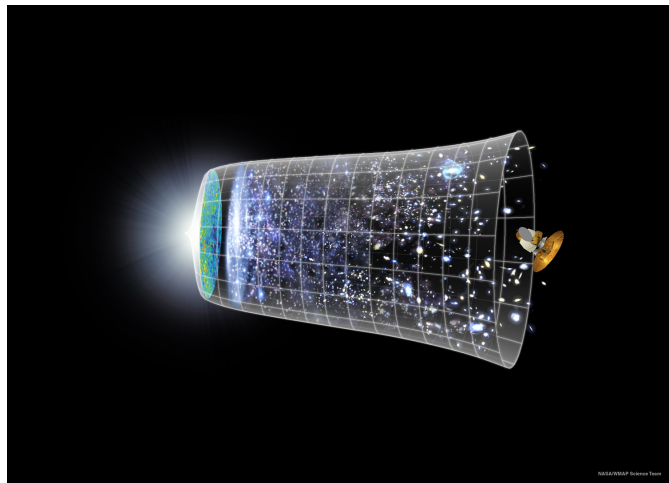


# COSMIC MICROWAVE BACKGROUND RADIATION



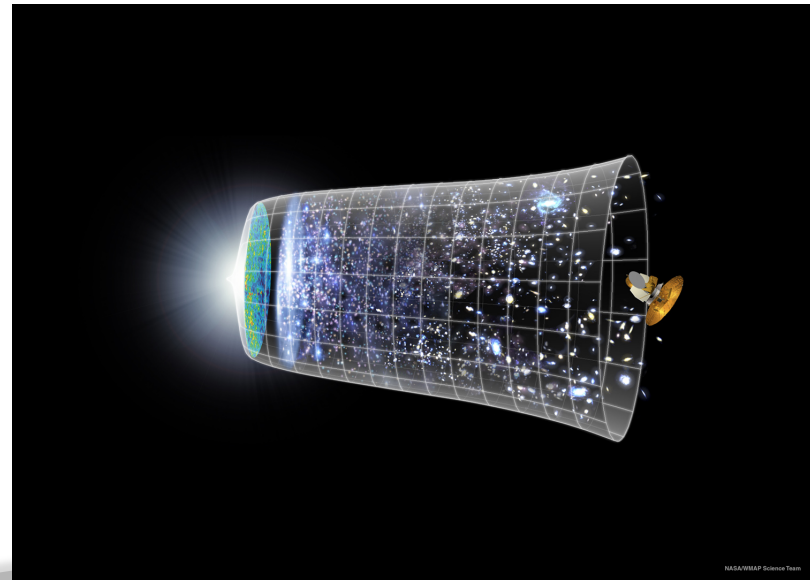
Sean Morrison

10/28/2011

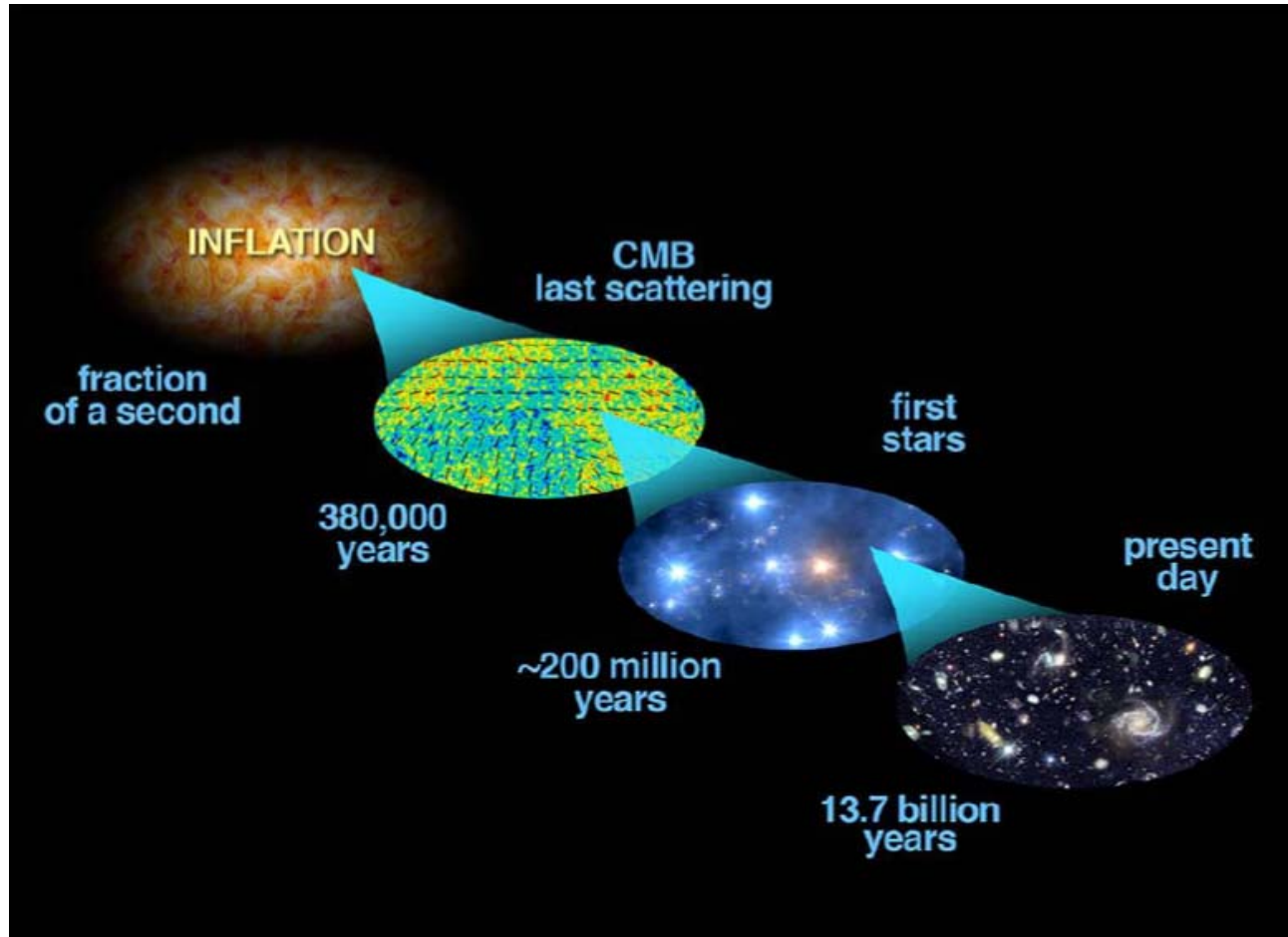
Graduate Seminar PHYS 730

# Introduction

- ◎ The Big Bang
- ◎ Blackbody Radiation
- ◎ What is Cosmic Microwave Background Radiation?



# The Primordial Fireball



# Outline

- ⦿ Early History and Discovery
- ⦿ Early Research
- ⦿ Polarization and Anisotropies
