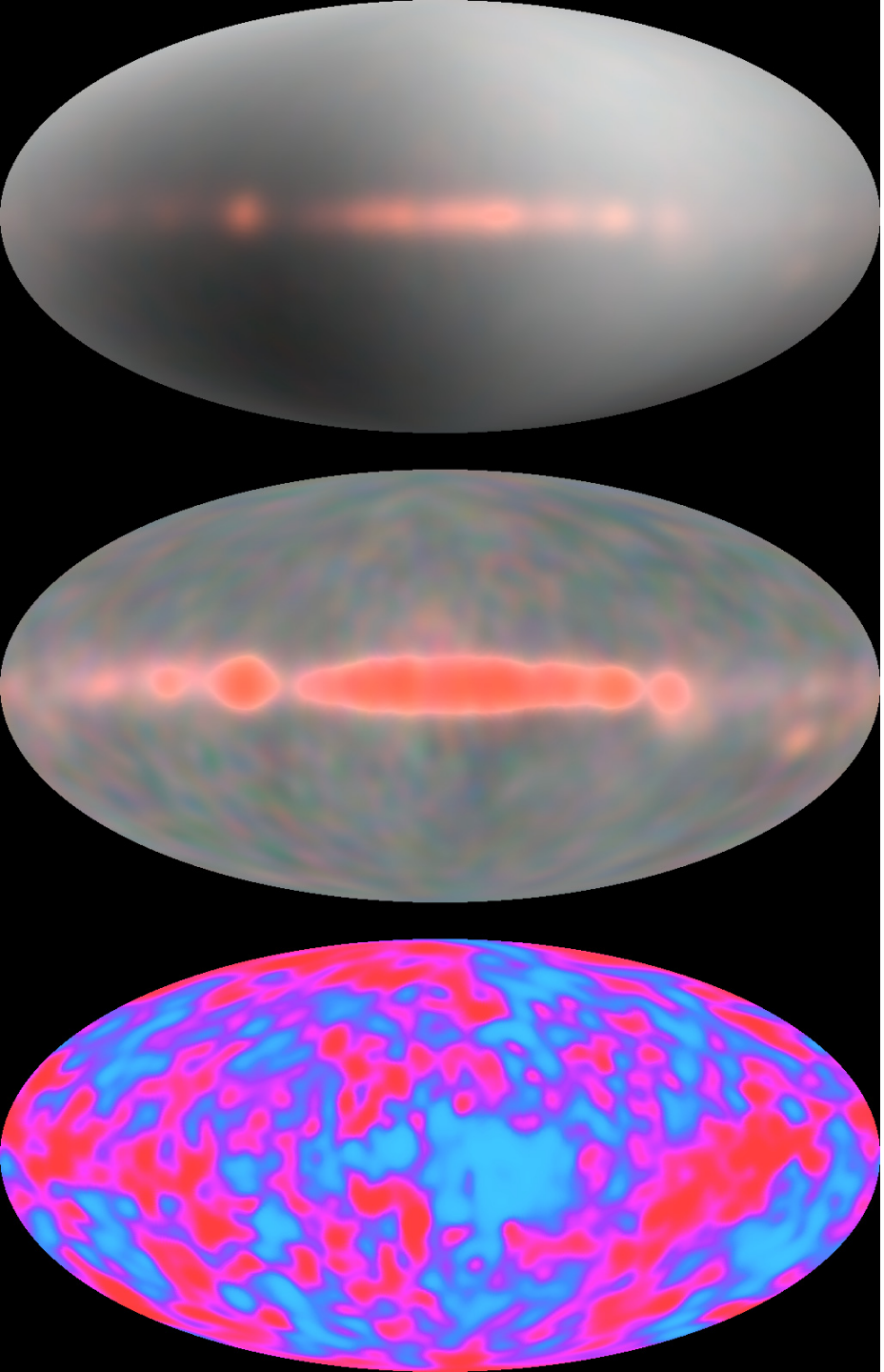



Selected Measurements of CMB Spectrum
Wavelength (cm)
300
30
3
0.3
0.03
3.5
3.0
2.5
2.0
Thermodynamic Temperature (K)
Penzias & Wilson
Ground-Based
Balloon
DMR
Cyanogen
COBRA
FIRAS
0.1
1
10
100
1000
Frequency (GHz)

