First Year WMAP Results

Ned Wright, UCLA

See:

http://www.astro.ucla.edu/~wright/cosmolog.htm

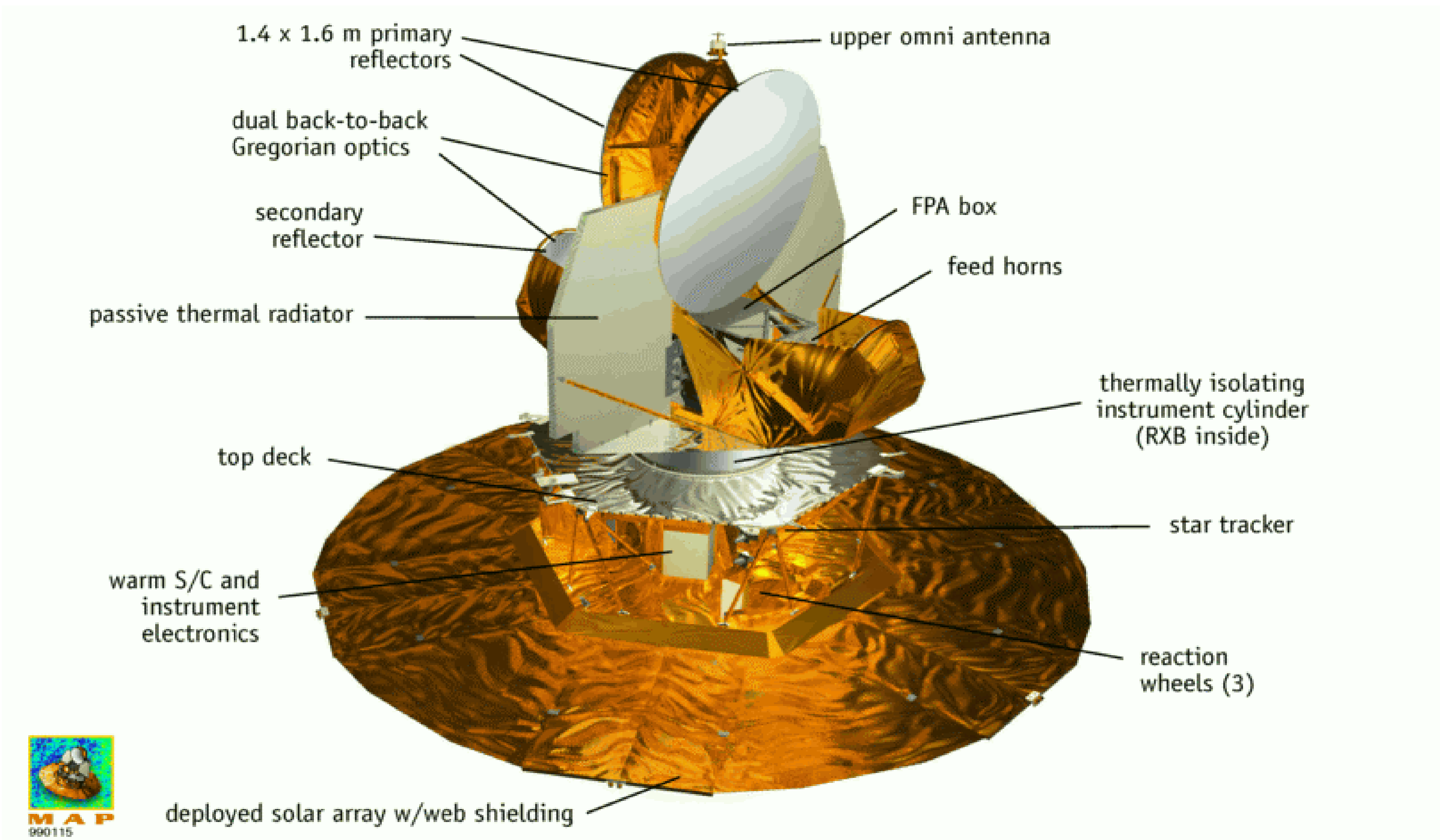
http://map.gsfc.nasa.gov

http://www.astro.ucla.edu/~wright/CMB-DT.html

WMAP Briefly:

- The Microwave Anisotropy Probe has been renamed in honor of David T. Wilkinson
- Maps and power spectra from the first full year of WMAP data have been released 11 Feb 2003
- The TE temperature-polarization signal has been seen at large and small angles
  - $\tau = 0.17 \pm 0.04$
  - Reionization: $z \sim 17$, $t \sim 180$ Myr ABB
- ΛCDM is a good fit to the power spectrum

A New Cosmology Satellite

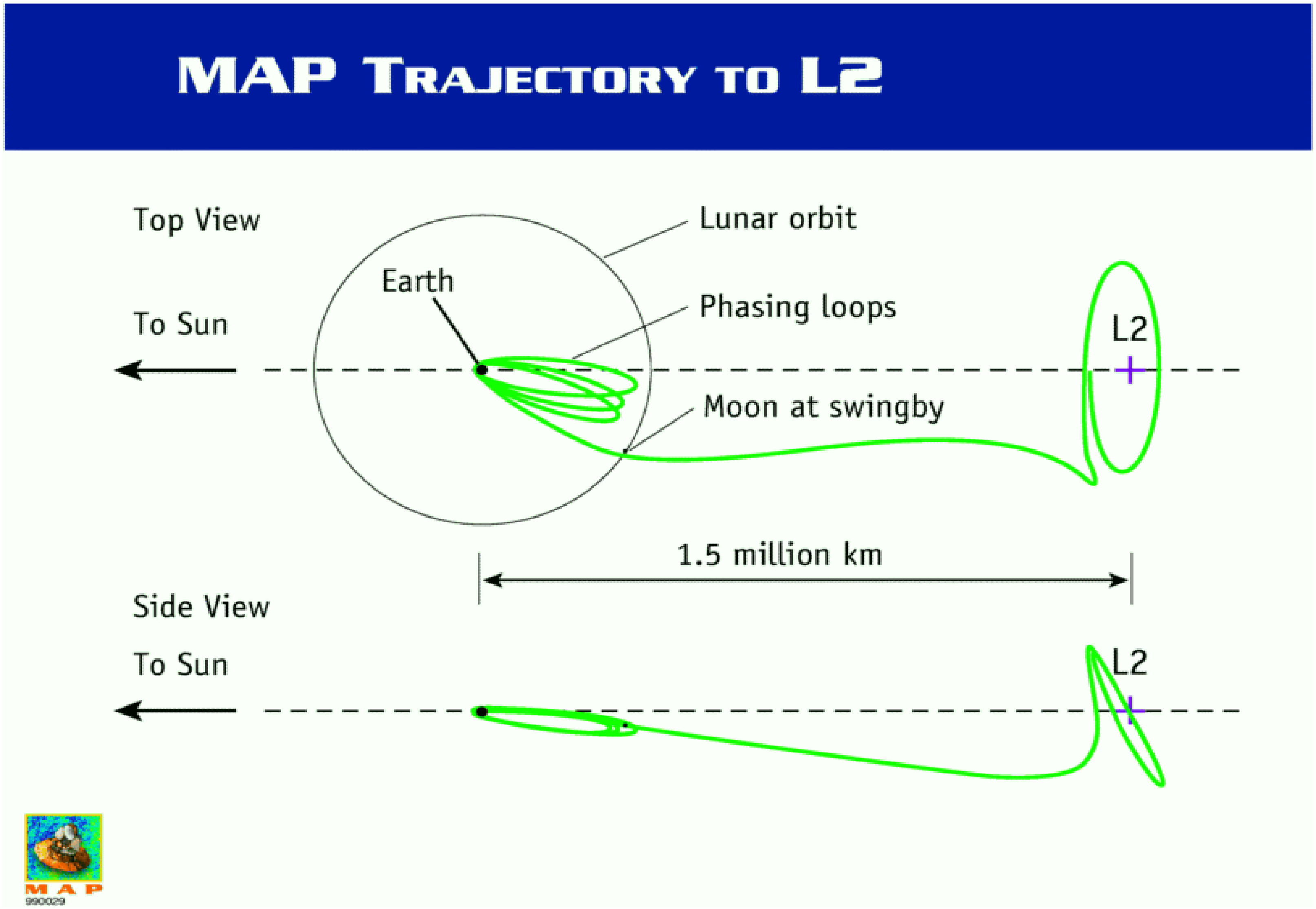


WMAP Science Working Group

WMAP Specifications

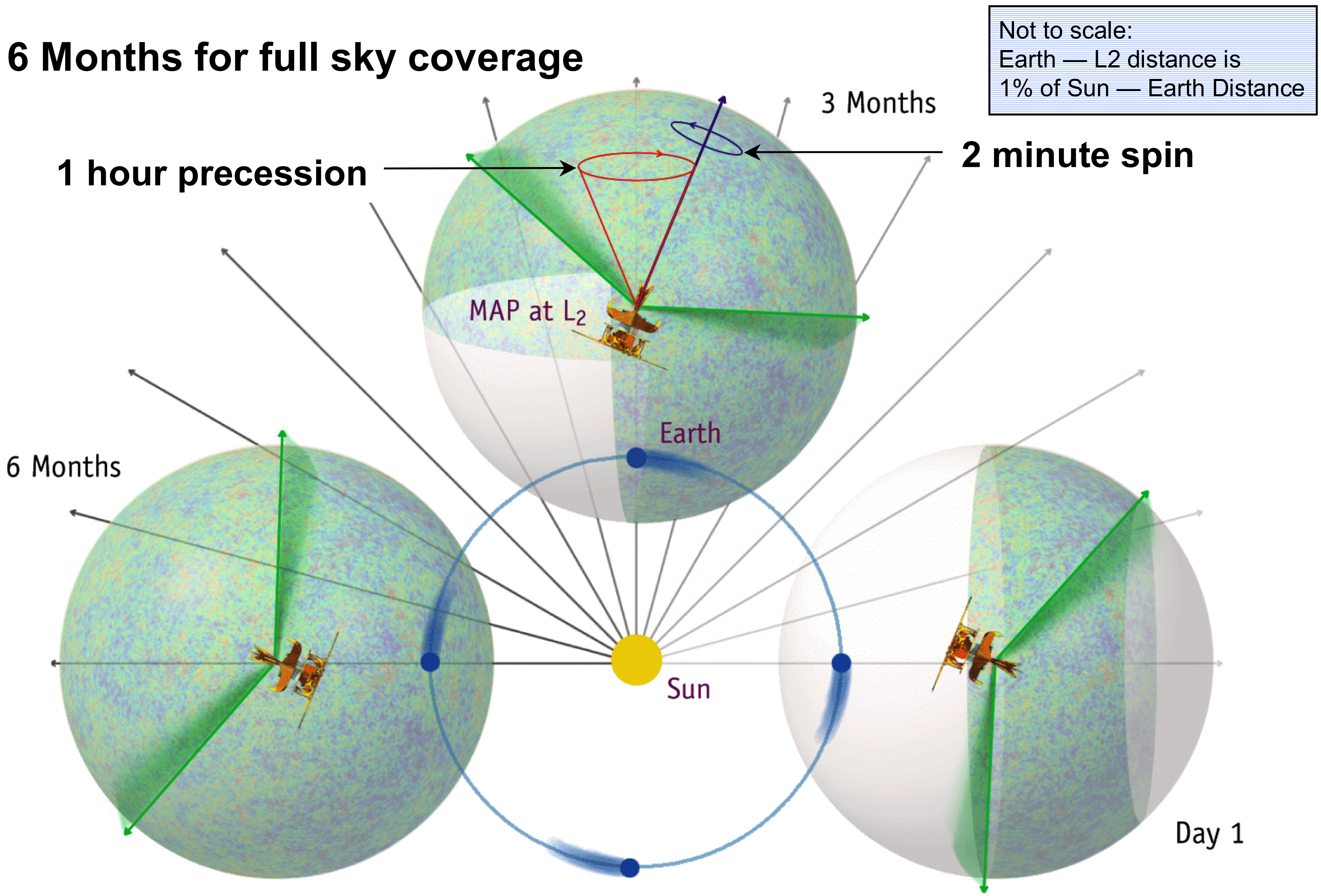
- WMAP has 30× better angular resolution than COBE: < 0.25 *vs* 7 degrees.
- WMAP has 45× better sensitivity than COBE: 2 years with WMAP equals 4000 years with COBE.
- WMAP is at the Earth-Sun L2 point, avoiding systematic errors due to the Earth's magnetic field and emission from the Earth's limb.
- Like COBE, WMAP chops rapidly between two widely separated beams.