- ⦿ Far InfraRed Absolute Spectrophotometer (FIRAS)
- ⦿ Differential Microwave Radiometer (DMR)
- ⦿ Cosmic Background Explorer (COBE) Results
- ⦿ Post-COBE Research
- ⦿ Improvements of Cosmological Parameters



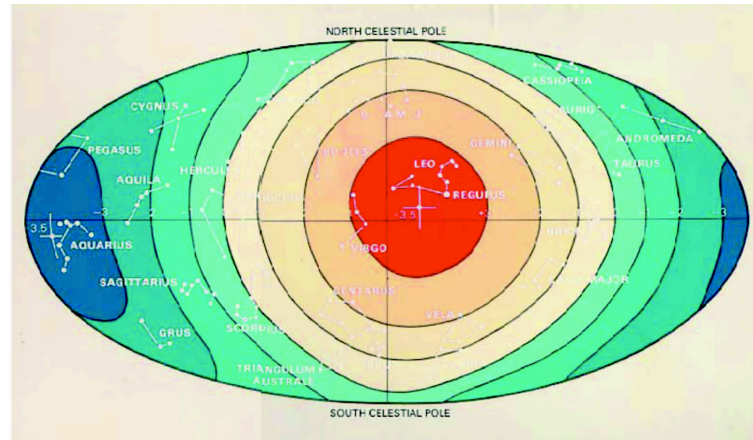
# Early History and Discovery

- ◎ Arno Penzias and Robert Wilson
  - Bell Lab's Echo
  - $\sim 3\text{K}$
  - 1964
- ◎ Robert Dicke
  - Princeton University
  - Big Bang