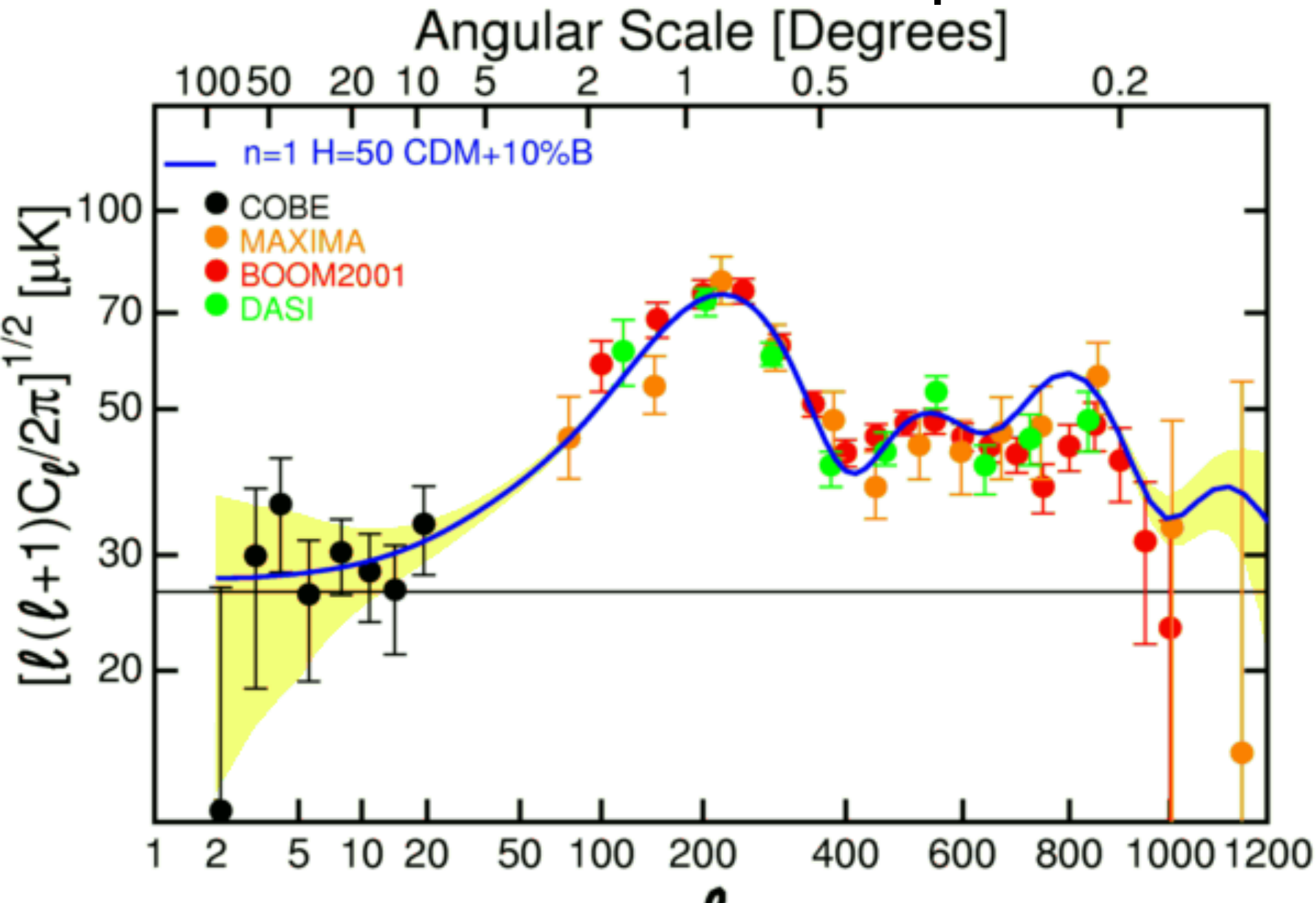
COBE showi



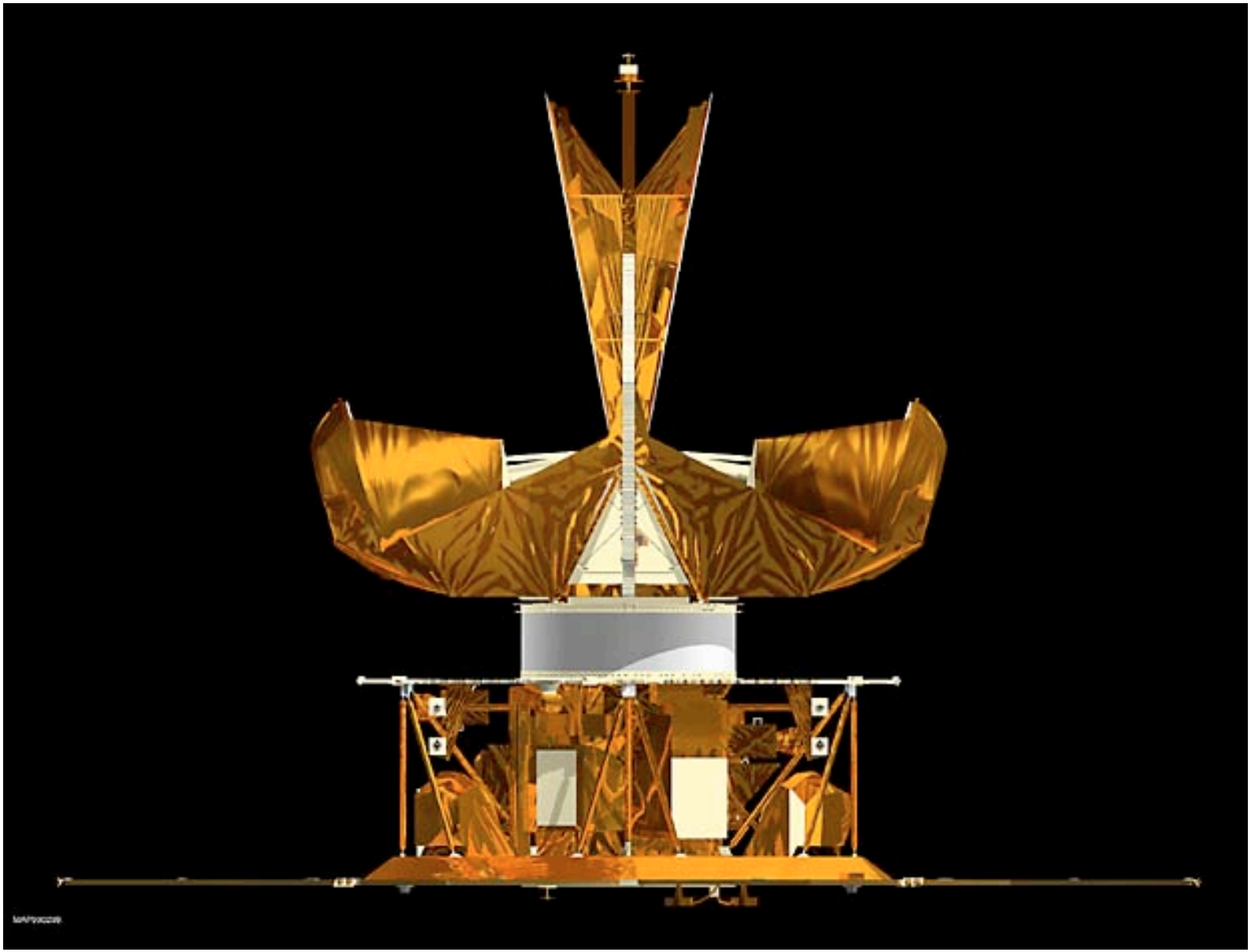




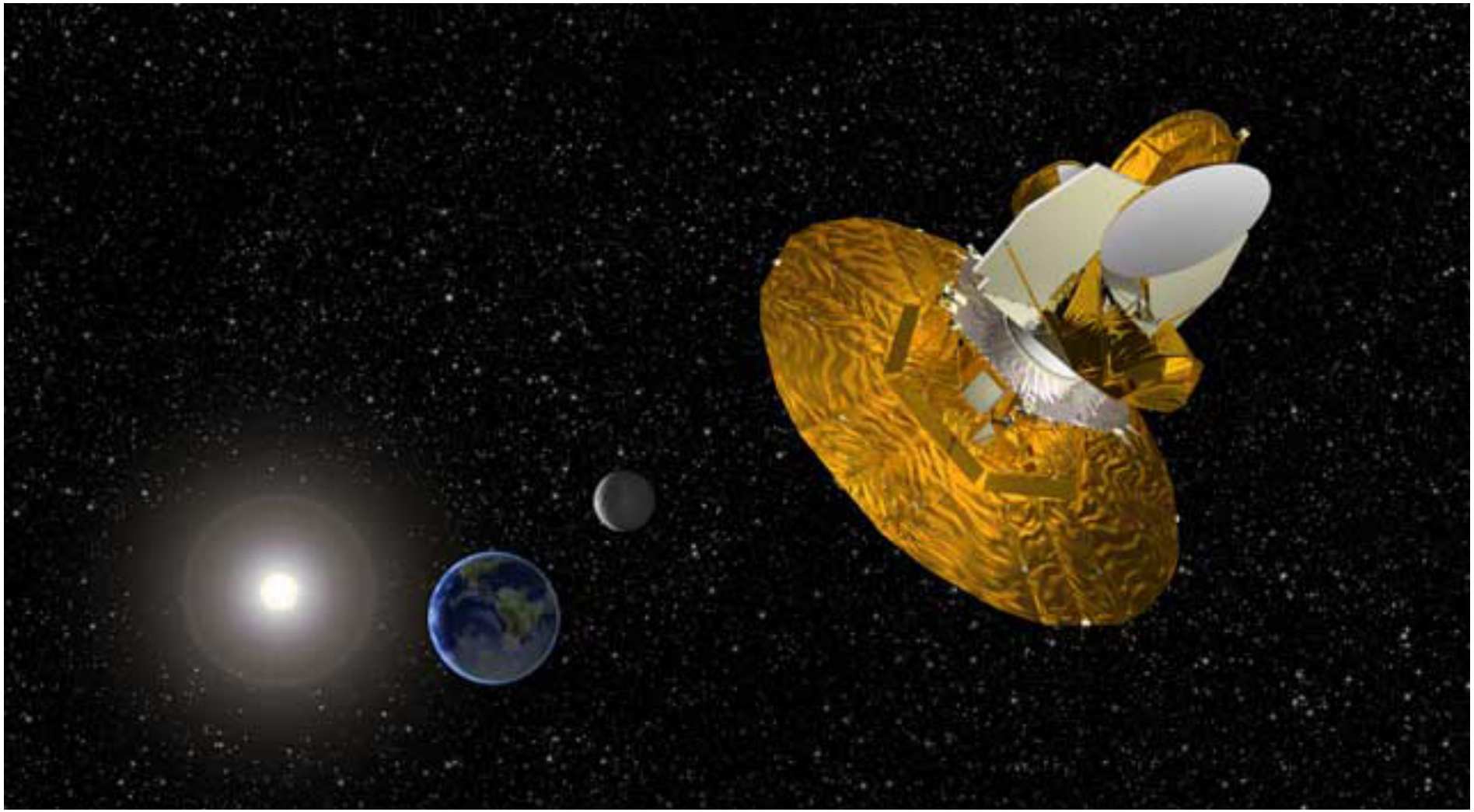
COBE + Balloons Power Spectrum



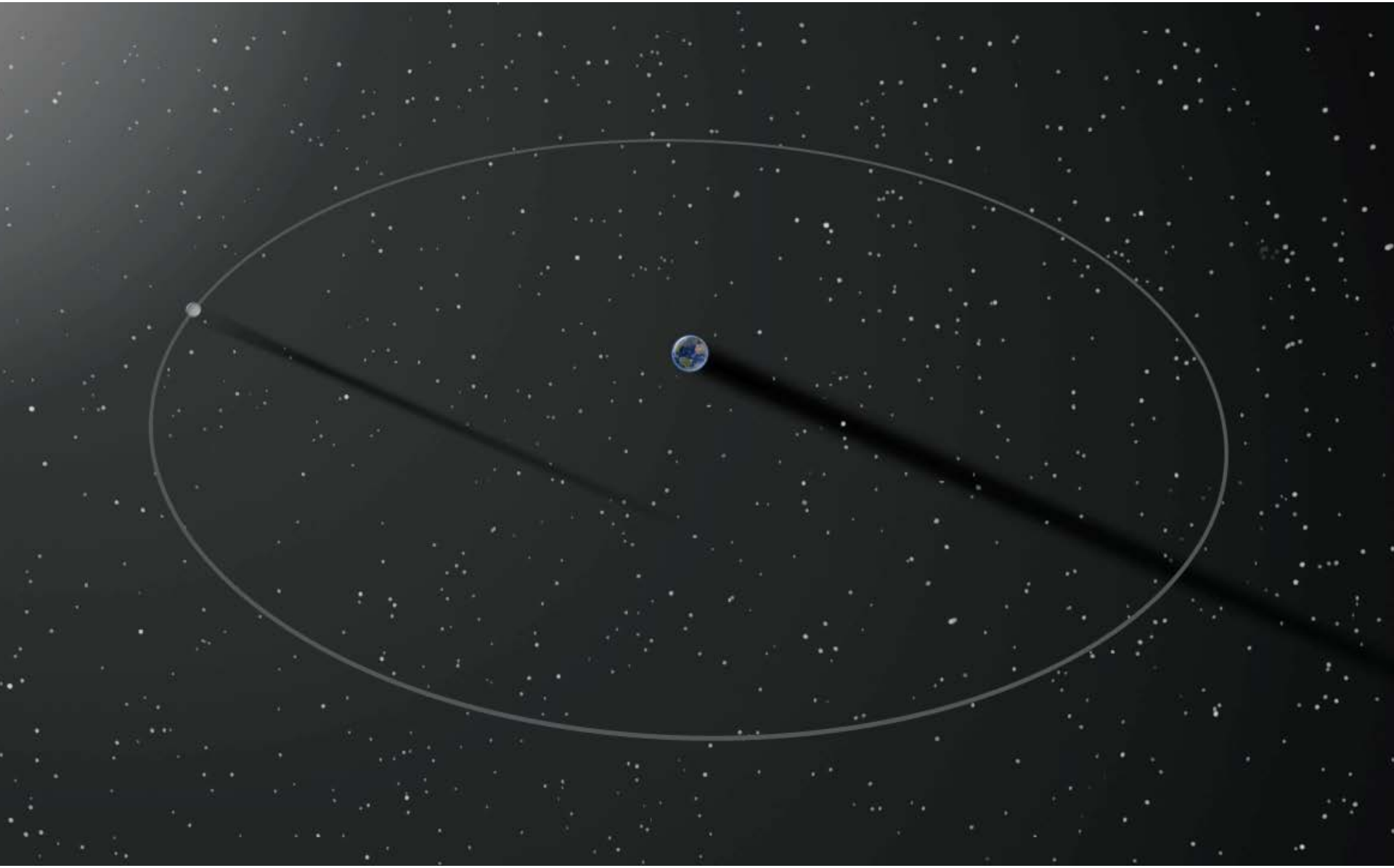
WMAP Side View (back to back dishes)