WMAP’s Orbit

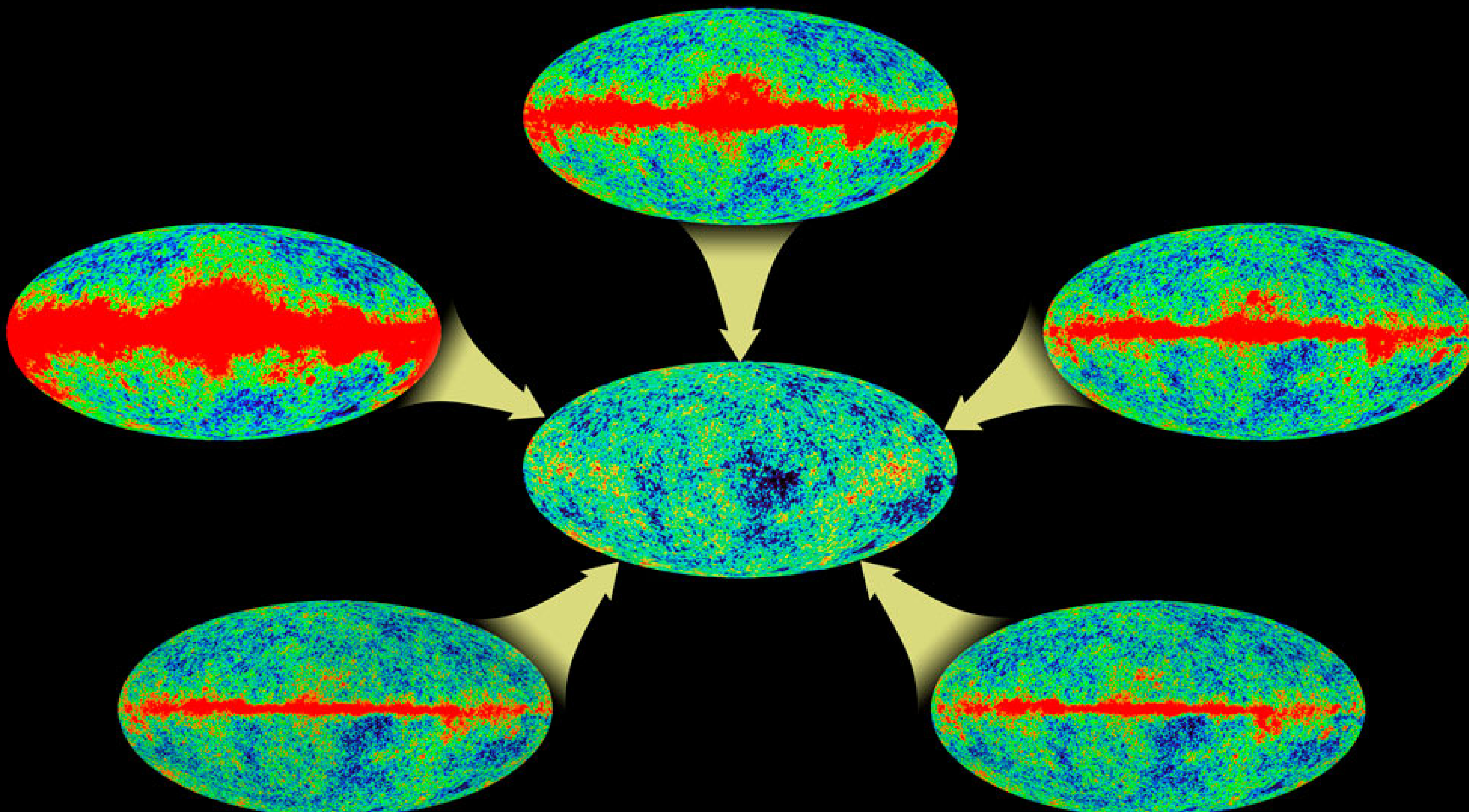

MAP Trajectory to L2
Top View
To Sun
Earth
Lunar orbit
Phasing loops
Moon at swingby
L2
1.5 million km
Side View
To Sun
L2
MAP
990029