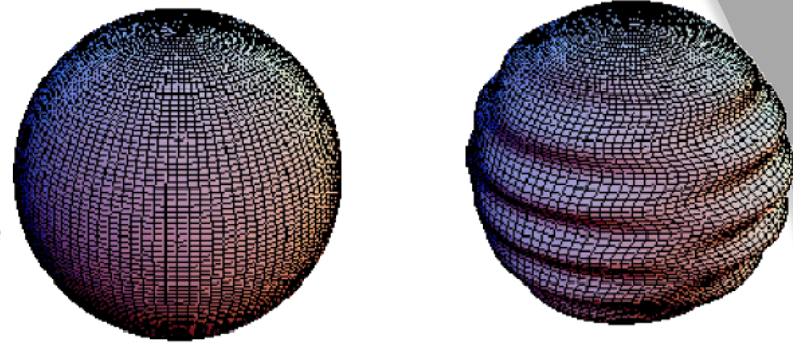
# Early Research

- ◎ The Differential Microwave Radiometer (DMR) and U2
- ◎ Balloon-Borne Anisotropy Experiment

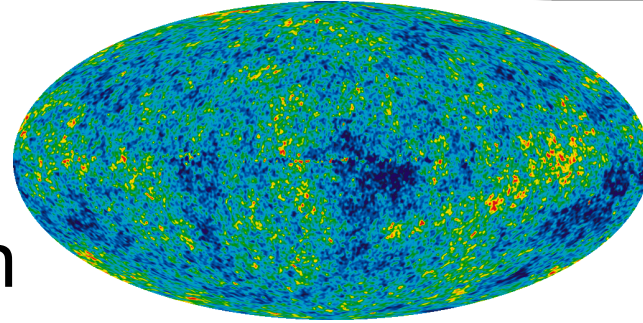


# Polarization of the CMB

- ⊙ Explosive expansion of space created ripples in the fabric of space
  - Gravity waves left a signature in the polarization of the last-scattered photons
- ⊙ Polarized because it was scattered off of free electrons
- ⊙ EM wave incident on a free electron
  - Scattered wave is polarized perpendicular to the incidence direction
  - If the incident radiation were isotropic or had only a dipole variation
    - No net polarization
  - If the incident radiation from perpendicular directions had different intensities
    - Net linear polarization would result



# Anisotropy



## ◎ Results from polarization

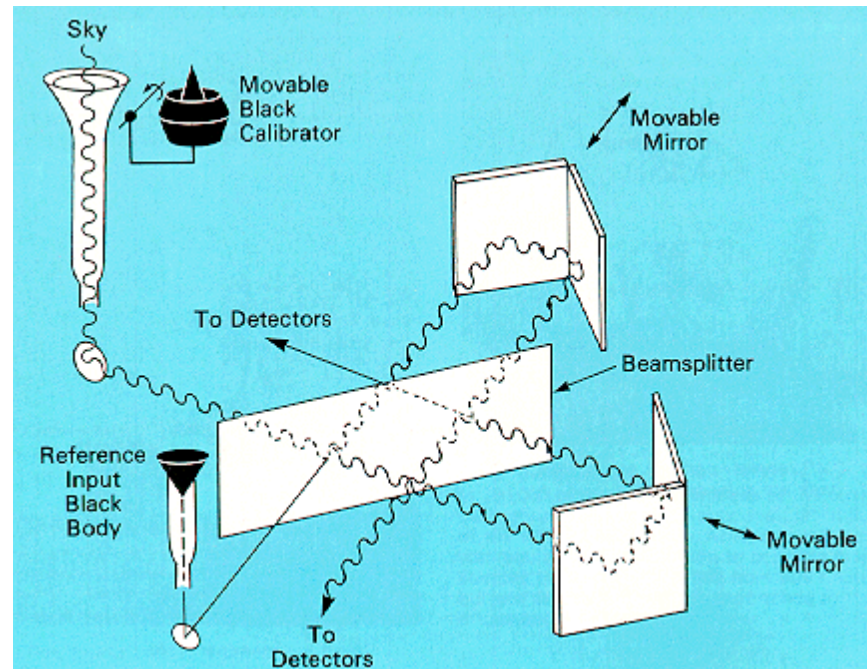
- Gravity waves
  - Dipole
- EM wave incident on a free electron
  - Quadrupole