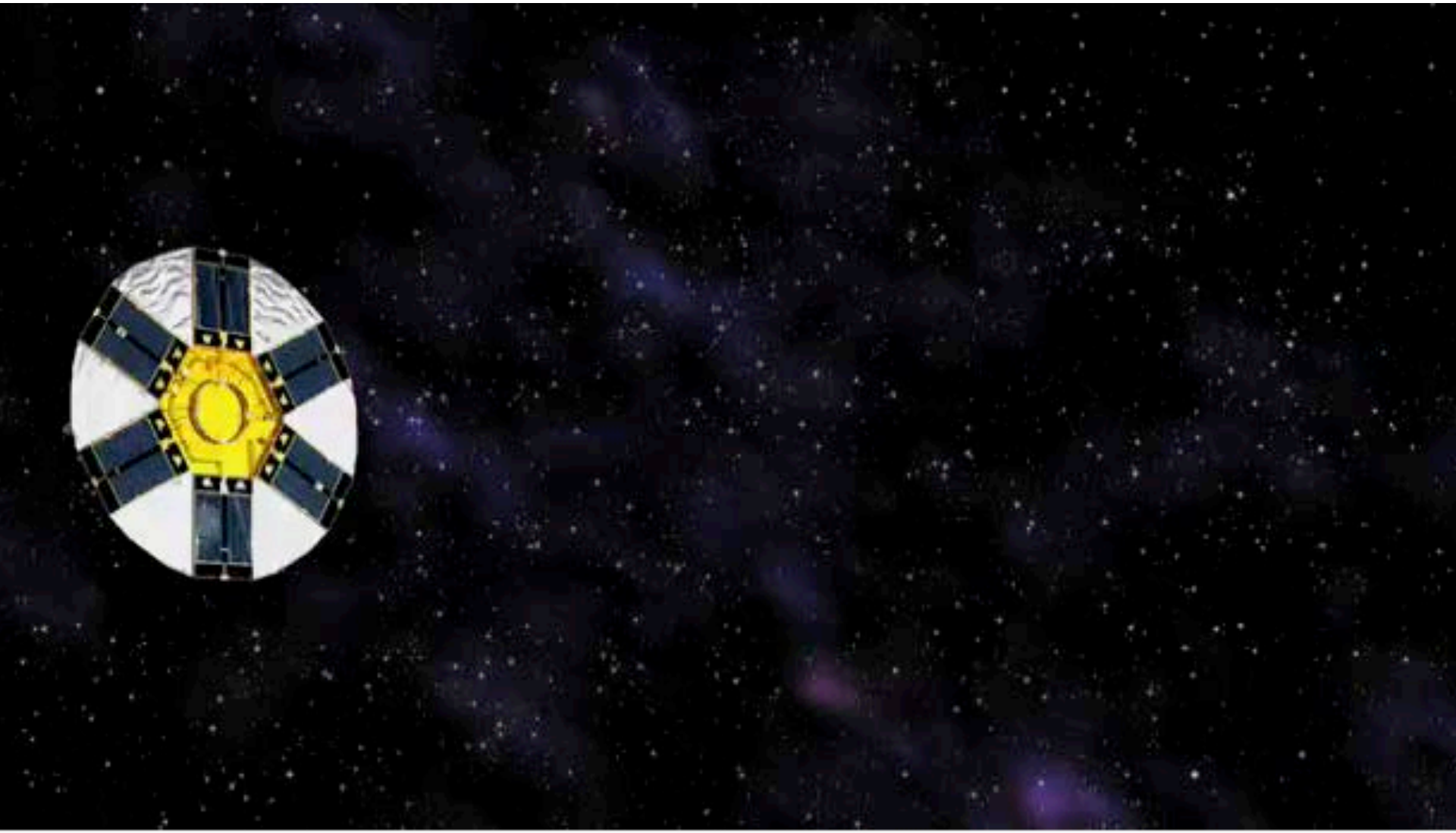
WMAP to Earth-Sun L2



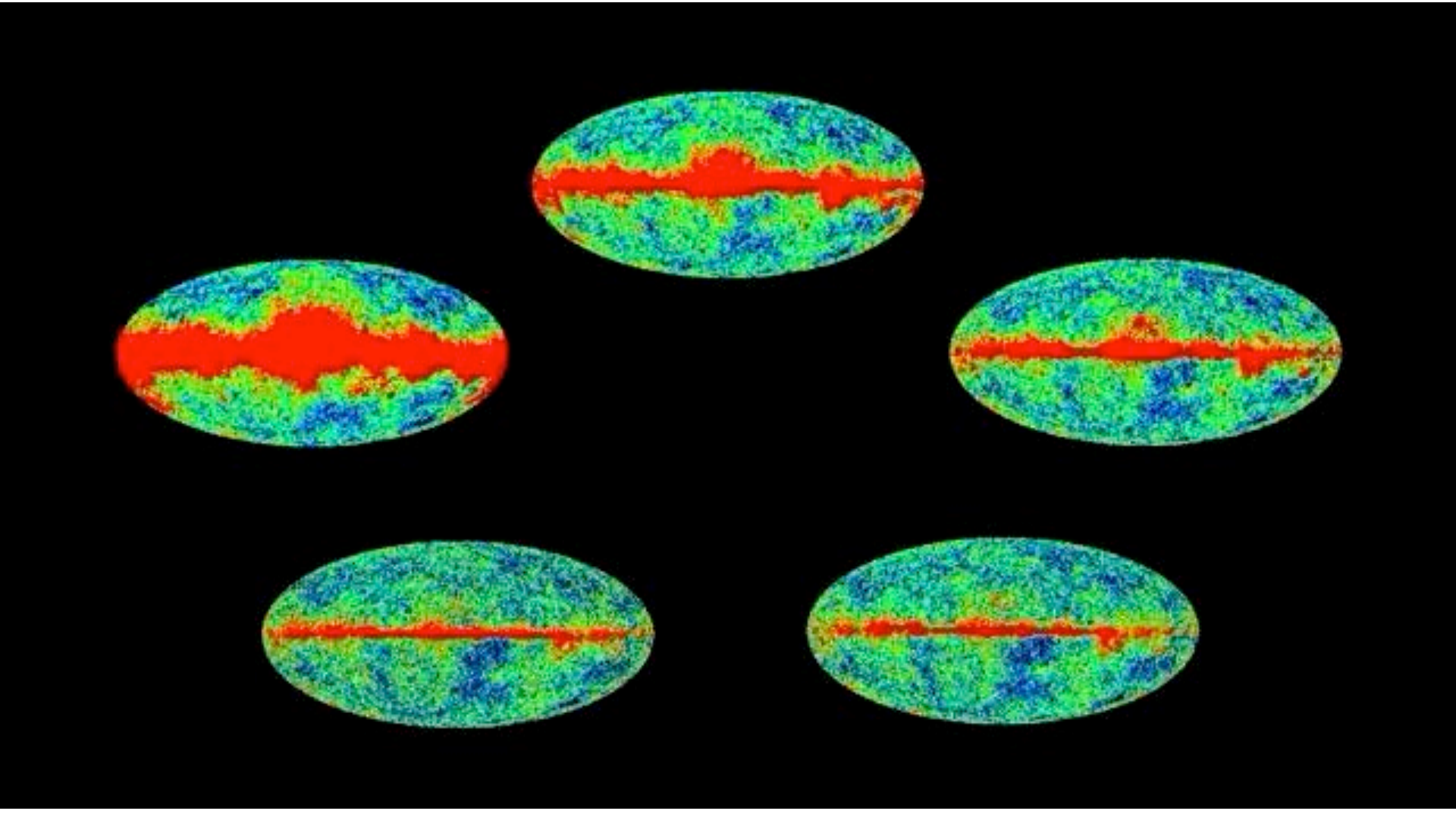
WMAP launched to L2 (Sun-Earth)



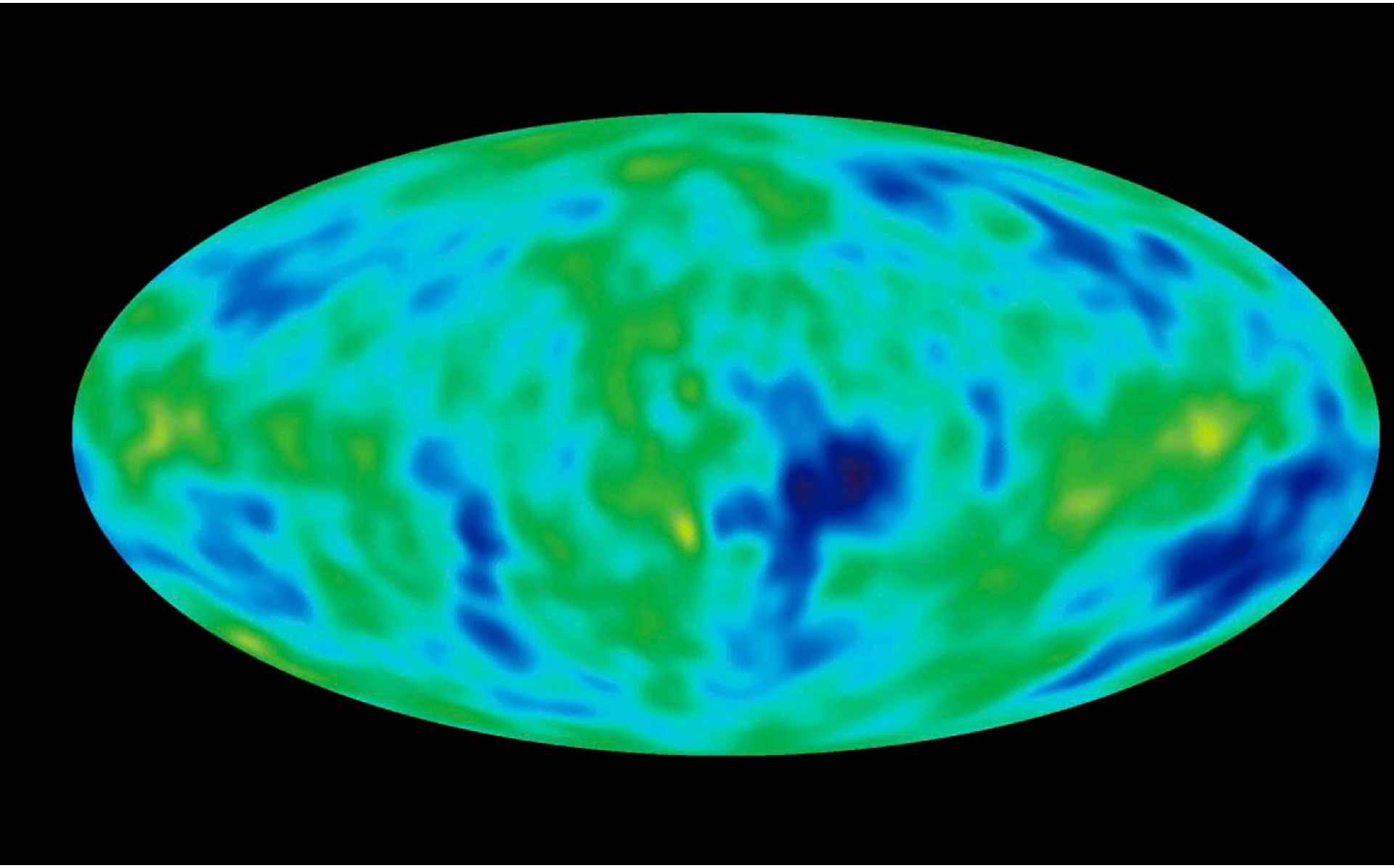
WMAP at L2



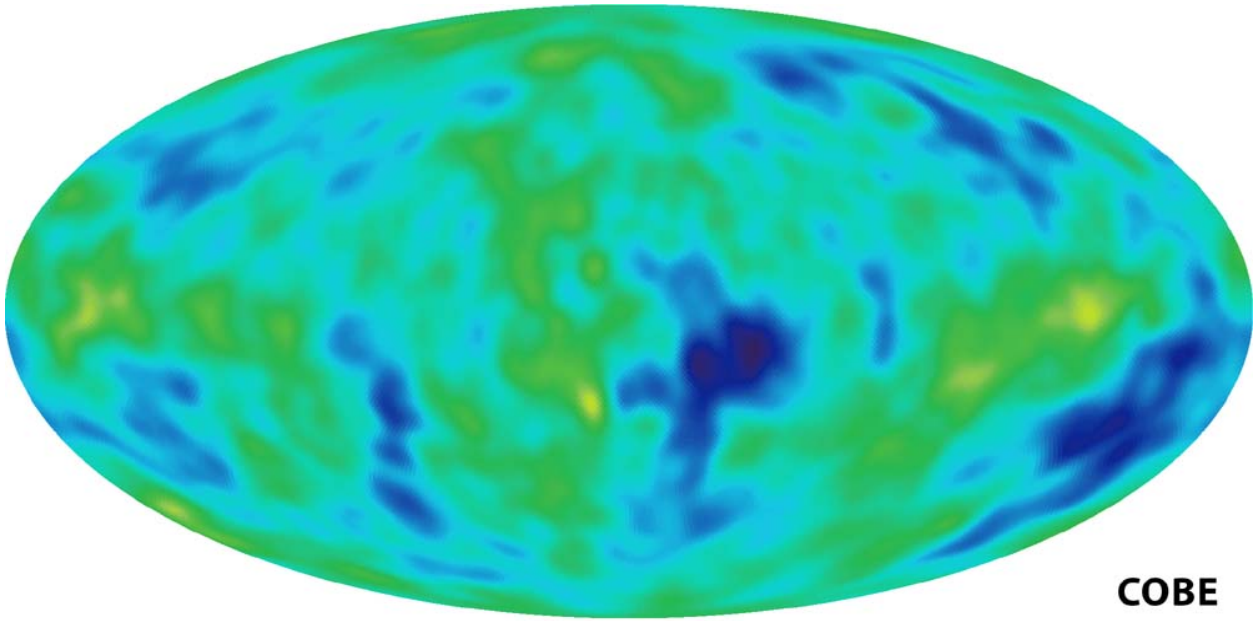
Why multiple wavelengths ?