Scan Strategy

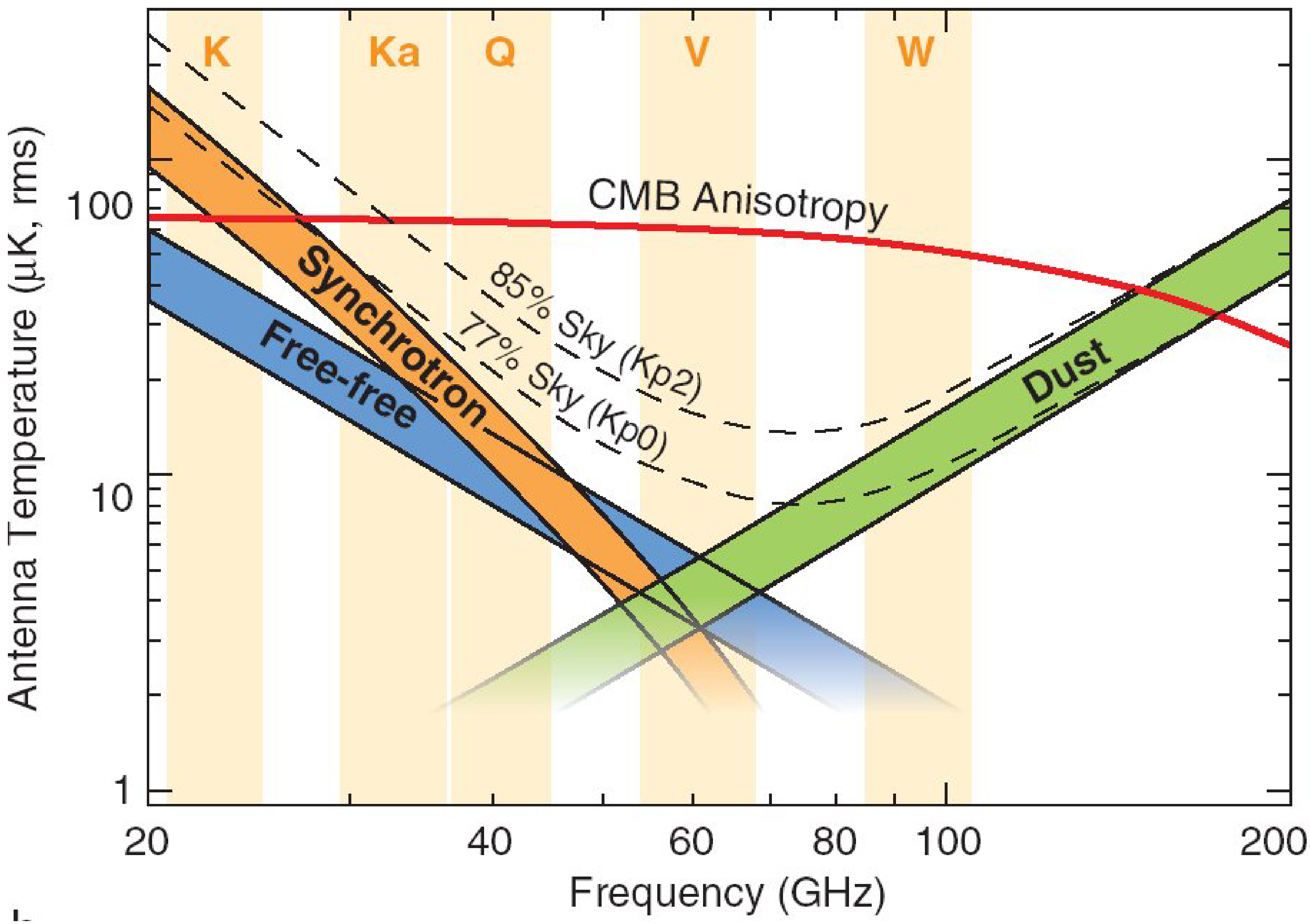
- **6 Months for full sky coverage**



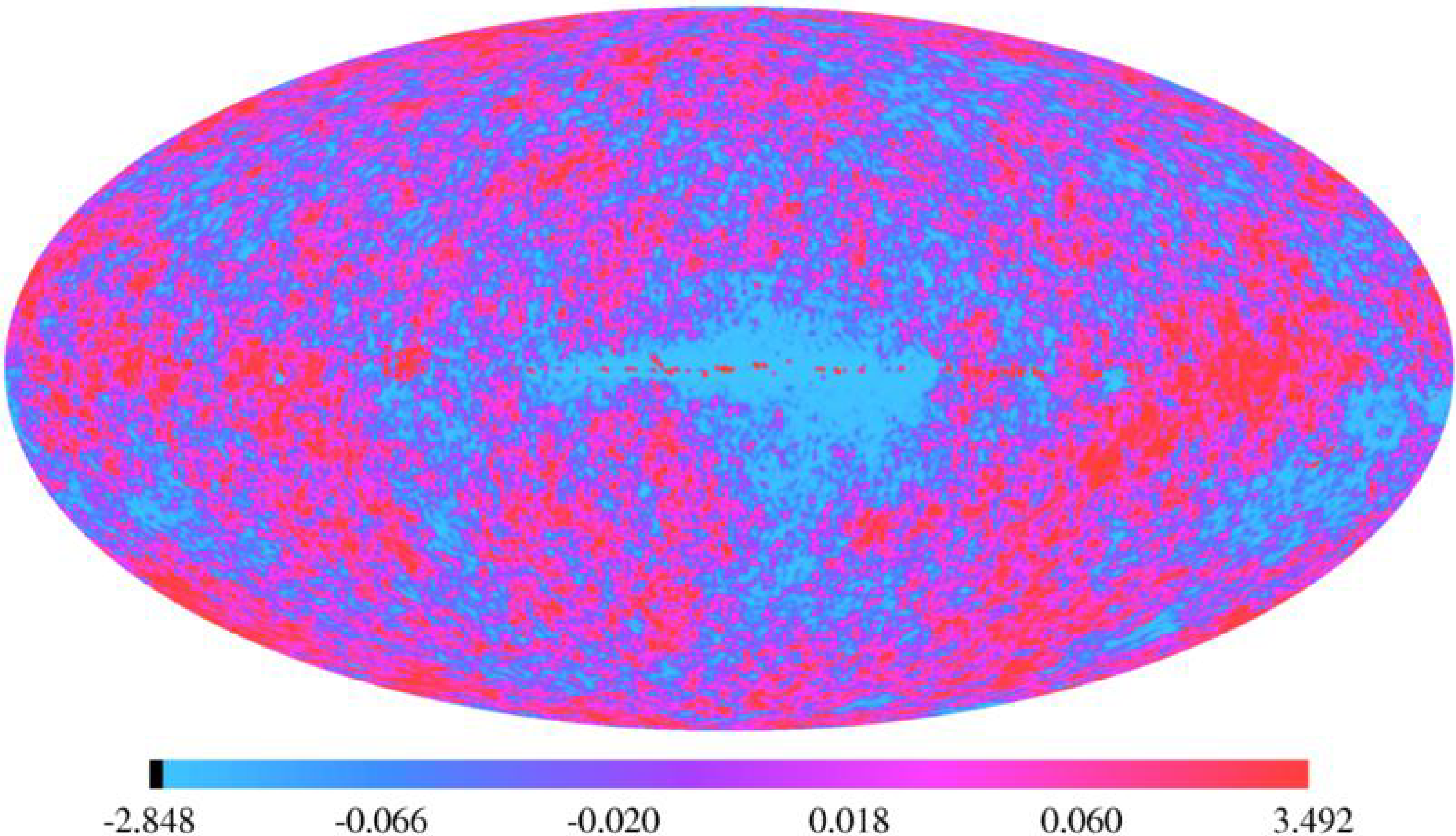
Combination to remove foreground



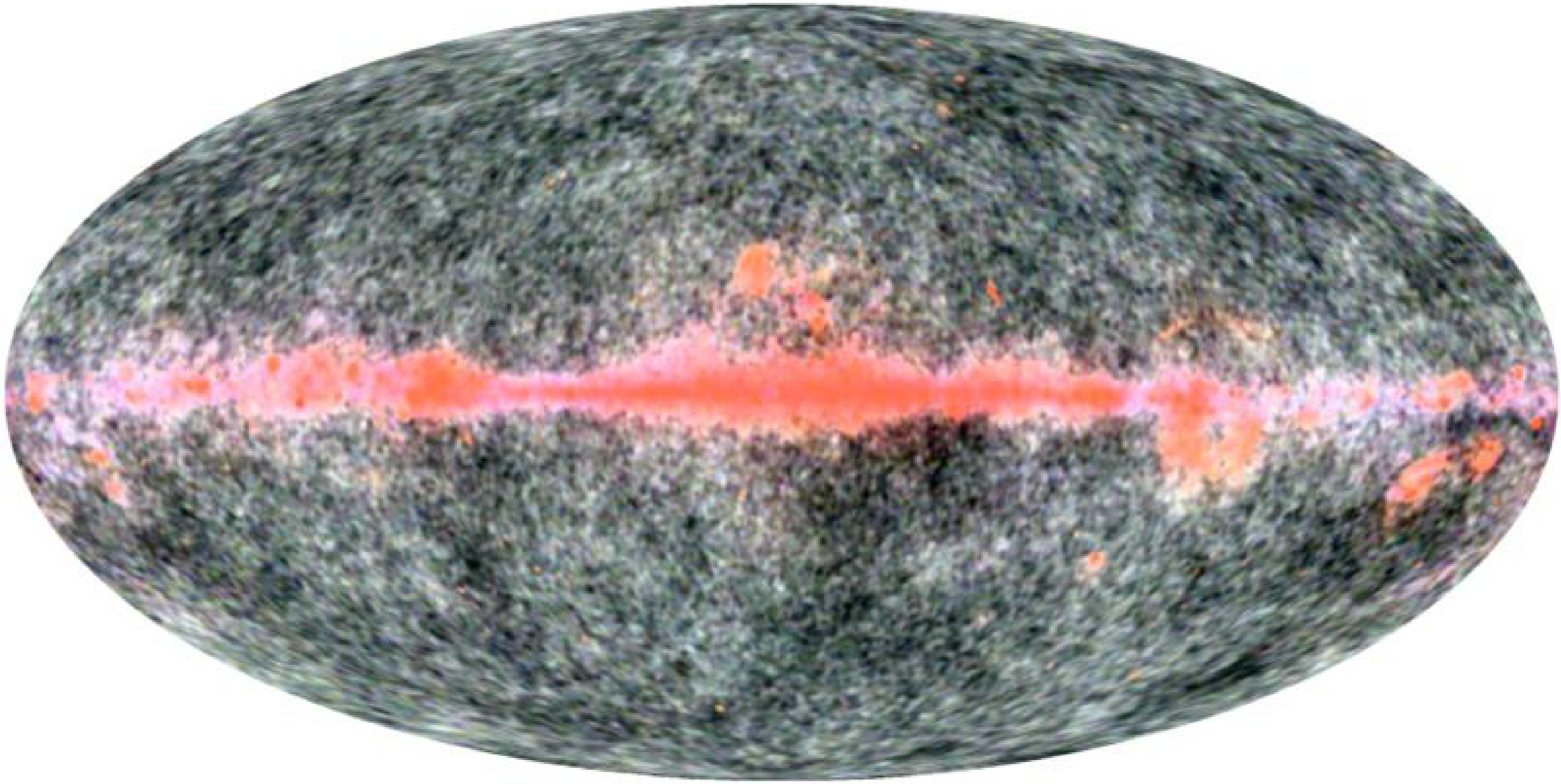
Foreground vs CMB Power



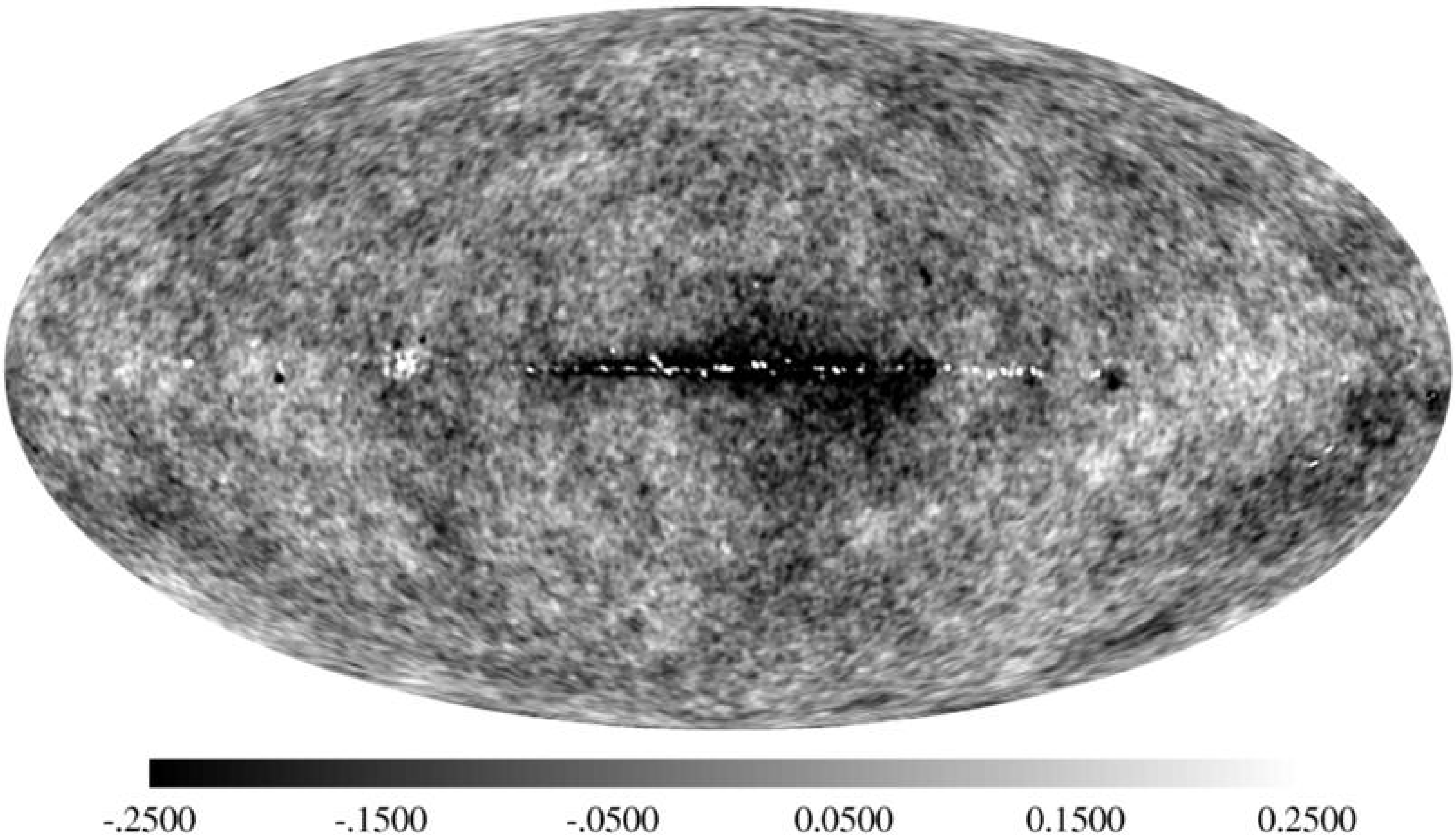
Remove Galaxy, 19000x Contrast



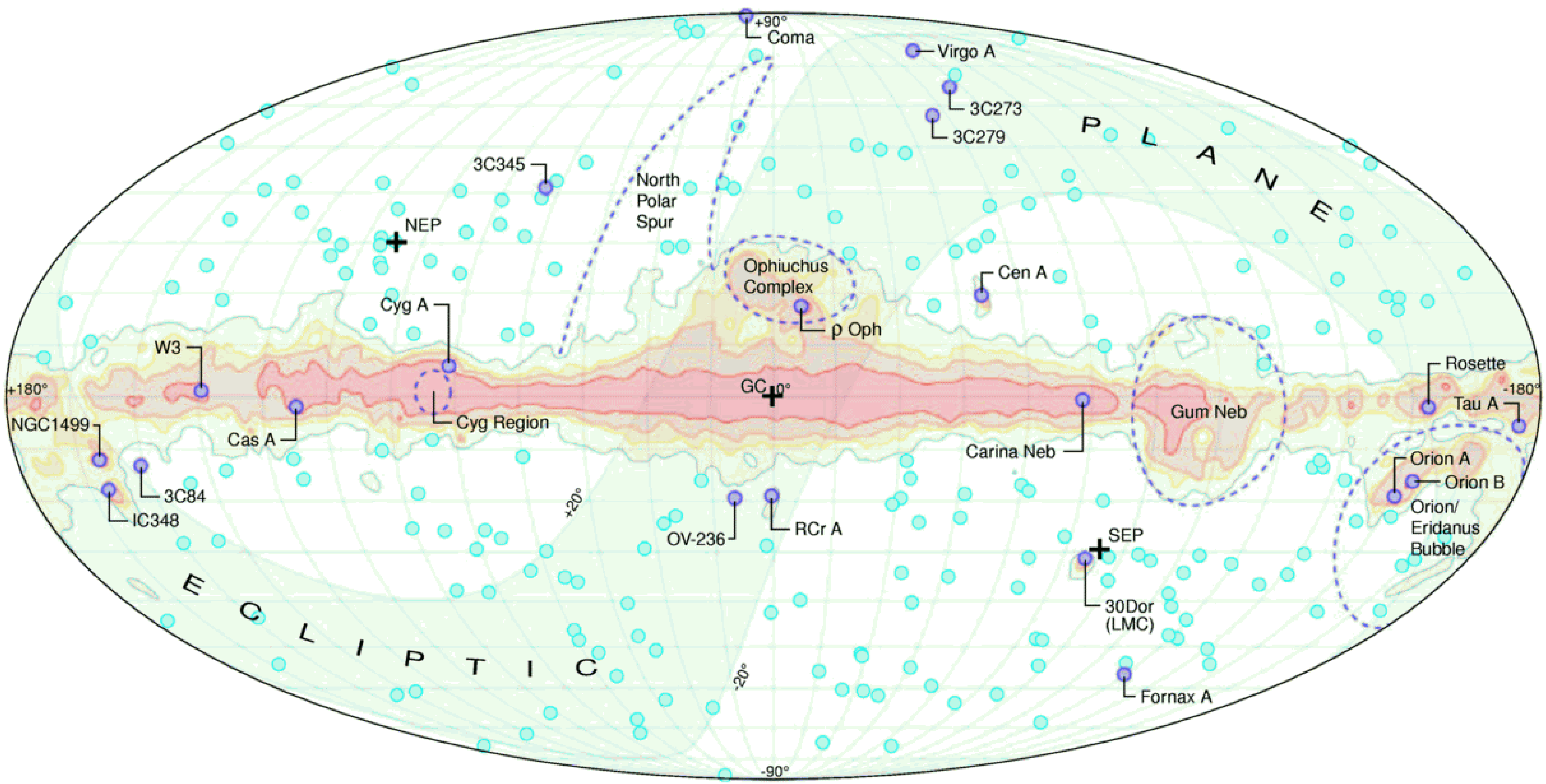