## ◎ Inhomogeneity in the temperatures

# COBE: FIRAS

Cosmic Background Explorer: Far InfraRed Absolute Spectrophotometer

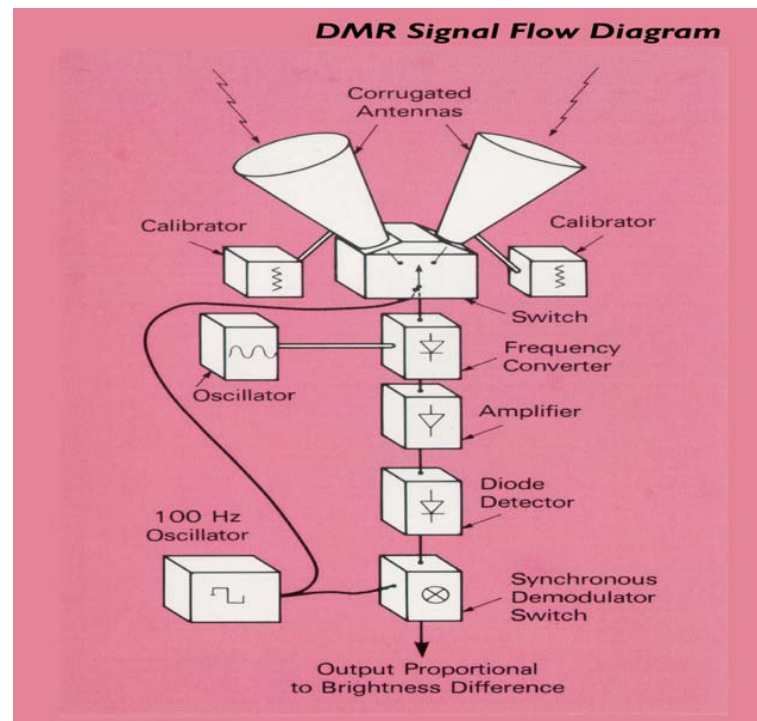
- Measure Spectral Distribution
- 2 Beam Interferometer
- 0.1 – 10mm
- Black Body Curve



# COBE: DMR

Cosmic Background Explorer: Differential Microwave Radiometer

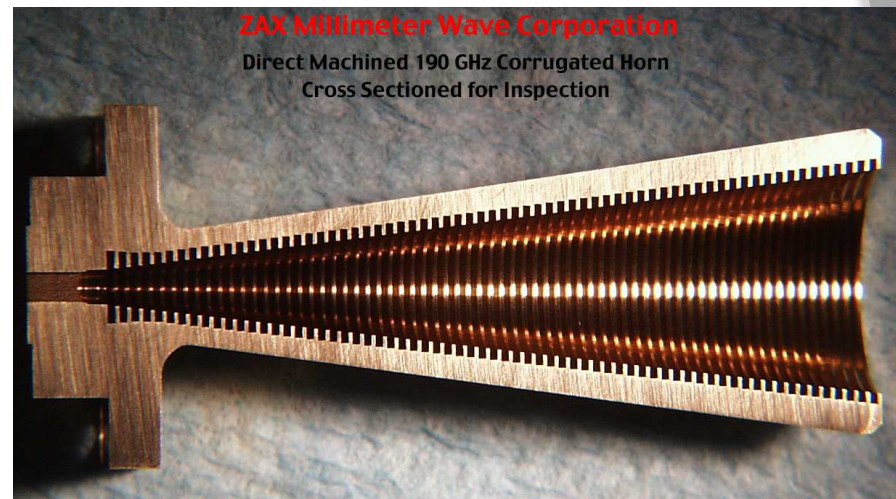
- Search for Anisotropies
- 3.3mm, 5.7mm, and 9.5mm (90, 53, 31.5 GHz)
- 7° Angular Resolution
- 3 sets of 2 corrugated horns at 60°
- Liquid He Cooled