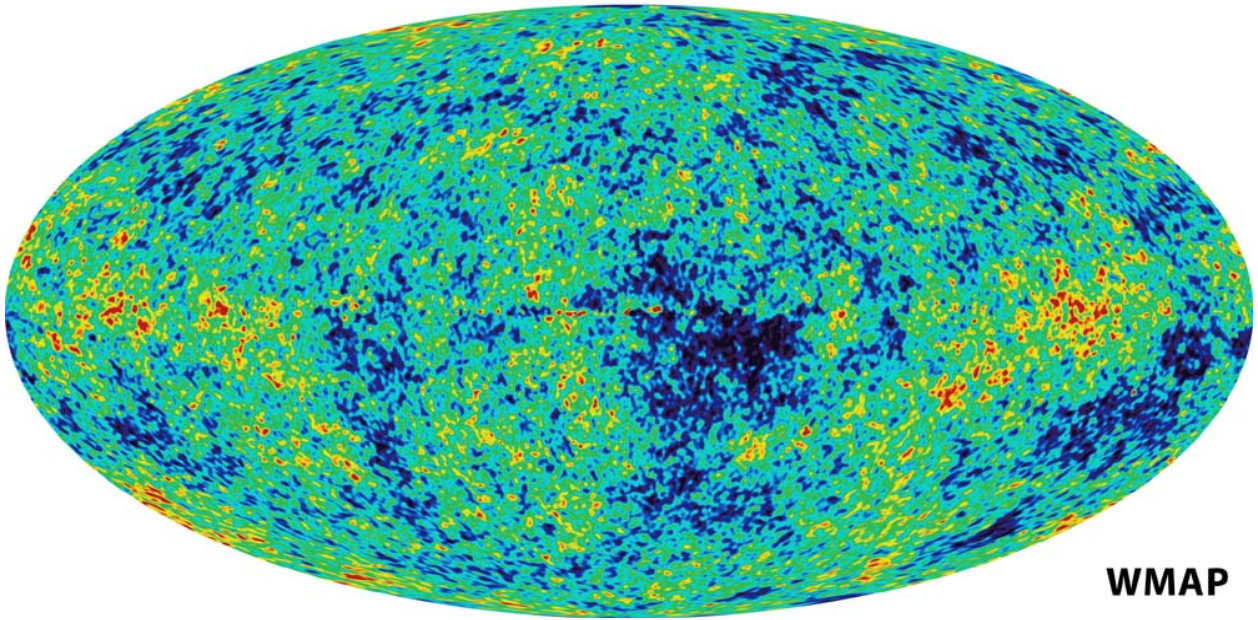


COBE to WMAP

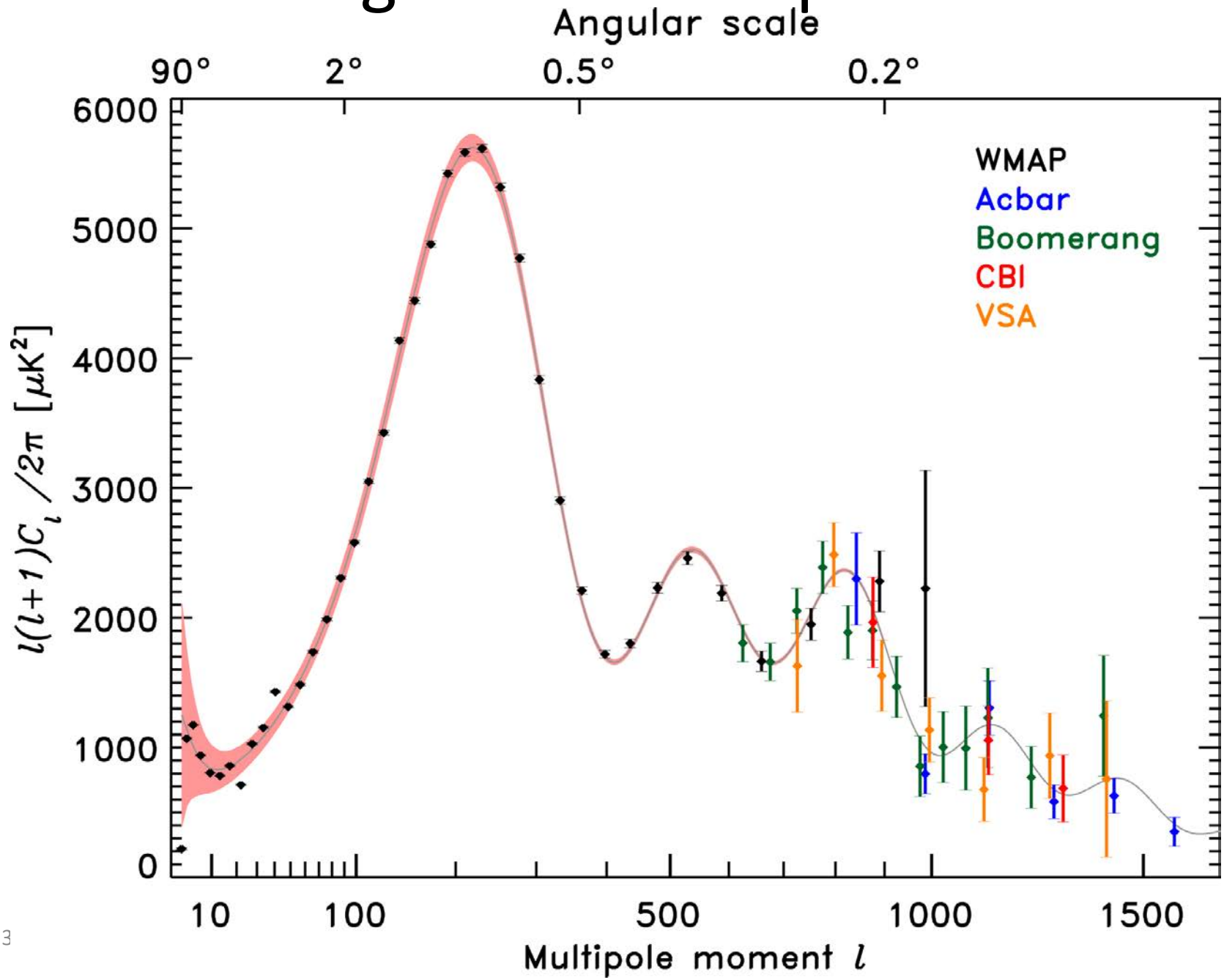


WMAP Continues CMB Effort

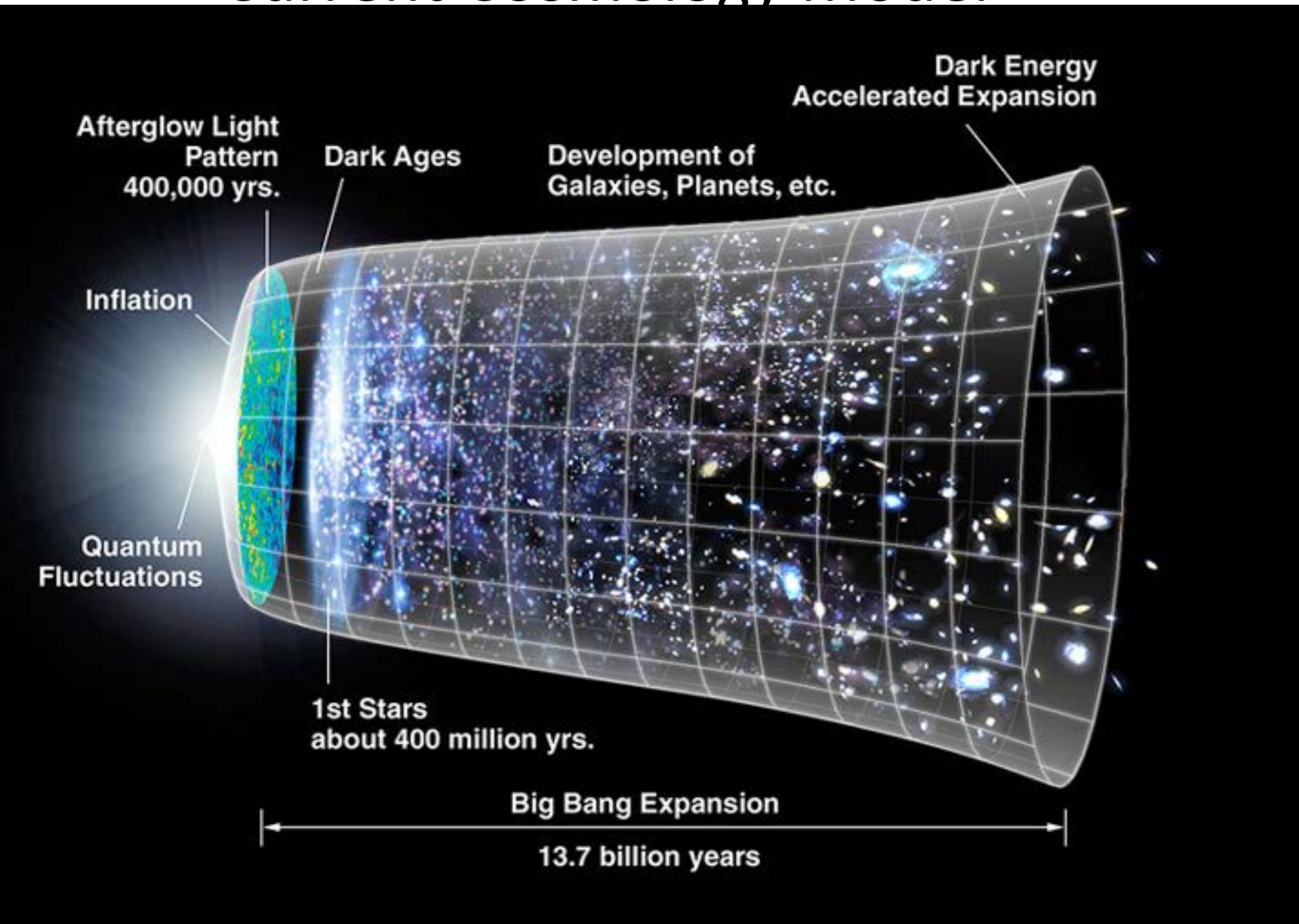




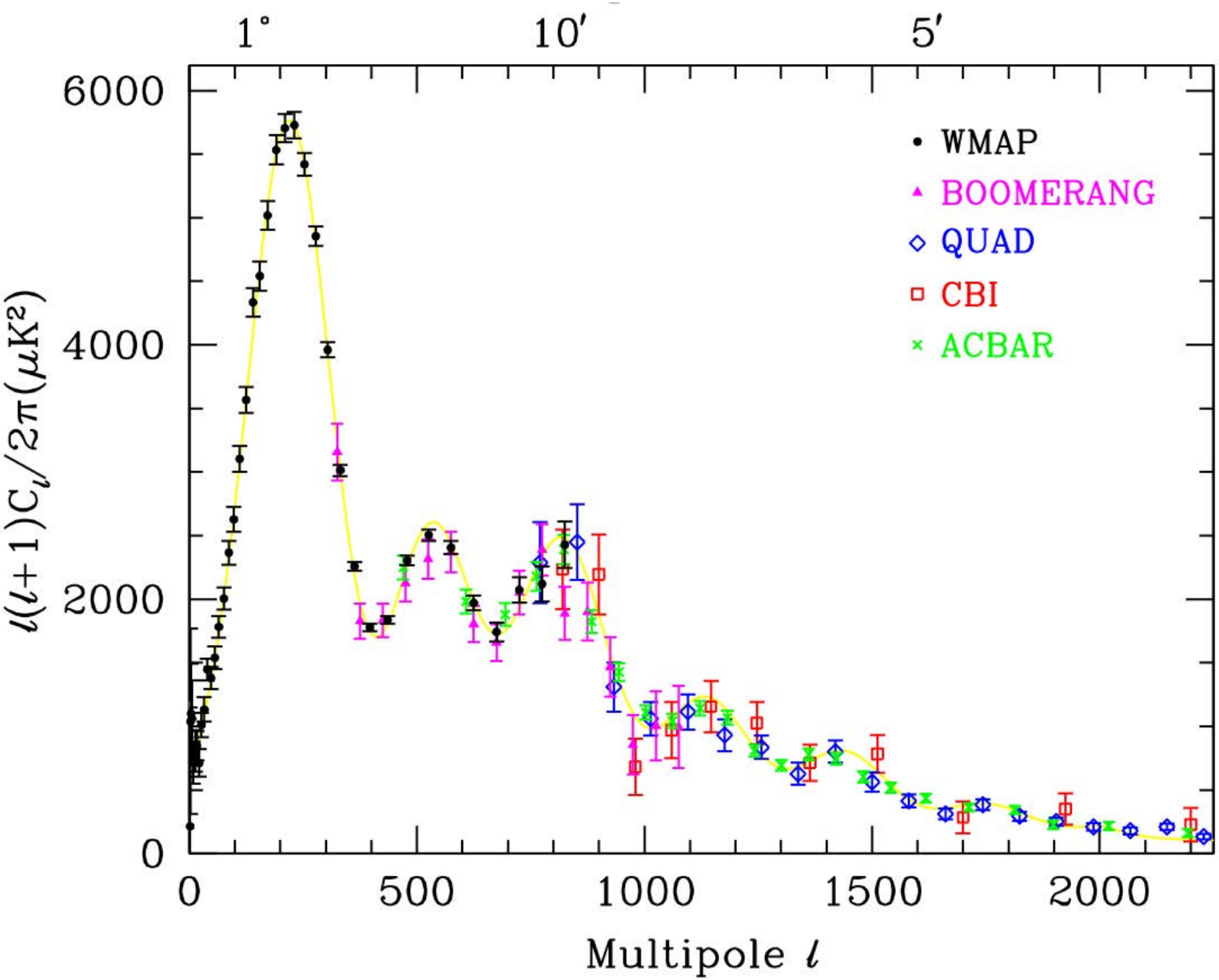
CMB Angular Power Spectrum



Current Cosmology Model



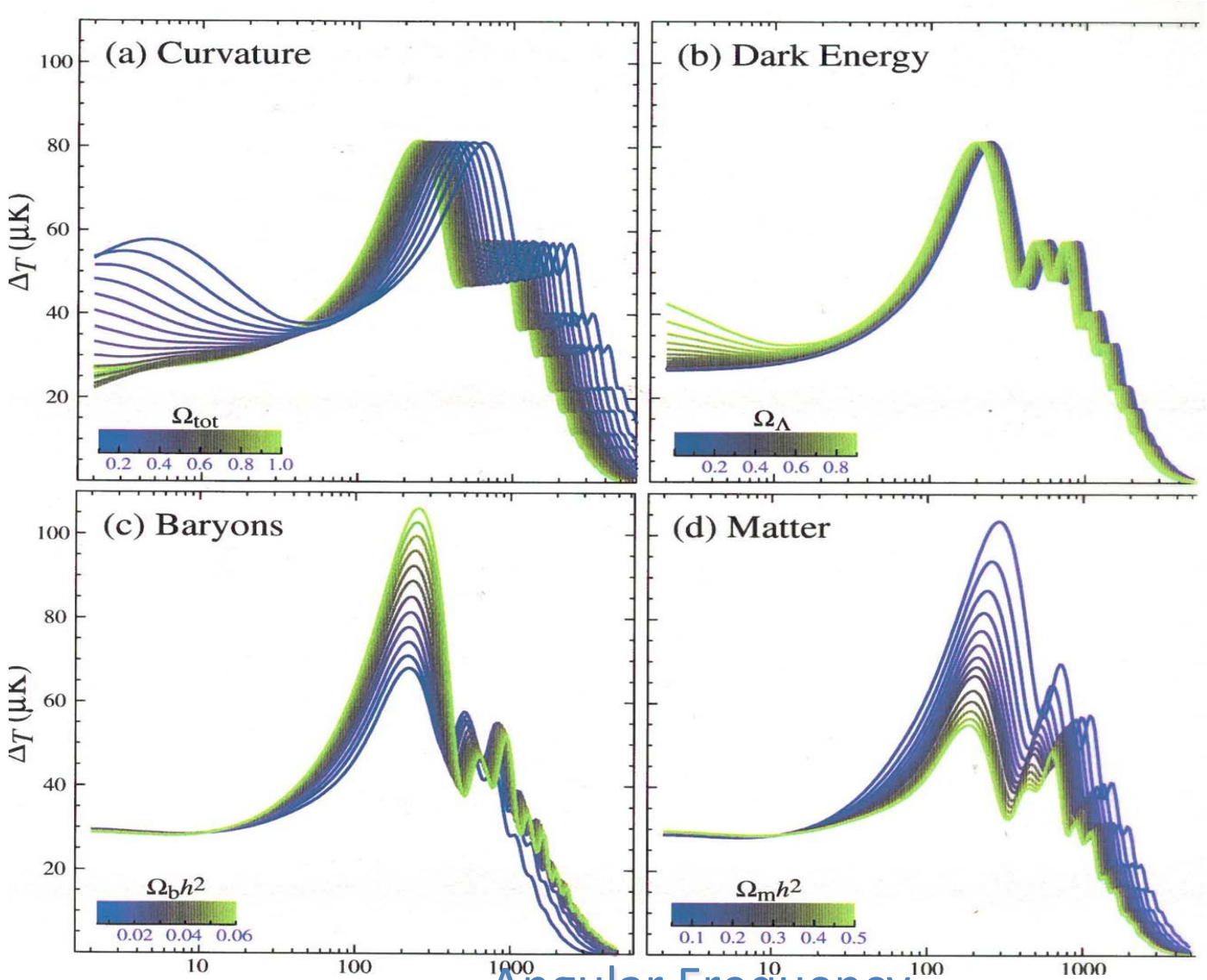
CMB Angular Power Spectrum