QVW as RGB



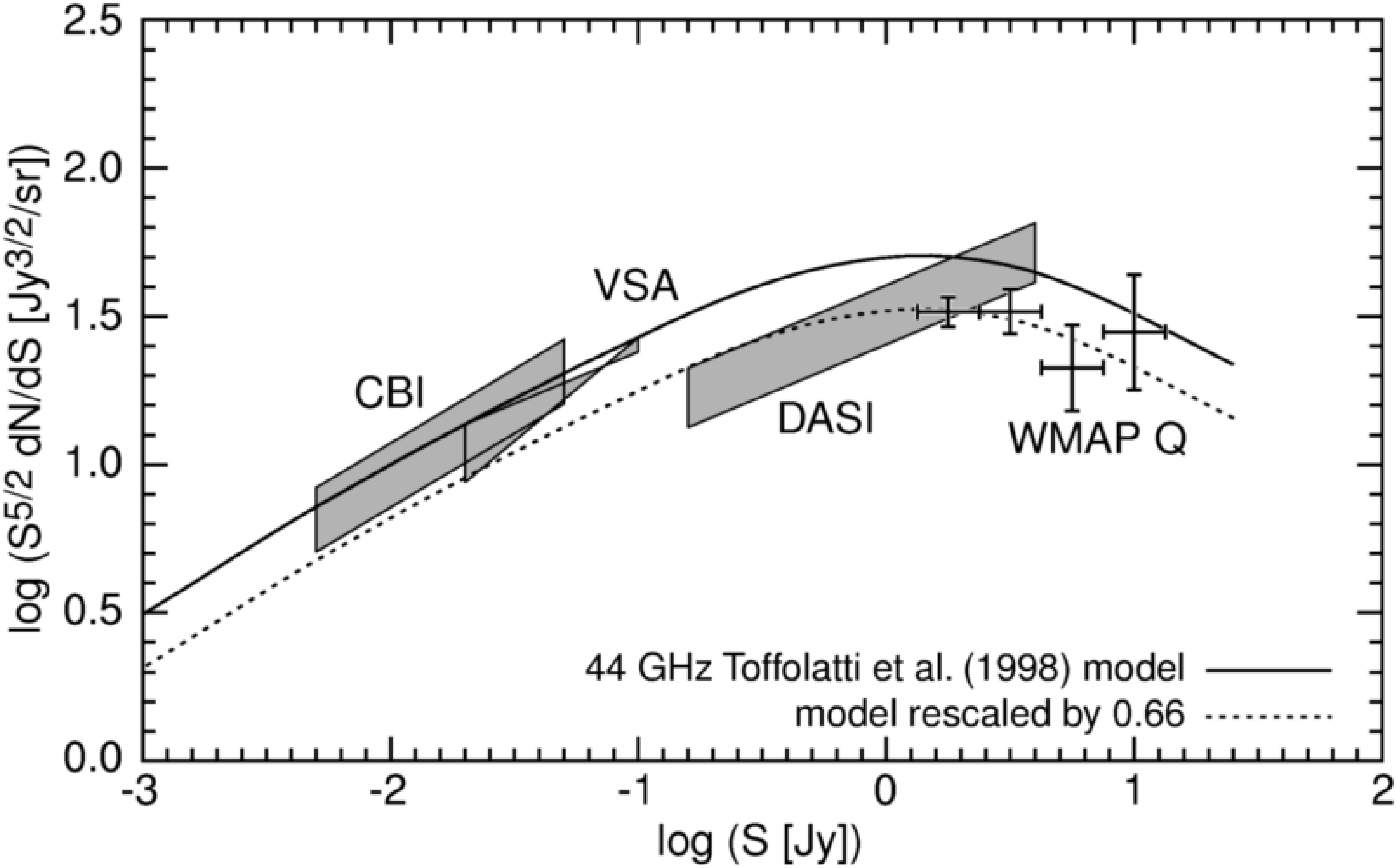
No Galaxy on same scale



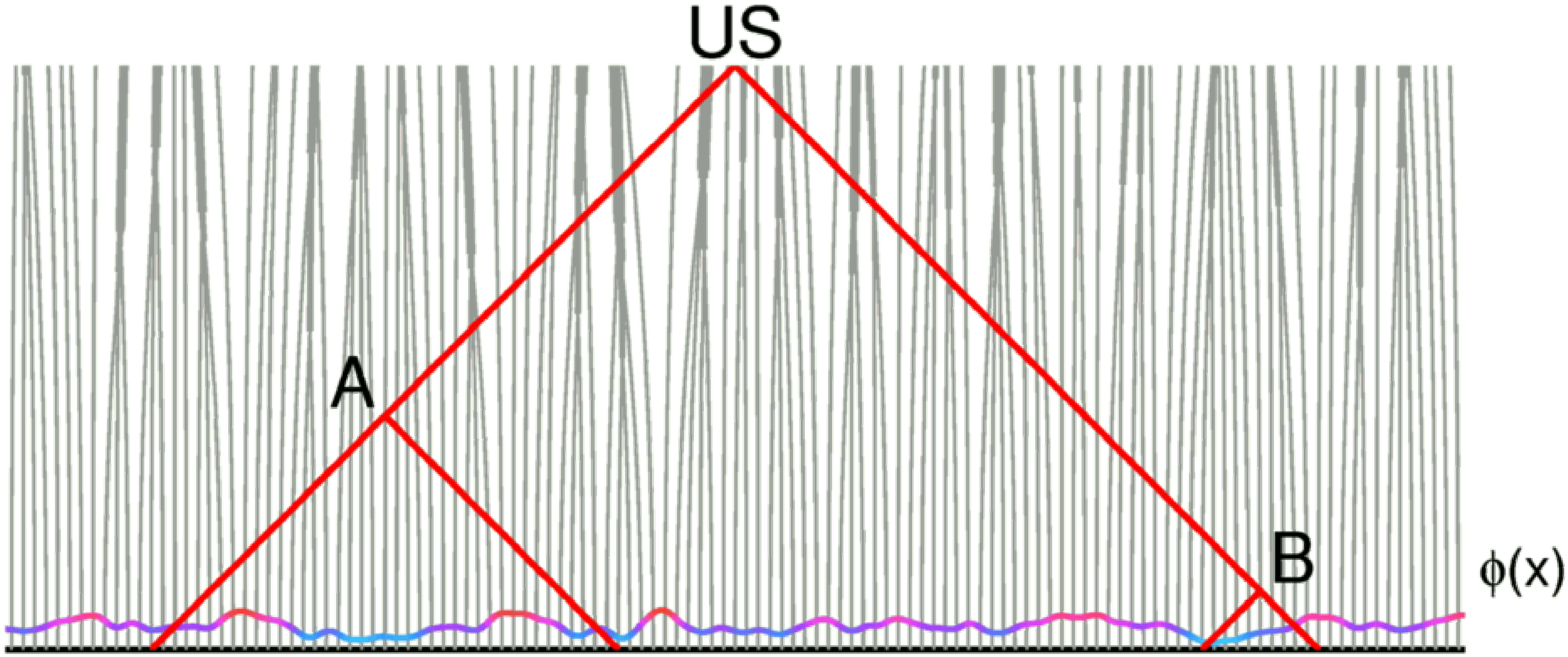
Key to these maps



208-(5±4) Detected Radio Sources



Gravitational Potential $\rightarrow \Delta T$



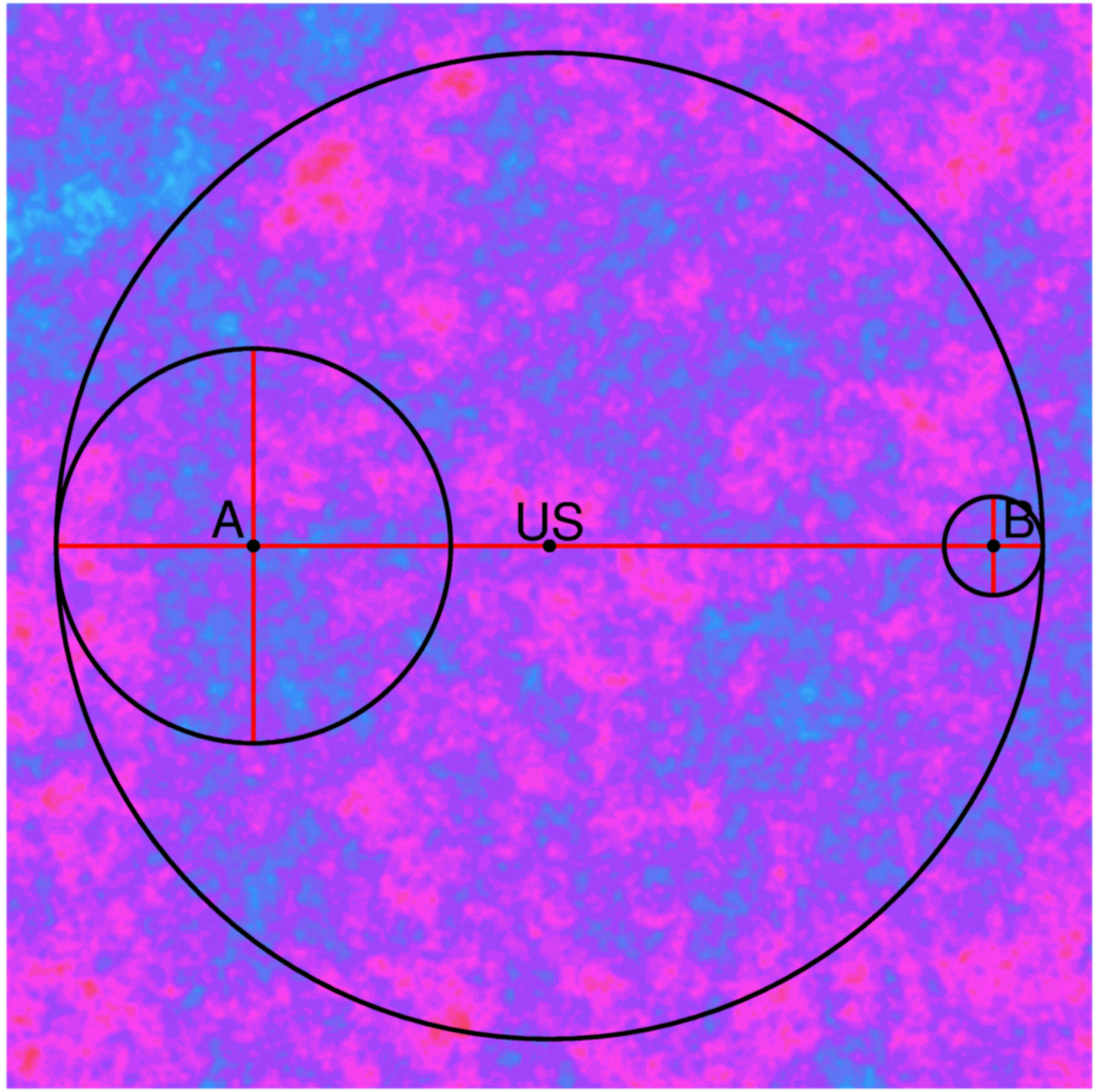
This potential also leads to large scale structure formation.