# Corrugated Horns

- ◉ quarter wavelength grooves
- ◉ get better beam response and eliminate outside interference
- ◉ Beam pattern
  - Corrugated
    - Same in both planes
  - Standard Gain Horn
    - Depends on looking in Magnetic or electric field
- ◉ Optical diffraction Pattern
  - 1 part in million for corrugated vs. 1 in ten thousand for standard



$$\frac{\sin x}{x}$$

# COBE Results: FIRAS

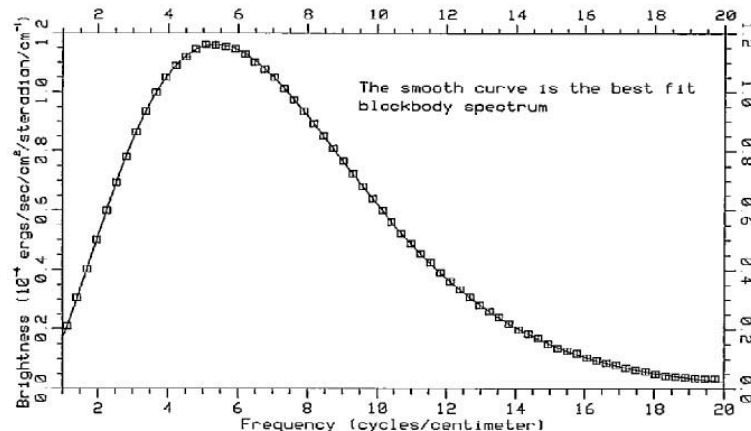
Cosmic Background Explorer: Far InfraRed Absolute Spectrophotometer