No preferred direction means we can average over m's to get power for each ℓ

$C_\ell \equiv \Sigma_m |a_{\ell m}|^2$

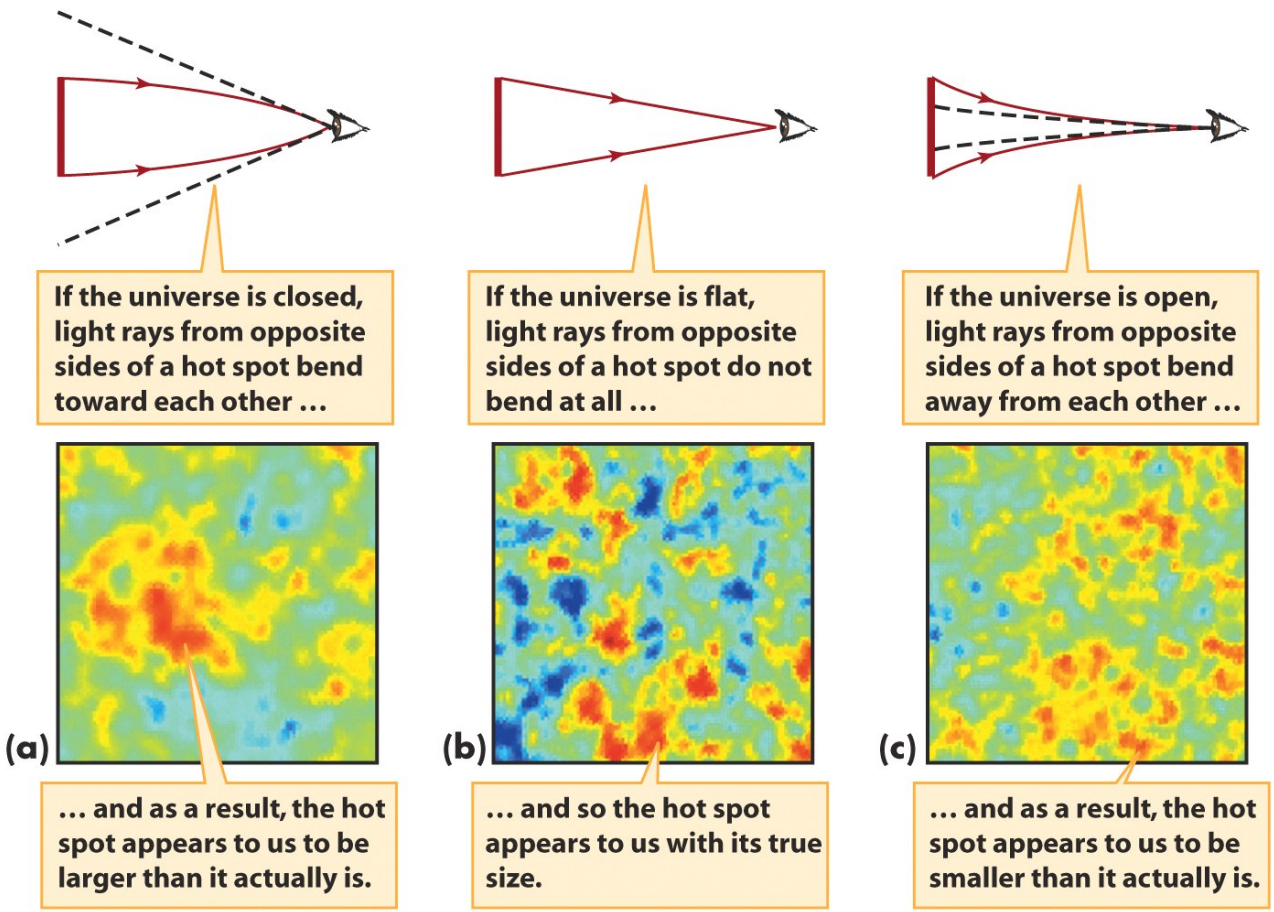
What we can learn from Spectral Analysis/Comparison



Our Universe is flat - to high accuracy

- The theoretically predicted hot spot size (about 1 degree) is very close to what is observed
- Therefore, our universe is flat, or density parameter is ~1.0