Reionization puts scatterers at A: many degree scale

Scatterers during recombination are at B: sub-degree scale

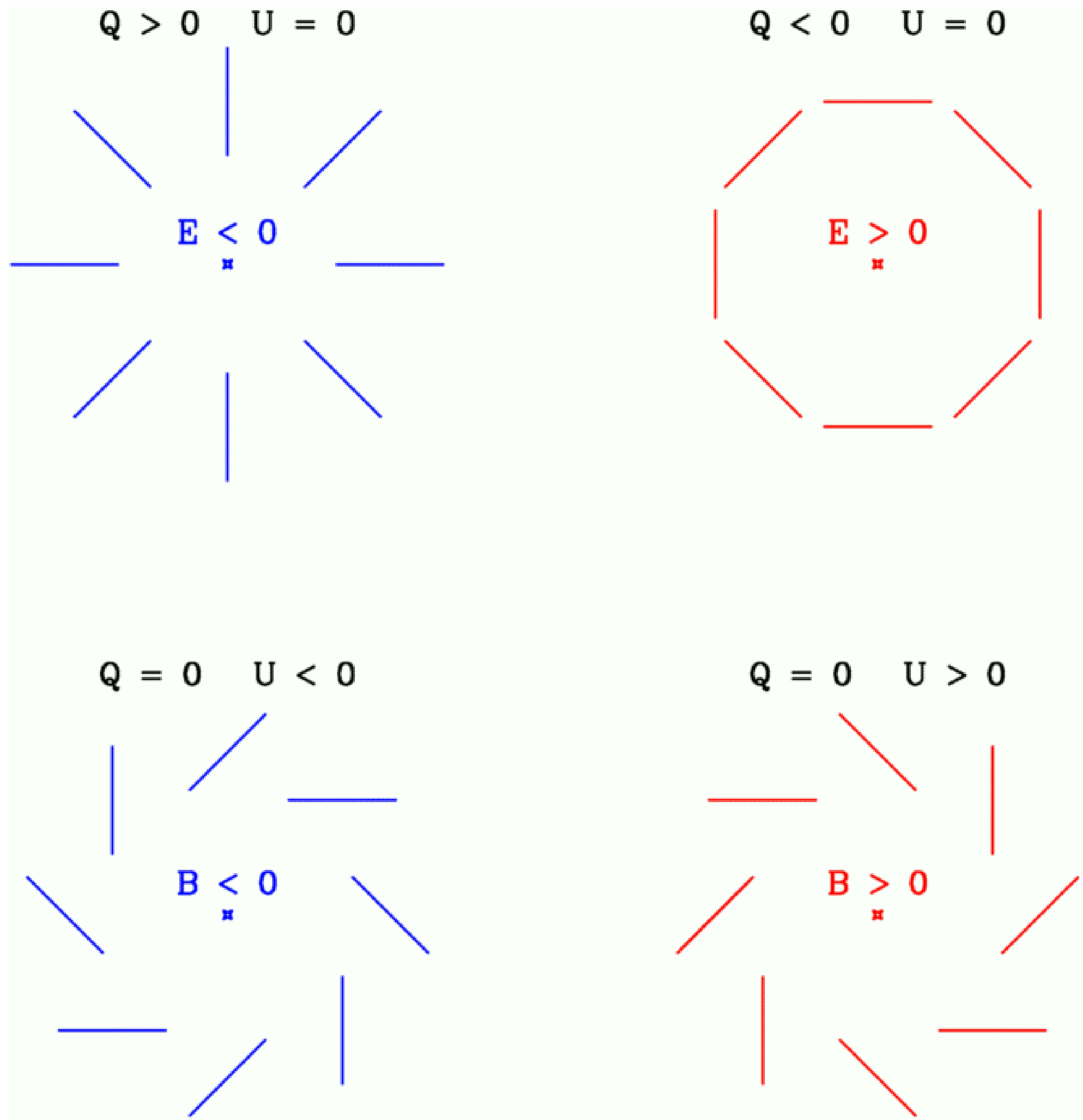
Top view of same S-T Diagram

- Electrons at A or B see a somewhat different piece of the surface of last scattering than we do.
- If electrons at A or B see a quadrupole anisotropy then we get polarization.