●  $2.725 \pm 0.002$  K

- One of the best determined cosmological parameters

$$T = \frac{b}{\lambda_{\max}}$$

$$B(\lambda) = \frac{8\pi hc^2}{\lambda^5} \frac{d\lambda}{e^{hc/kT} - 1}$$

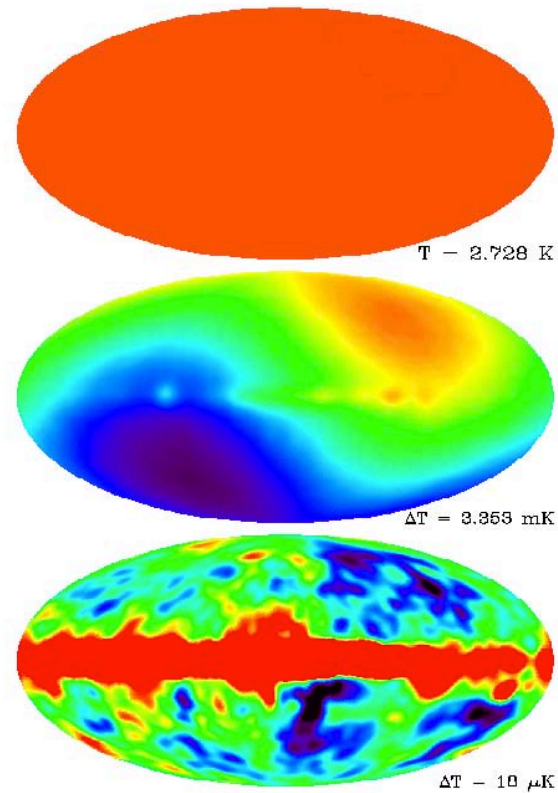




# COBE Results: DMR

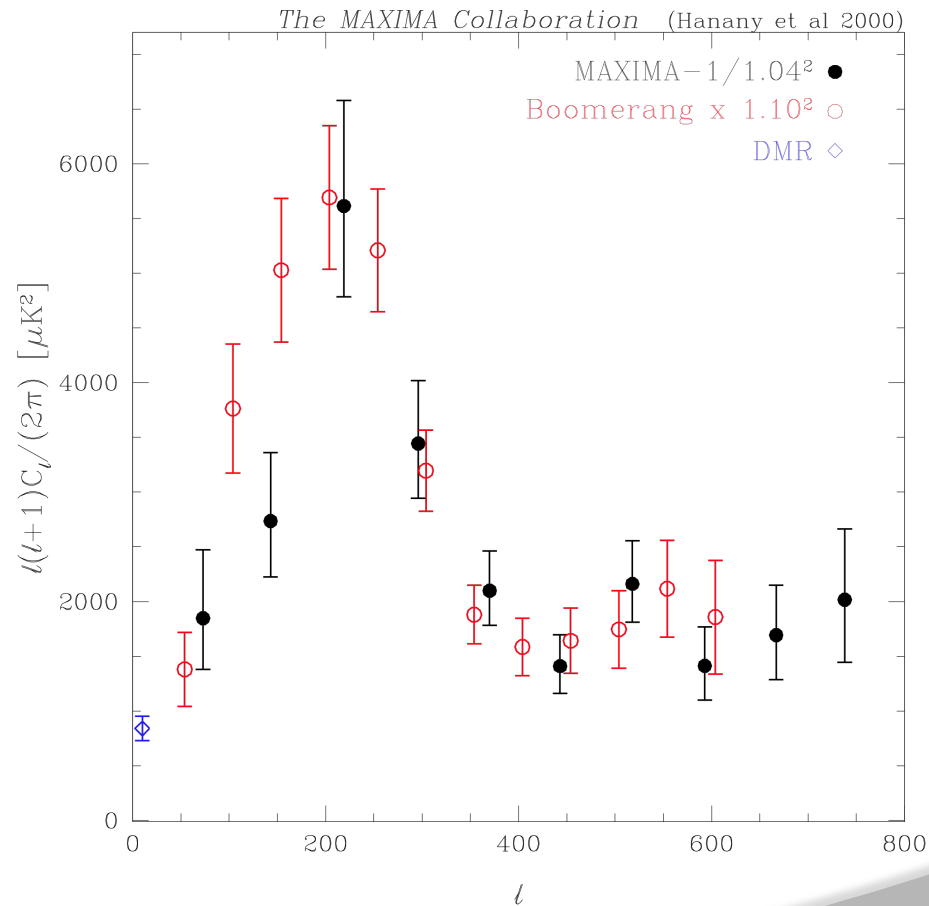
Cosmic Background Explorer: Differential Microwave Radiometer

- ⊙ Isotropic
- ⊙ Dipole temperature anisotropy -  $3.358 \pm 0.017$  mK
- ⊙ 3D density fluctuations give rise to 2D temp anisotropies



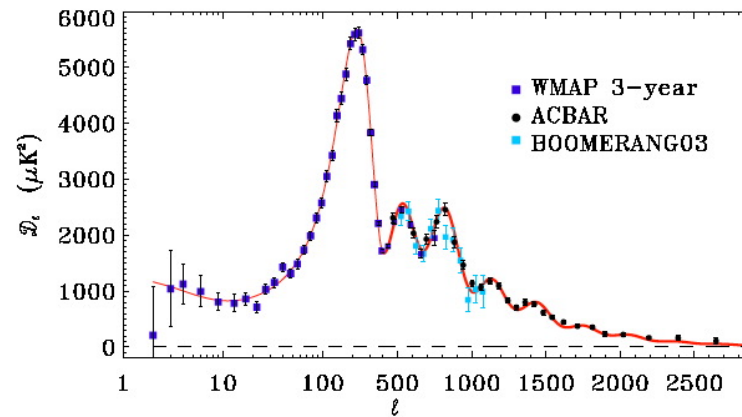
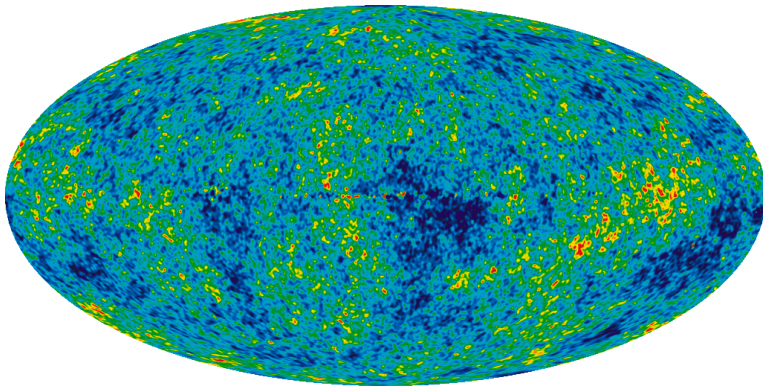
# Post-COBE:

Millimeter Anisotropy Experiment Imaging Array (**Maxima**) &  
Balloon Observations of Millimetric Extragalactic Radiation and  
Geophysics (**Boomerang**)



# Post-COBE:

Wilkinson Microwave Anisotropy Probe (WMAP) &  
Arcminute Cosmology Bolometer Array Receiver (ACBAR)