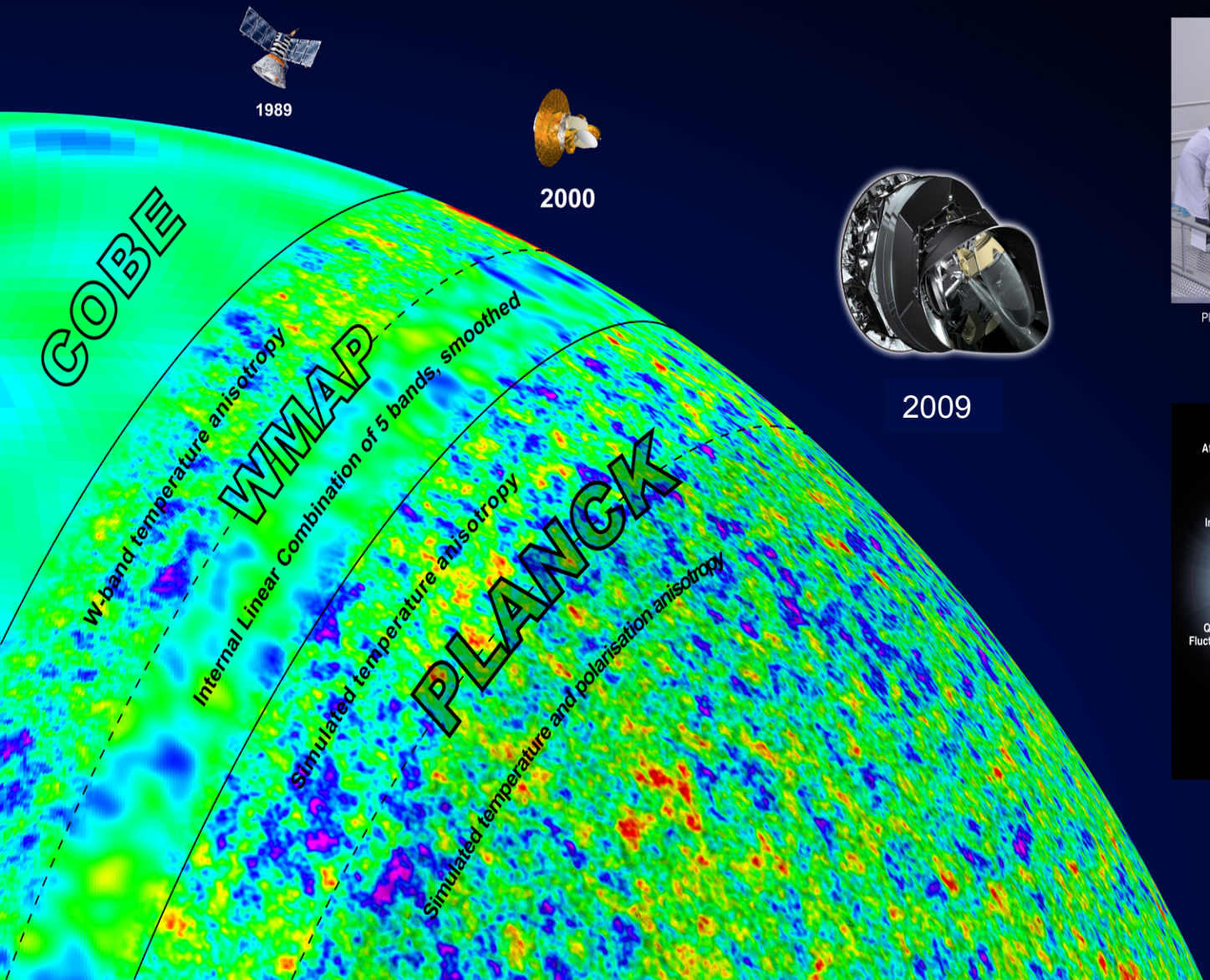
Sound Horizon

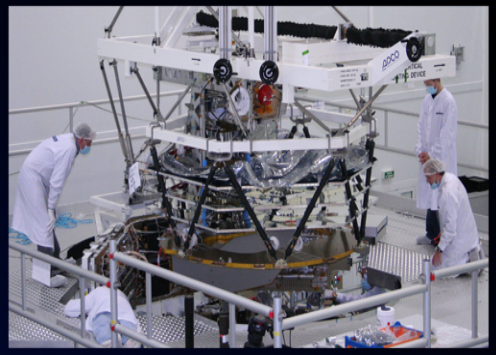


Measuring the Geometry of Space

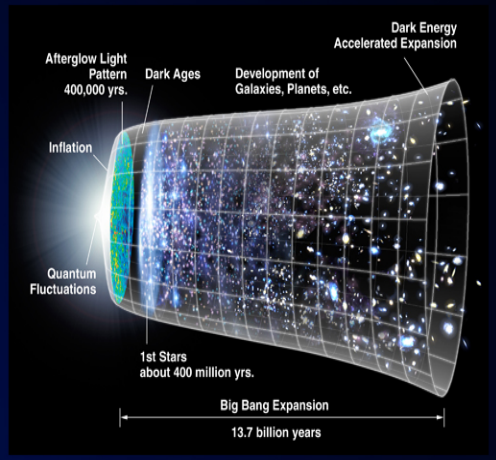
CMB Missions Revolutionise Our Understanding of the Universe

PLANCK





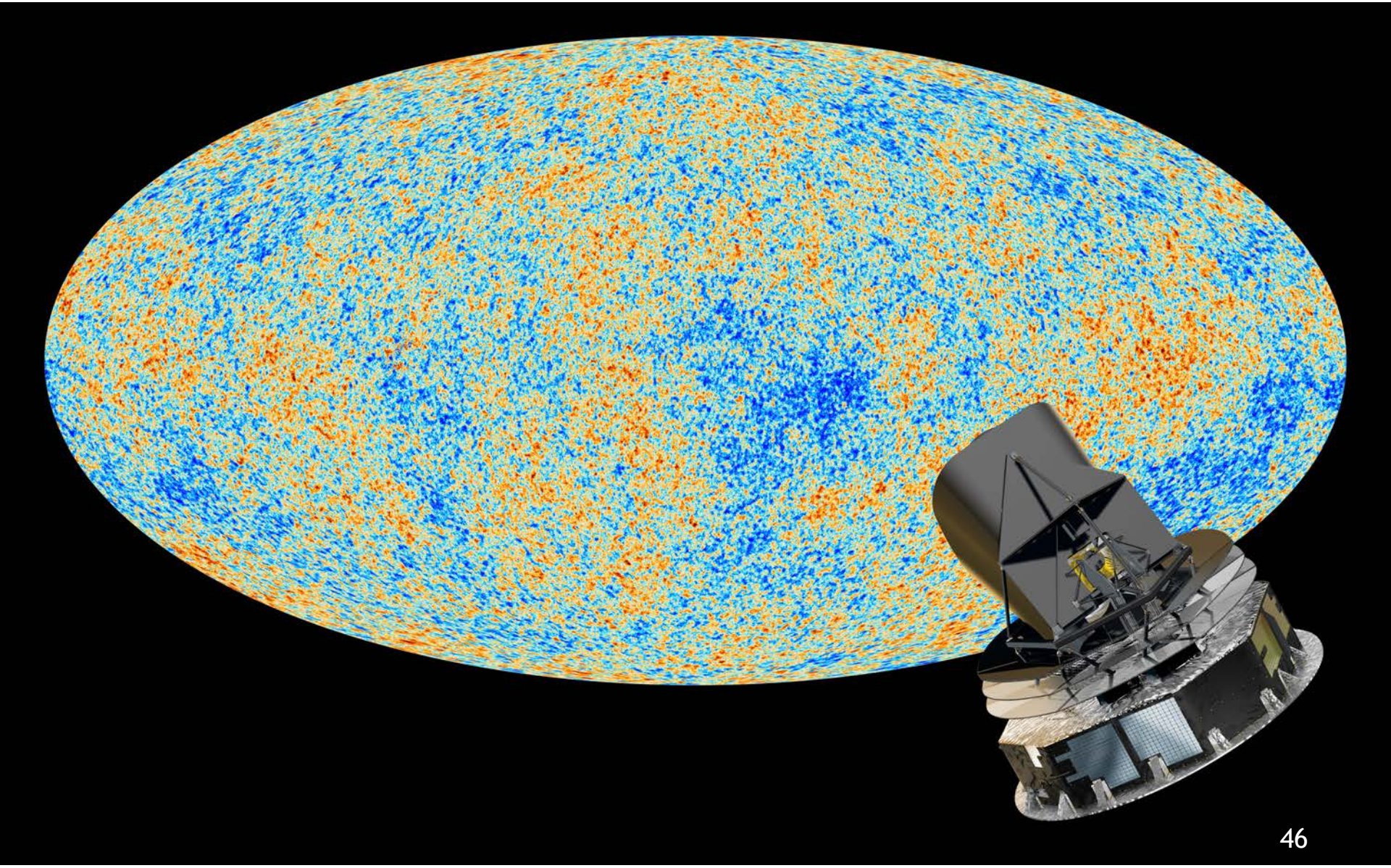
Planck spacecraft in clean assembly at Alcatel Alenia Space in January 2007