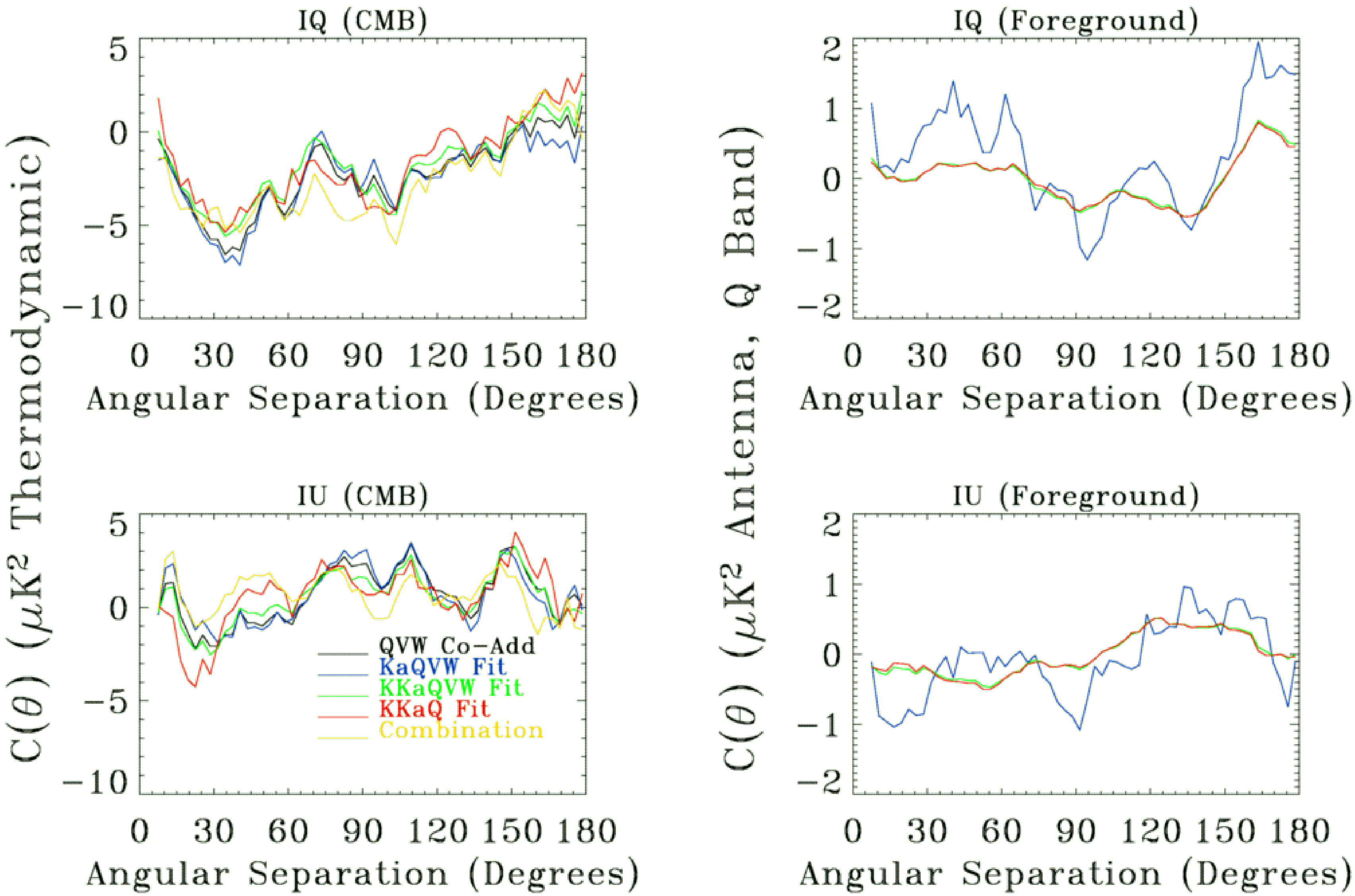


Two kinds of pattern: E & B

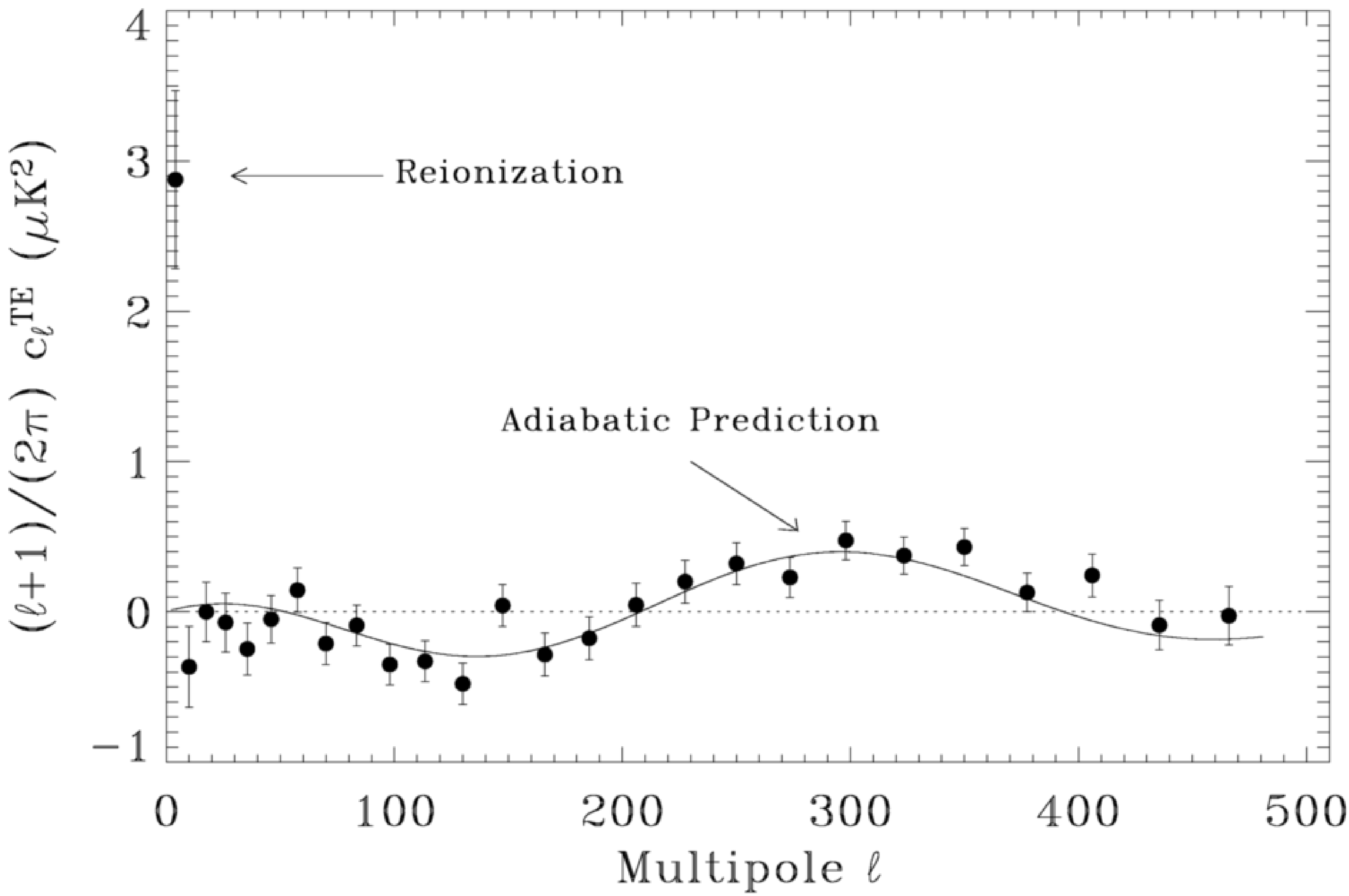
- E modes are the gradient of a scalar.
- B modes are rotated 45 degrees.
- Only E modes are generated by electron scattering acting on density perturbations.