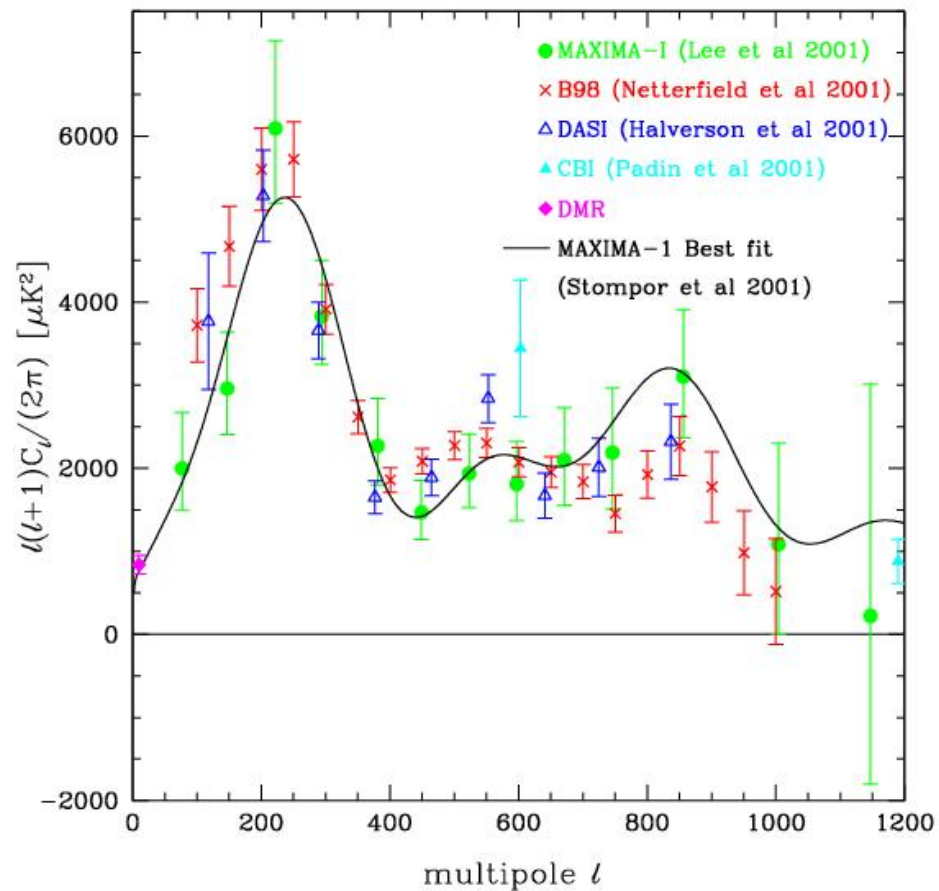
# Improvements of Cosmological Parameters

- ⊙ Hubble Constant
- ⊙ Reduced Hubble parameter
- ⊙ Scalar Spectral Index
- ⊙ Baryon Density
- ⊙ Dark energy Density
- ⊙ Matter density
- ⊙ Age of the Universe
- ⊙ Reionization Optical Depth

# CMB Temperature at the Origin

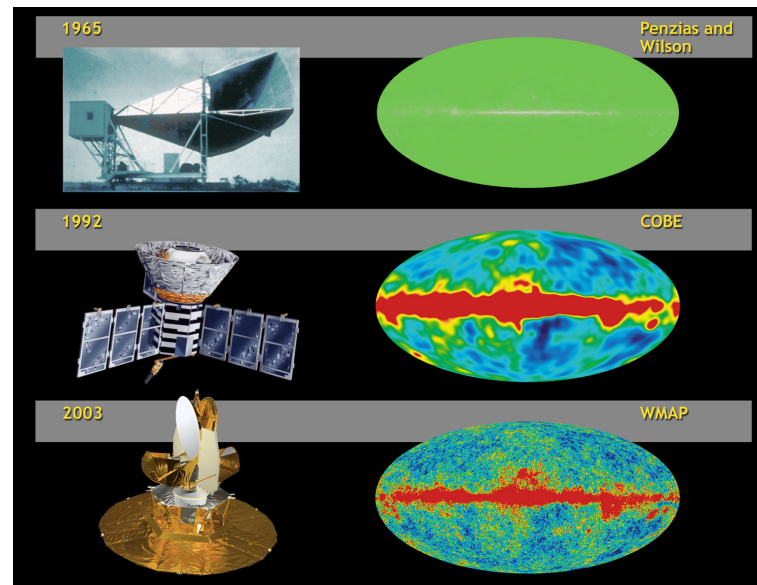
- ◎  $T_{then} = (1 + z)T_{now}$
- ◎ Assuming a preserved blackbody spectrum in redshift
- ◎ CMB spectrum distorted in the direction of galaxy clusters
  - Can use this distortion to determine the CMB temperature
  - Limited by intrinsic cluster properties
- ◎ Planck satellite will put better limits on it