Planck Maps the Microwave Sky

Planck отображает микроволновое небо

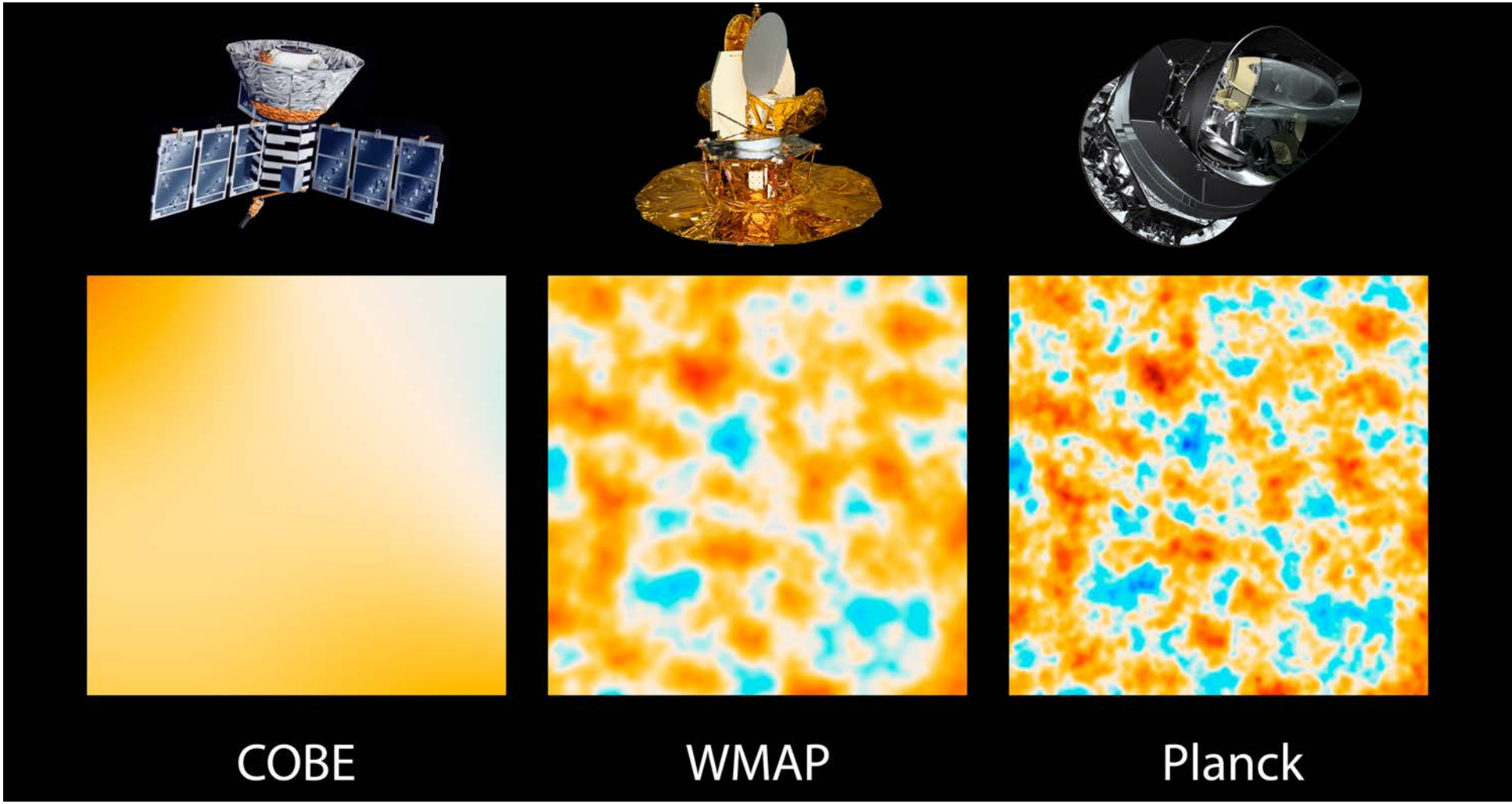
Planck 2013 CMB Map



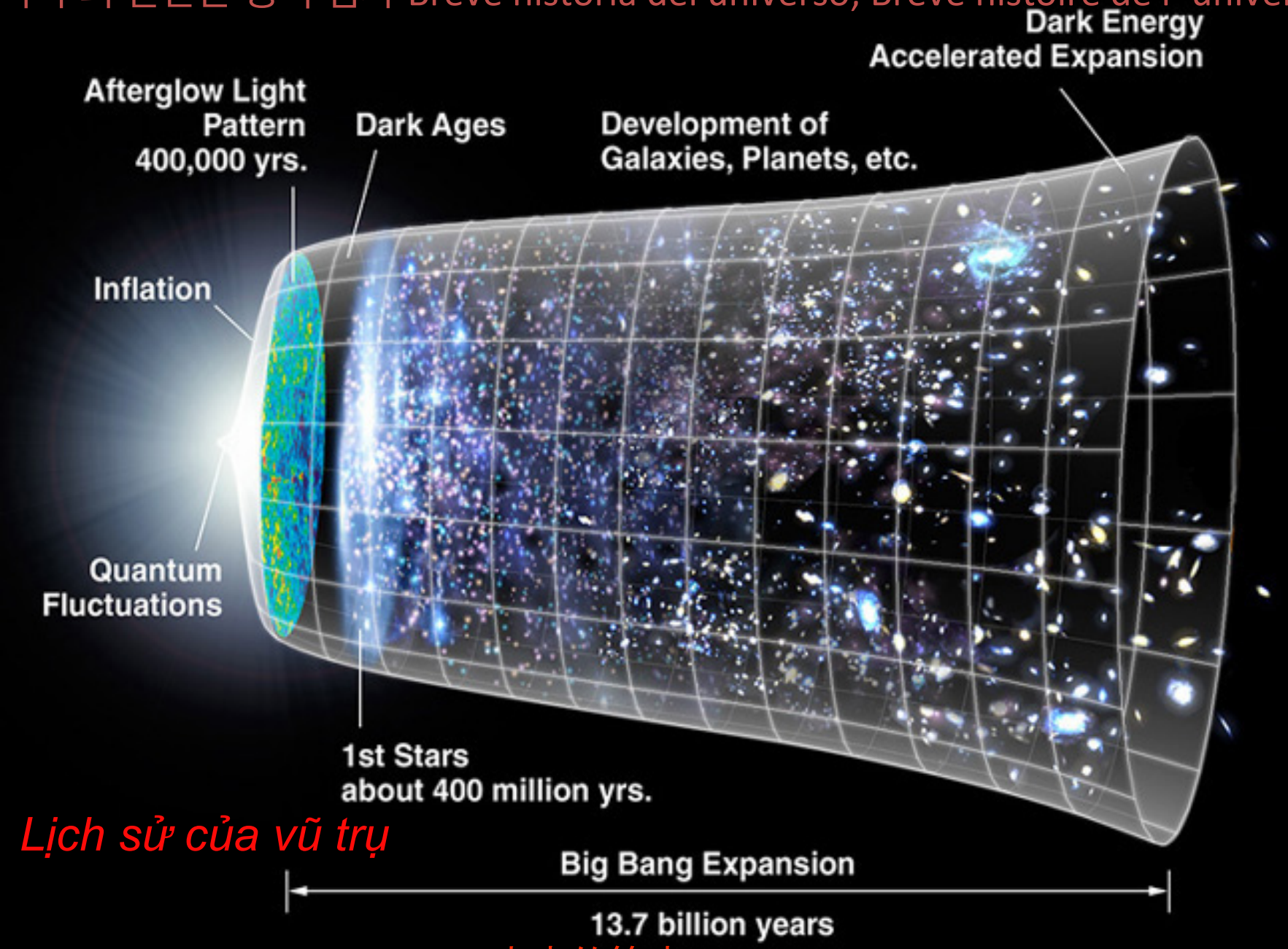
Vues avec l'augmentation de résolution

взгляды 0Nc увеличением разрешением

Higher Resolution Views



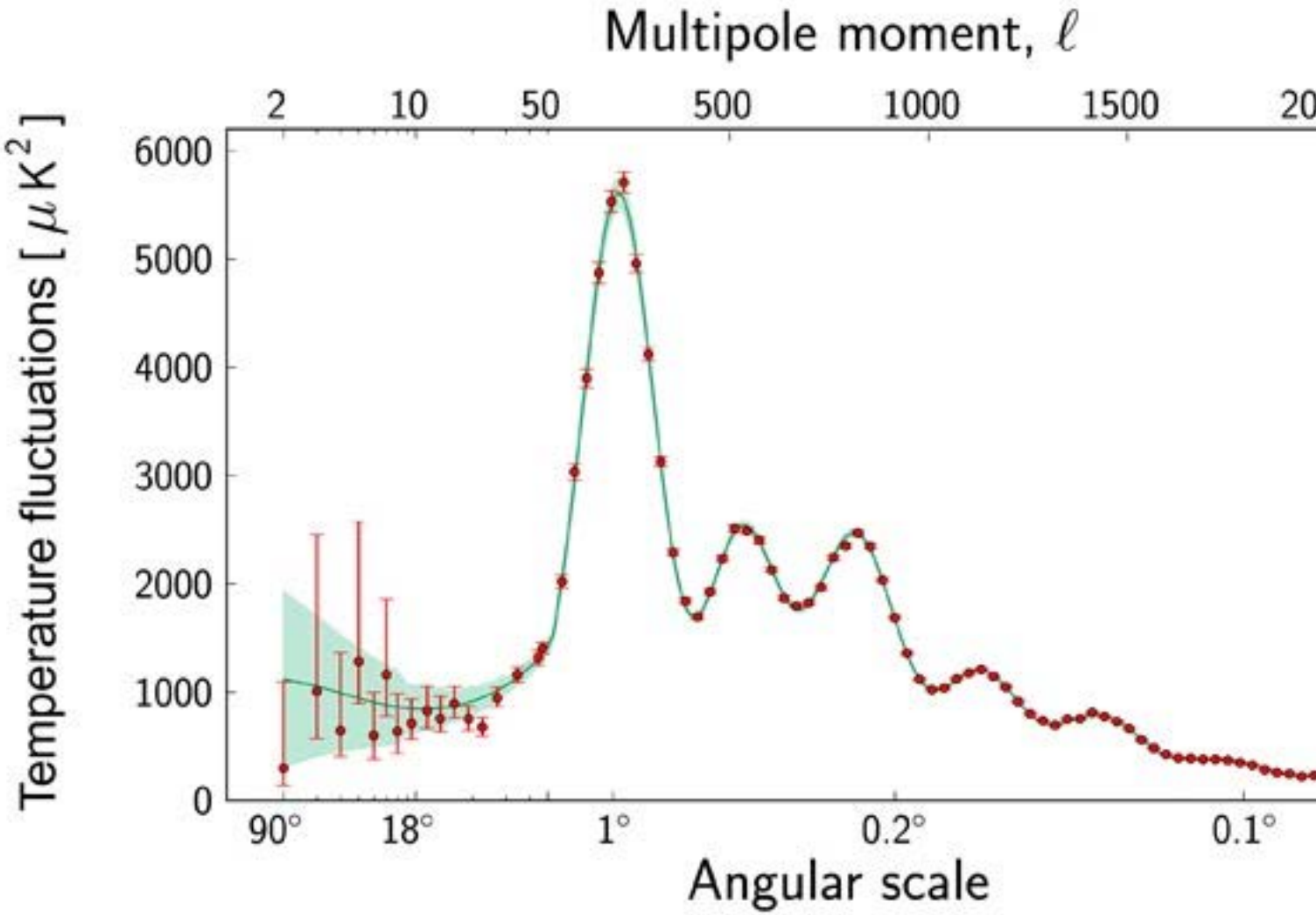
우주의 간단한 병력 검사 Breve historia del universo; Brève histoire de l’univers