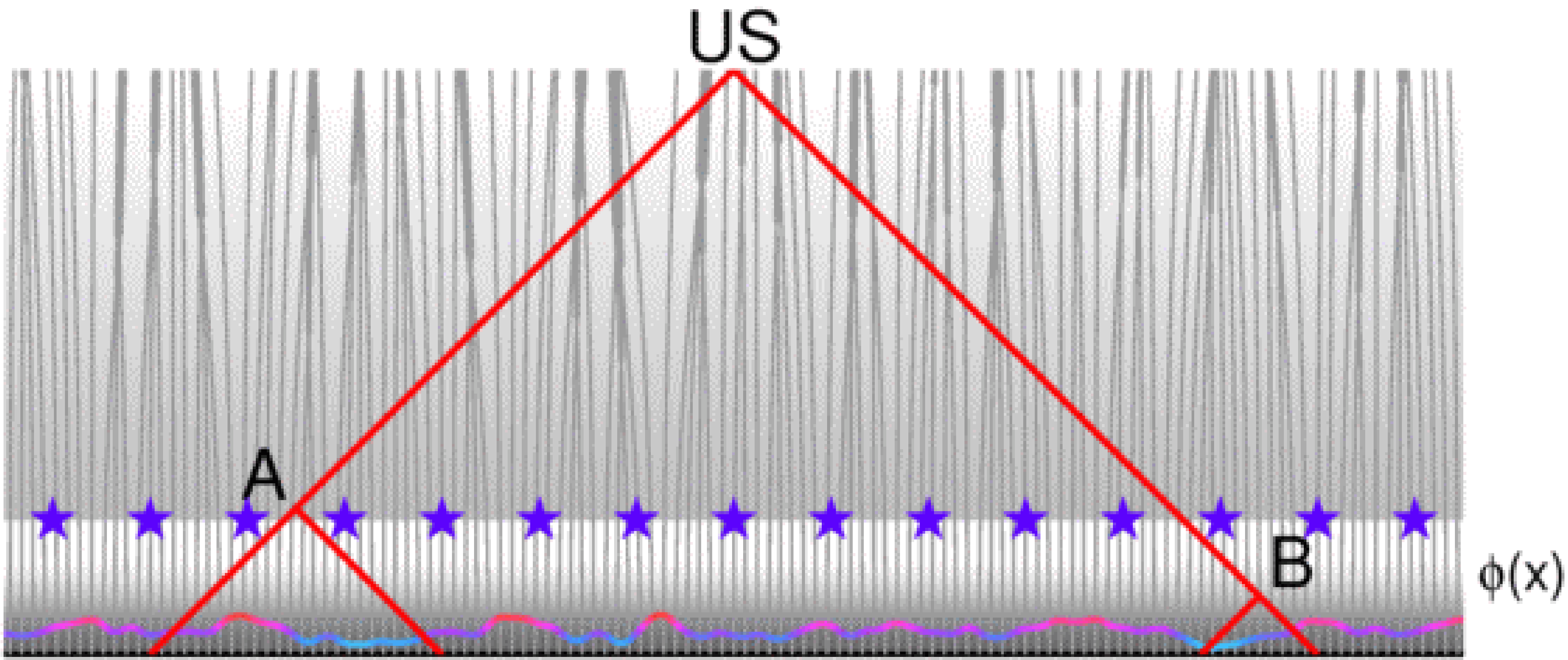
Polarized Foreground Removal



Small Angle TE Signal

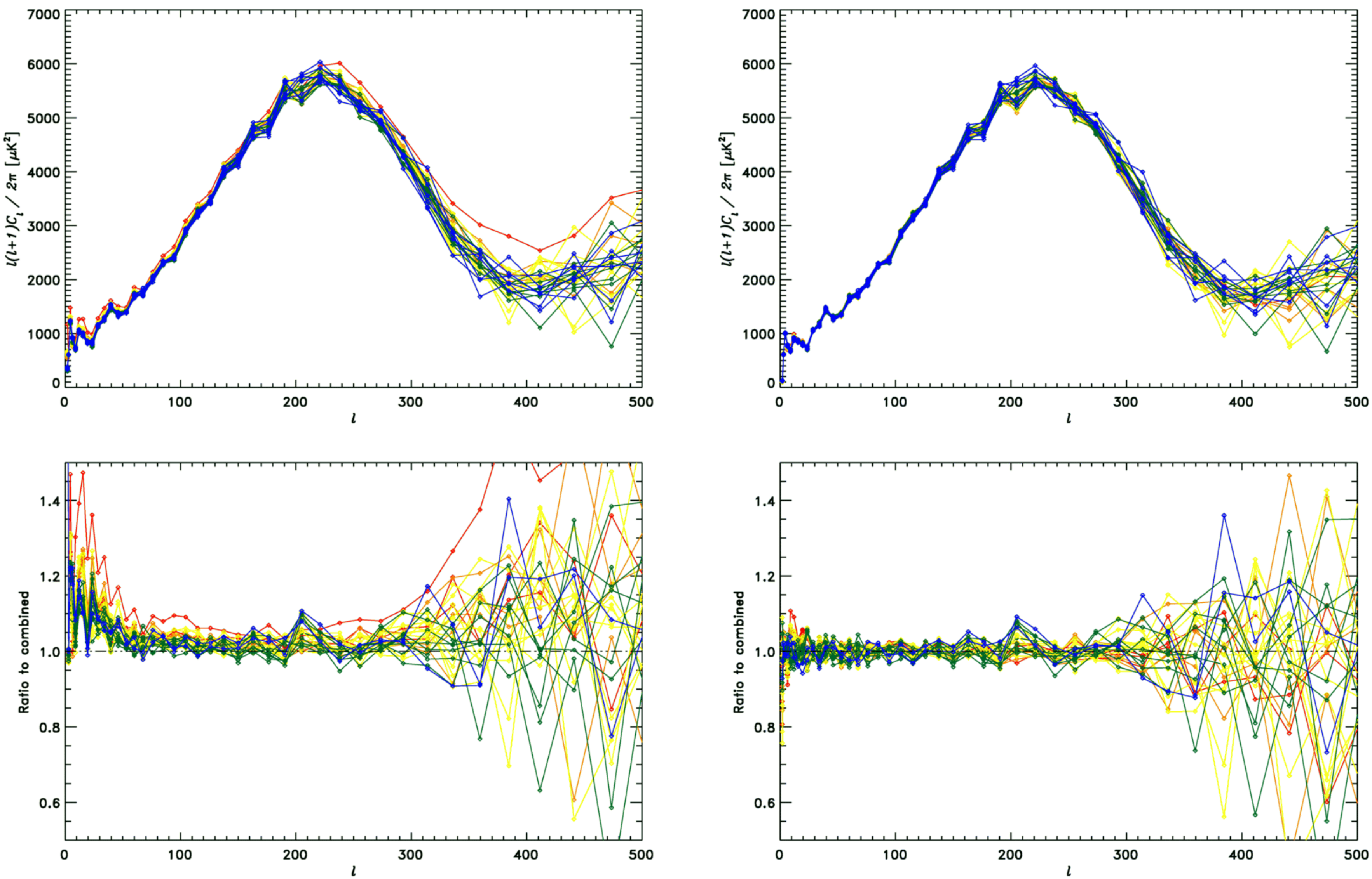


Reionization at z=20, t=180 Myr ABB

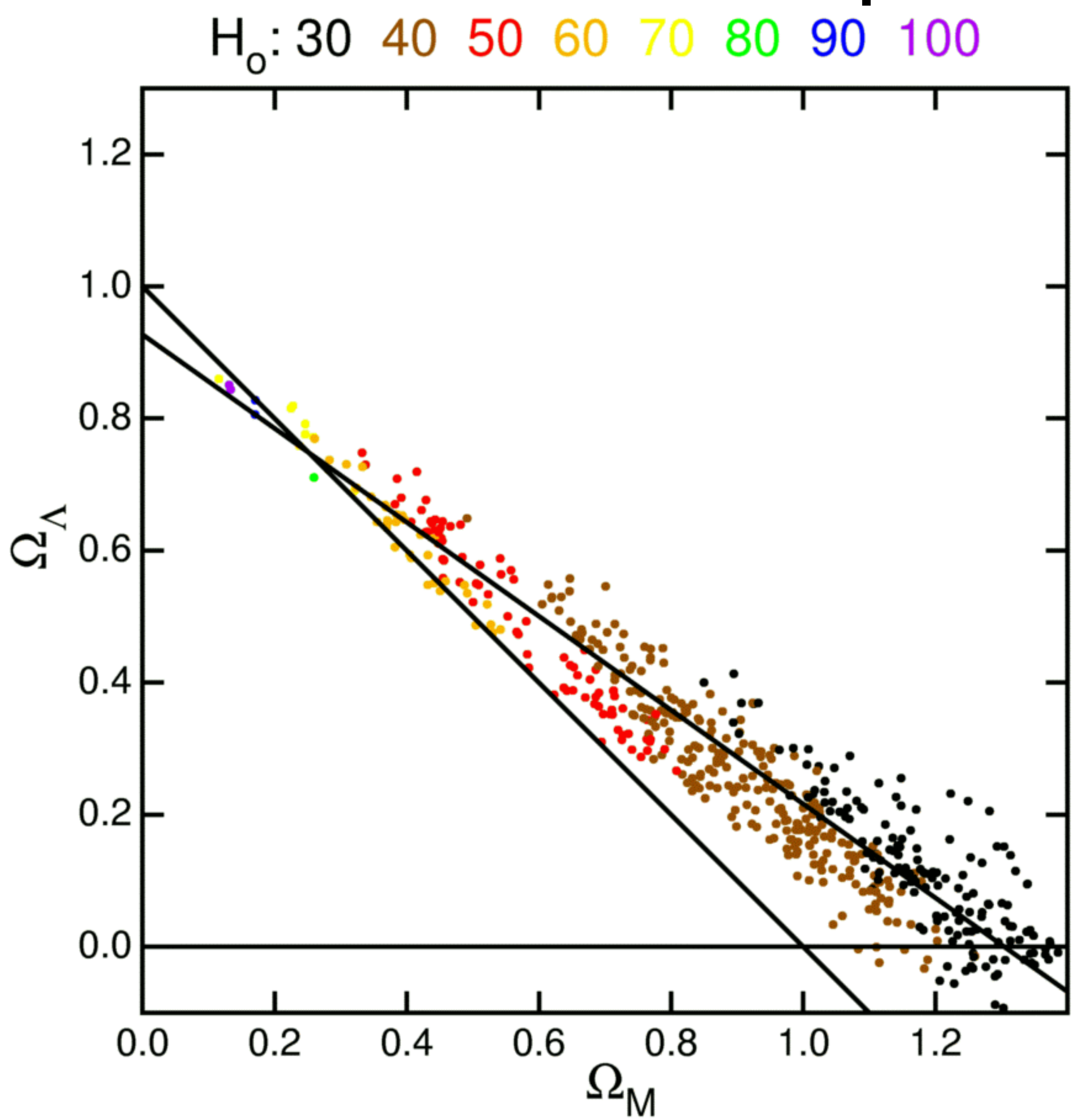


Polarization is where more integration time will pay off the most. MAP is funded to observe for 4 years, and the SNR on this reionization signal will increase significantly. In addition this will give 4 complete cycles to check for annual systematics.