# Summery of Results



# Conclusions

- ◎  $2.725 \pm 0.002$  K Blackbody
- ◎ Strong evidence for and improvements of the Big Bang Theory
- ◎ Improvements of the Cosmological Parameters



# References

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- ◉ “Maxima: Millimeter Anisotropy Experiment Imaging Array”. Cosmology. University of California Berkeley. 13 Sep 2011 <http://cosmology.berkeley.edu/group/cmb/image/mbdcd+fit.jpg>
- ◉ “ACBAR: Arcminute Cosmology Bolometer Array Receiver”. University of California Berkeley. 13 Sep 2011 <http://cosmology.berkeley.edu/group/swlh/acbar/index.html>
- ◉ “Penzias and Wilson discover cosmic microwave radiation:1965”. A Science Odyssey: People and Discoveries. 13 Sep 2011 <http://www.pbs.org/wgbh/aso/databank/entries/dp65co.html>
- ◉ "George F. Smoot - Nobel Lecture". Nobelprize.org. 13 Sep 2011 [http://www.nobelprize.org/nobel\\_prizes/physics/laureates/2006/smoot-lecture.html](http://www.nobelprize.org/nobel_prizes/physics/laureates/2006/smoot-lecture.html)
- ◉ [http://www.google.com/url?sa=t&rct=j&q=1%20plus%20z%20dependence%20of%20the%20cosmic%20microwave%20background&source=web&cd=1&sqi=2&ved=0CBoQFjAA&url=http%3A%2F%2Fpdg.lbl.gov%2F2011%2Freviews%2Frrp2011-rev-cosmic-microwave-background.pdf&ei=08upTqKUHYY5twethcwi&usg=AFQjCNG9misZgr5aGiRnvLVB6D\\_U6acdQg&sig2=jLveTD\\_VNt\\_yyZjPKmN73w](http://www.google.com/url?sa=t&rct=j&q=1%20plus%20z%20dependence%20of%20the%20cosmic%20microwave%20background&source=web&cd=1&sqi=2&ved=0CBoQFjAA&url=http%3A%2F%2Fpdg.lbl.gov%2F2011%2Freviews%2Frrp2011-rev-cosmic-microwave-background.pdf&ei=08upTqKUHYY5twethcwi&usg=AFQjCNG9misZgr5aGiRnvLVB6D_U6acdQg&sig2=jLveTD_VNt_yyZjPKmN73w)
- ◉ [http://www.google.com/url?sa=t&rct=j&q=1%20plus%20z%20dependence%20of%20the%20cosmic%20microwave%20background&source=web&cd=6&sqi=2&ved=0CEQQFjAF&url=http%3A%2F%2Fwww.astro.uni-bonn.de%2F~mnord%2Fbrunost%2Fex.ps&ei=08upTqKUHYY5twethcwi&usg=AFQjCNGGsqFCuG\\_gFMoPRcdiDGWuMRHYzg&sig2=22ICrP3SPjJoY-WTwsPNwg](http://www.google.com/url?sa=t&rct=j&q=1%20plus%20z%20dependence%20of%20the%20cosmic%20microwave%20background&source=web&cd=6&sqi=2&ved=0CEQQFjAF&url=http%3A%2F%2Fwww.astro.uni-bonn.de%2F~mnord%2Fbrunost%2Fex.ps&ei=08upTqKUHYY5twethcwi&usg=AFQjCNGGsqFCuG_gFMoPRcdiDGWuMRHYzg&sig2=22ICrP3SPjJoY-WTwsPNwg)
- ◉ <http://cosmology.berkeley.edu/~yuki/CMBpol/>