Lịch sử của vũ trụ

Краткая история Вселенной 宇宙的簡史 Brief History of the Universe

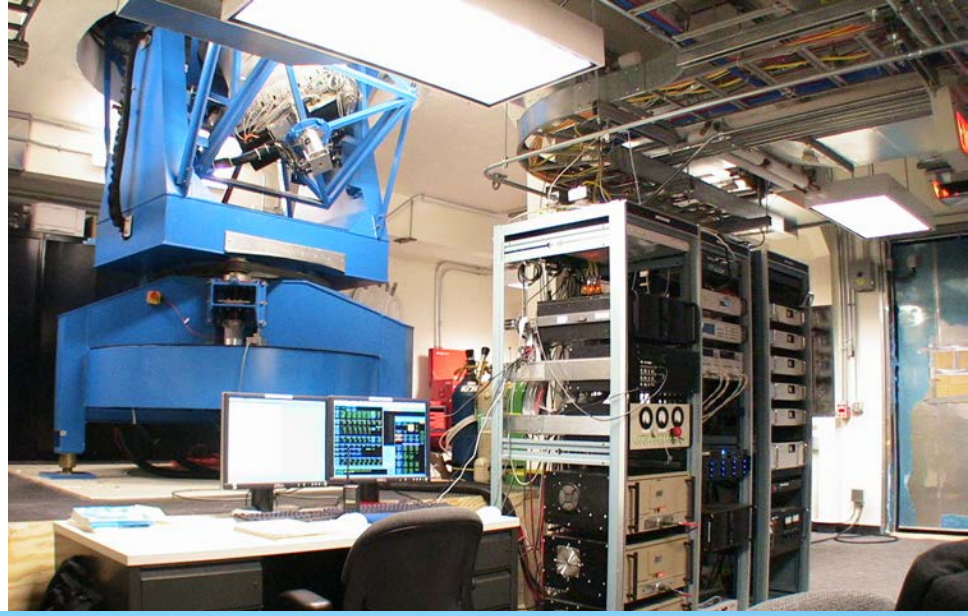
IBM BG/L

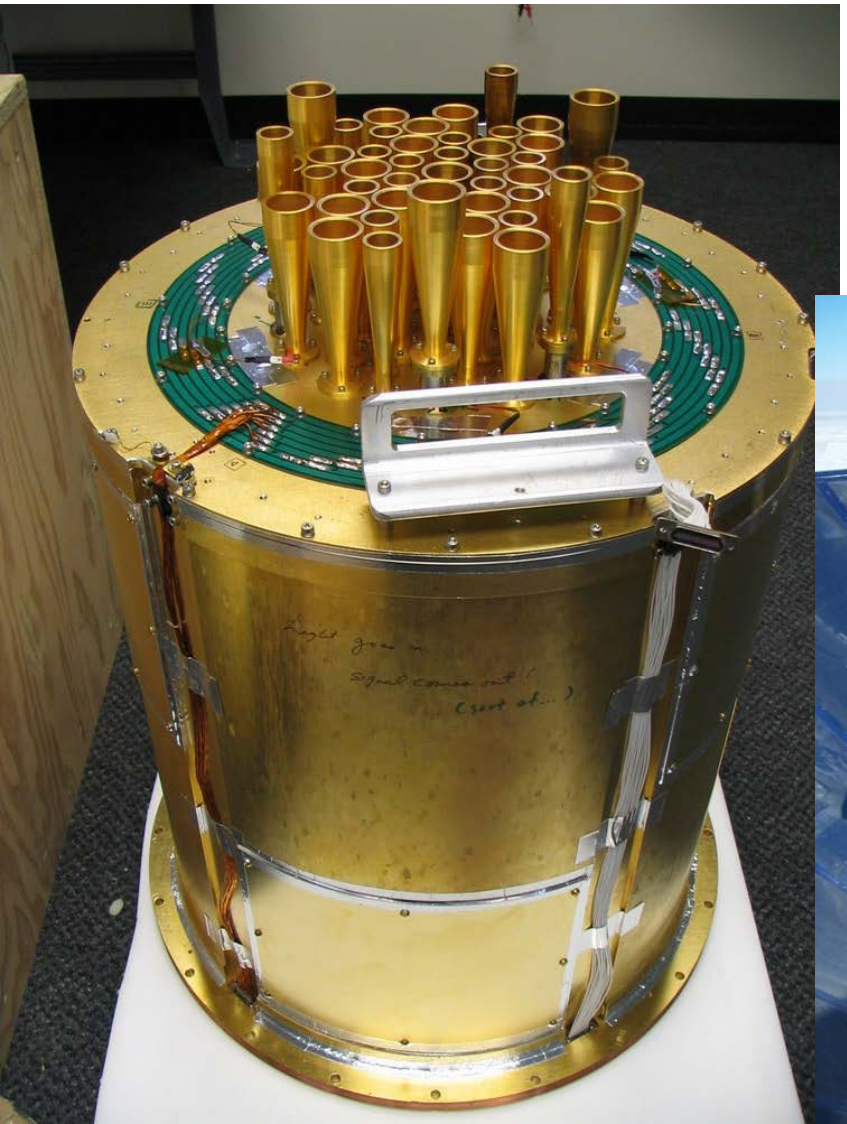


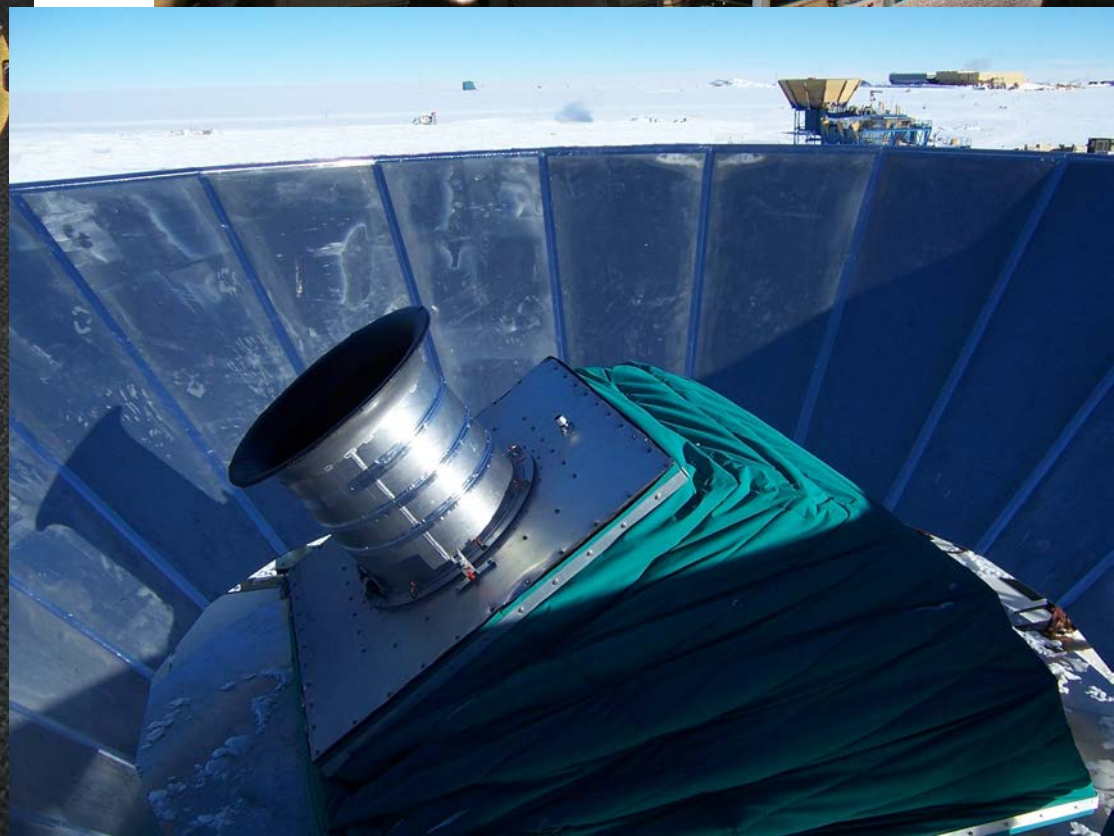
October 2013

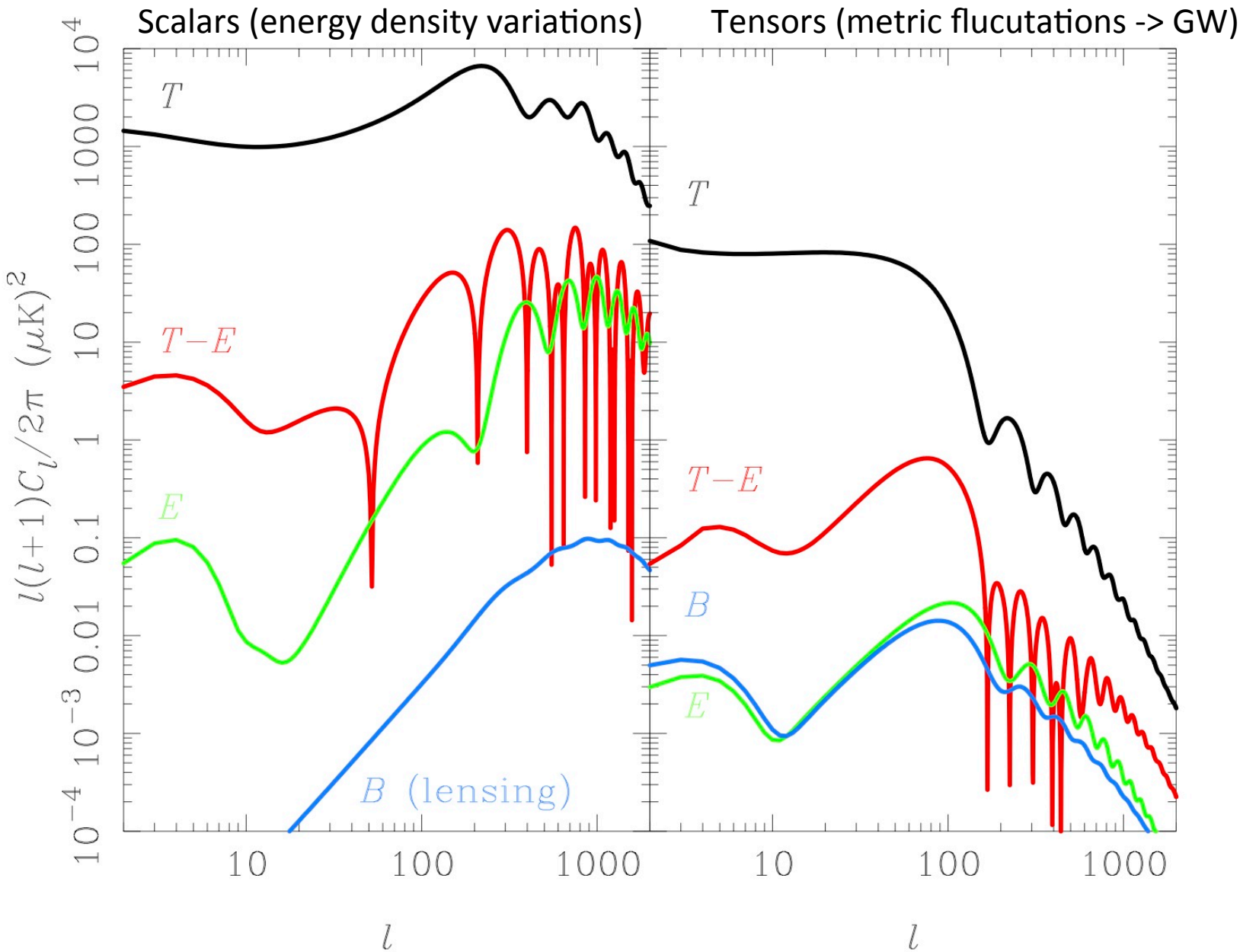
BICEP has just completed its first successful winter of observations

New constraints on CMB Polarization coming soon. – 2005 (Well 2014 !)



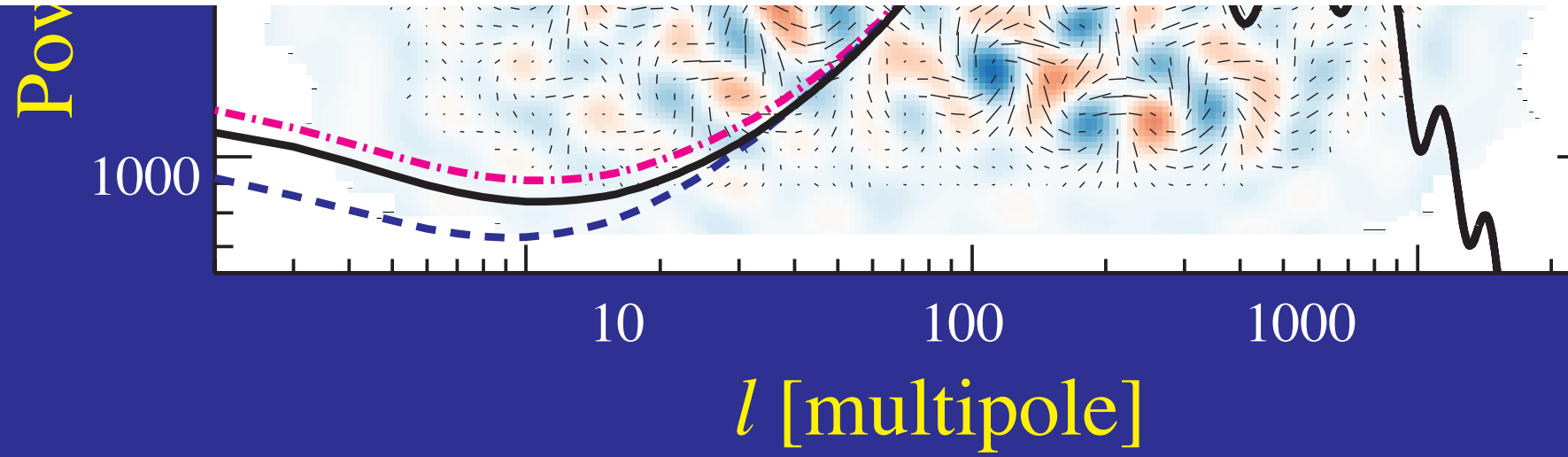





Scalars (energy density variations)
Tensors (metric flucutations -> GW)
$l(l+1)C_l/2\pi\ (\mu K)^2$
10^4
1000
100
10
1
0.1
0.01
10^{-3}
10^{-4}
T
T−E
E
B (lensing)
T
T−E
B
E
10
100
1000
10
100
1000
l
l

More Complicated = more Computation

CMB challenges computation on the most powerful systems



Wayne Hu

CosKASI, April 2014

The NERSC Hopper system a Cray XE6

CMB is reason Hopper runs red.