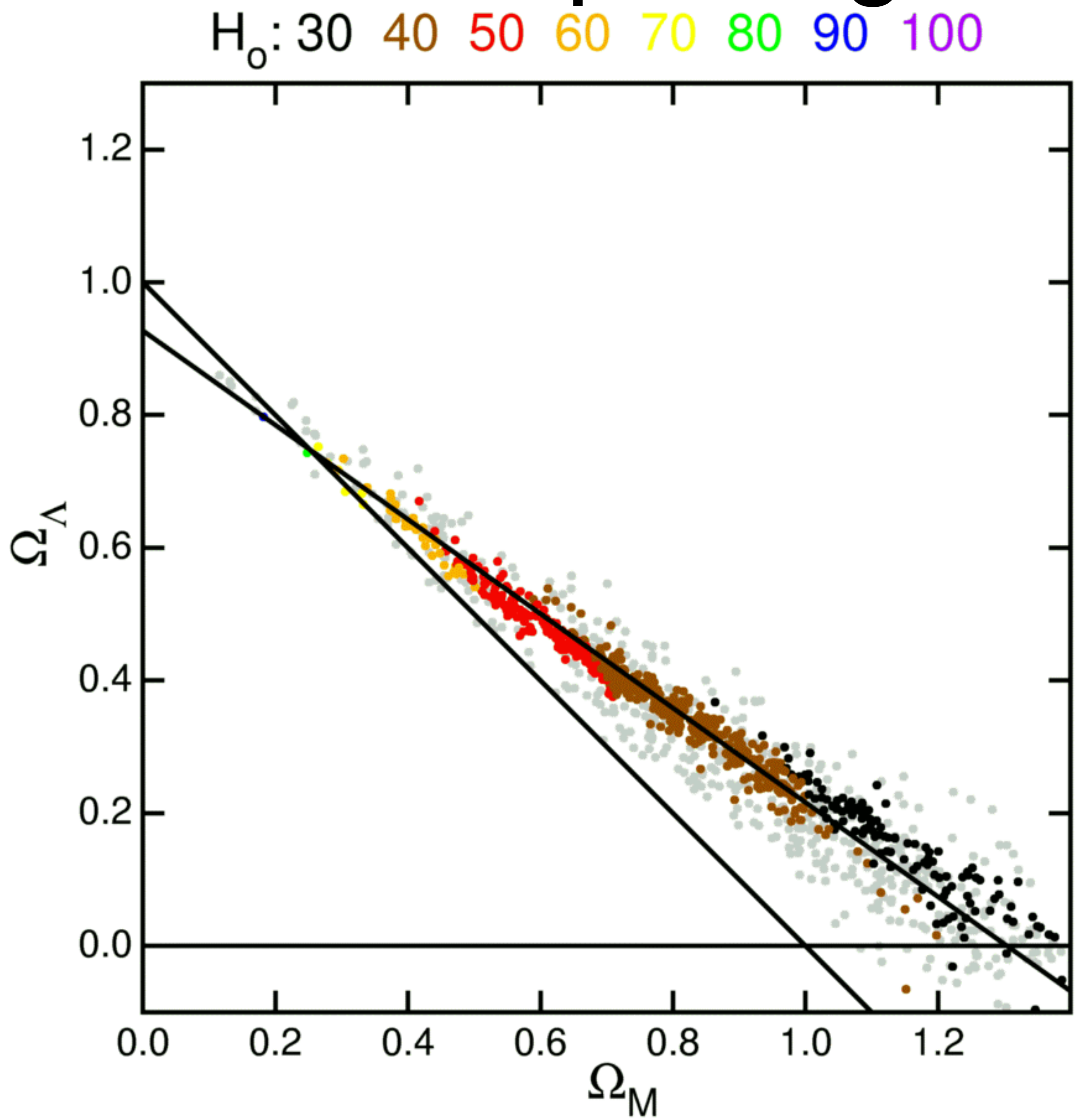
28 Cross Power Spectra



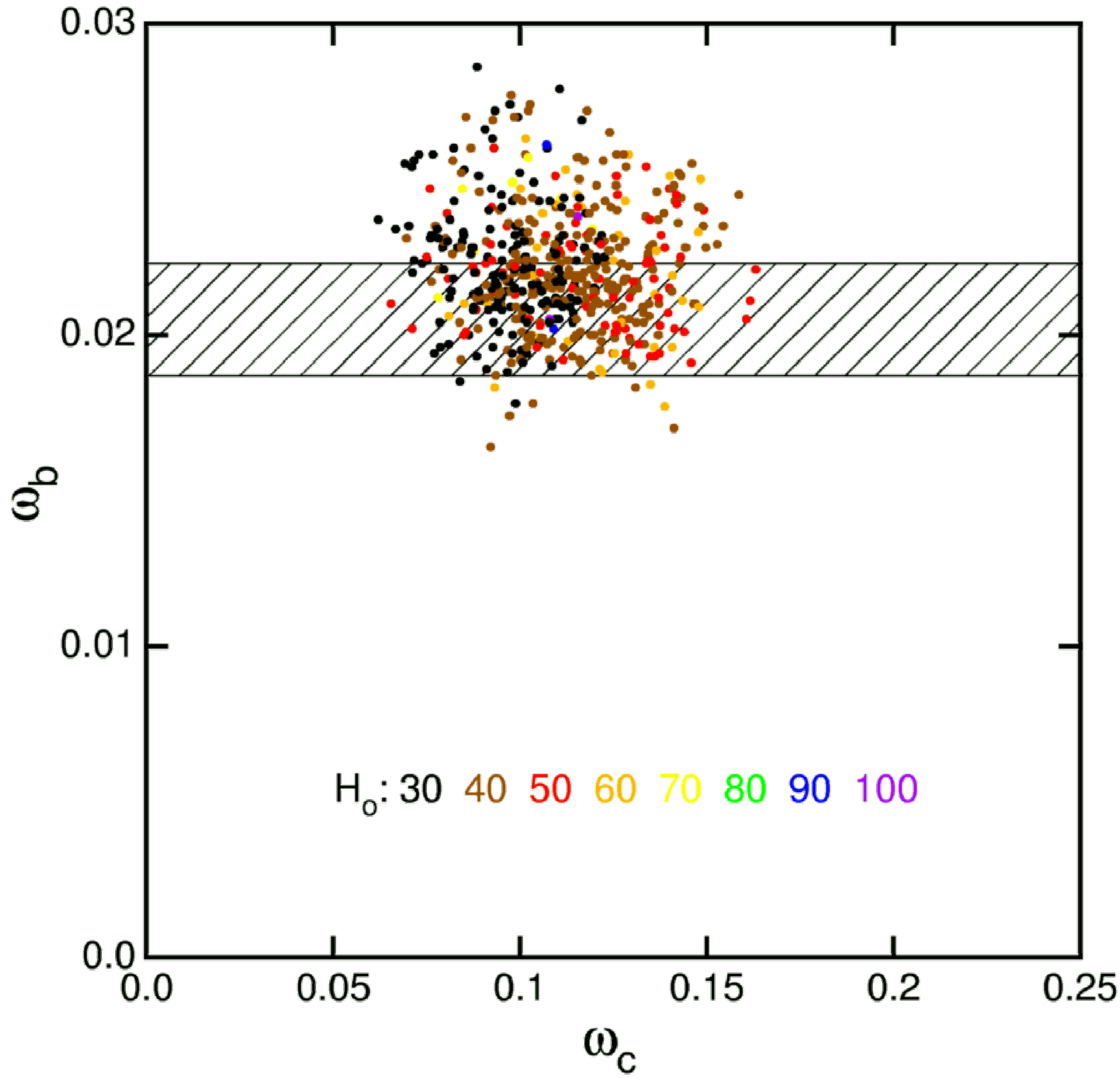
What We Have Learned: pre-WMAP



With WMAP replacing COBE

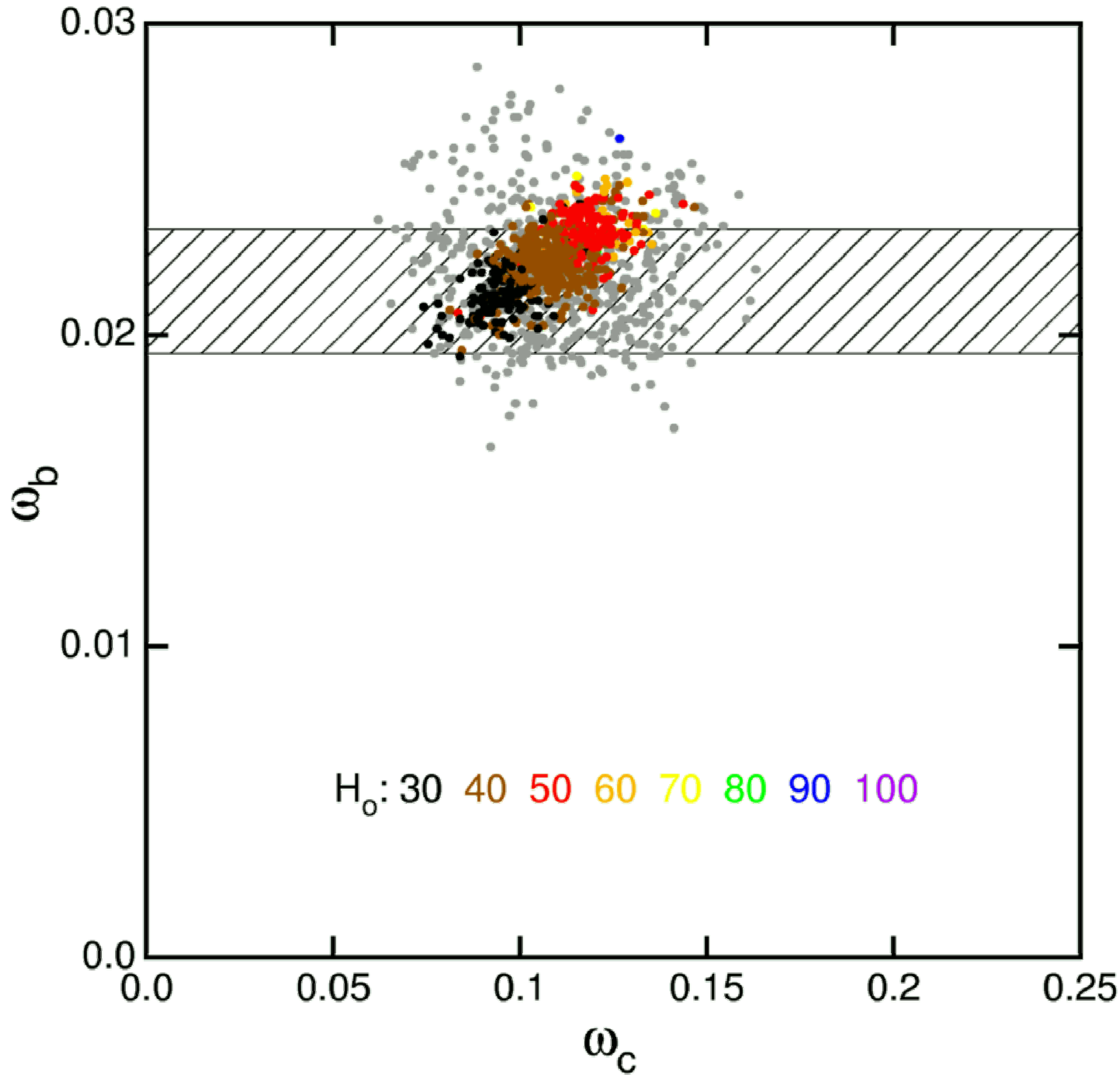


Pre-WMAP densities



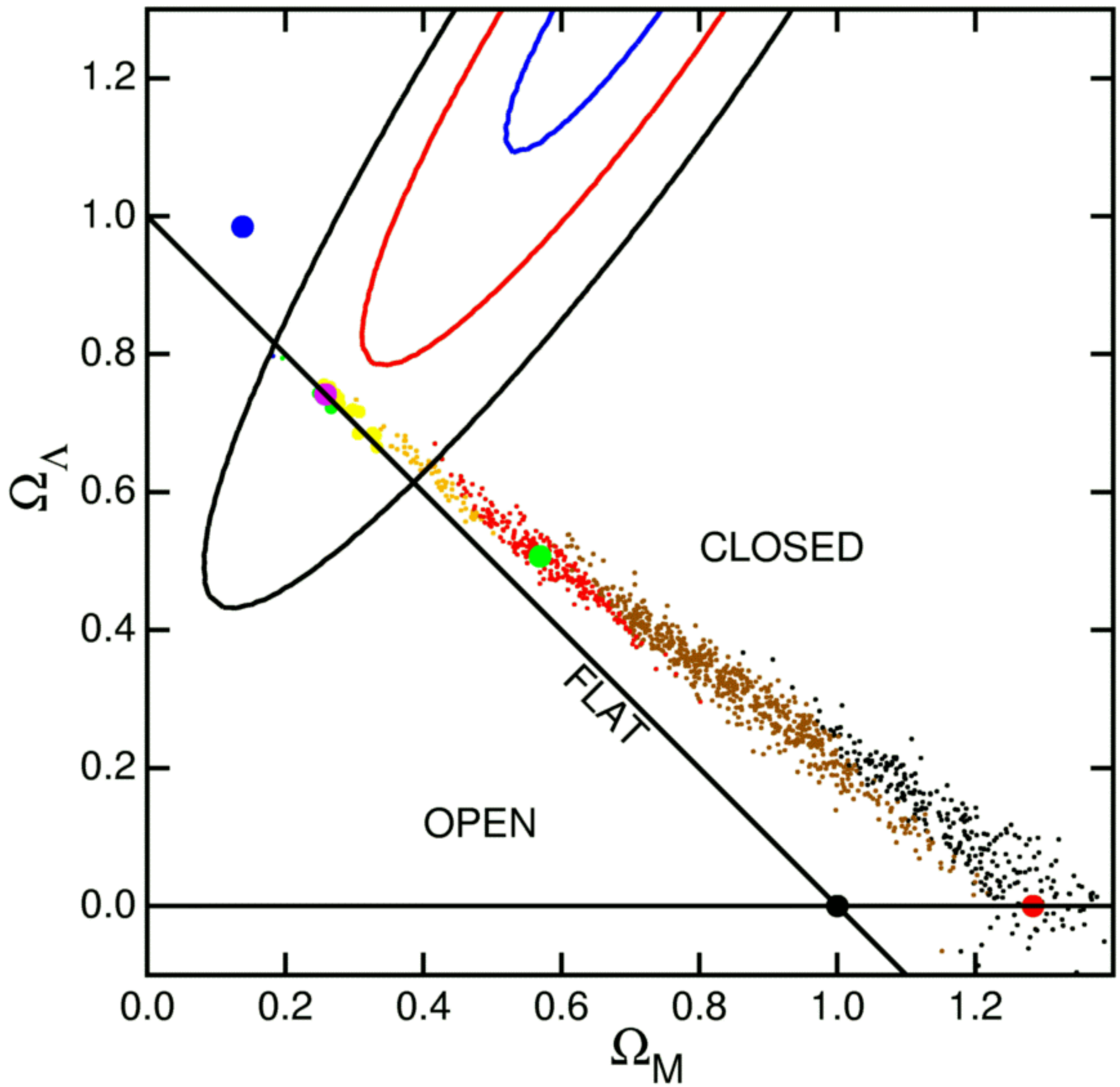
With WMAP replacing COBE

Note the new BBNS value from astro-ph/0302006

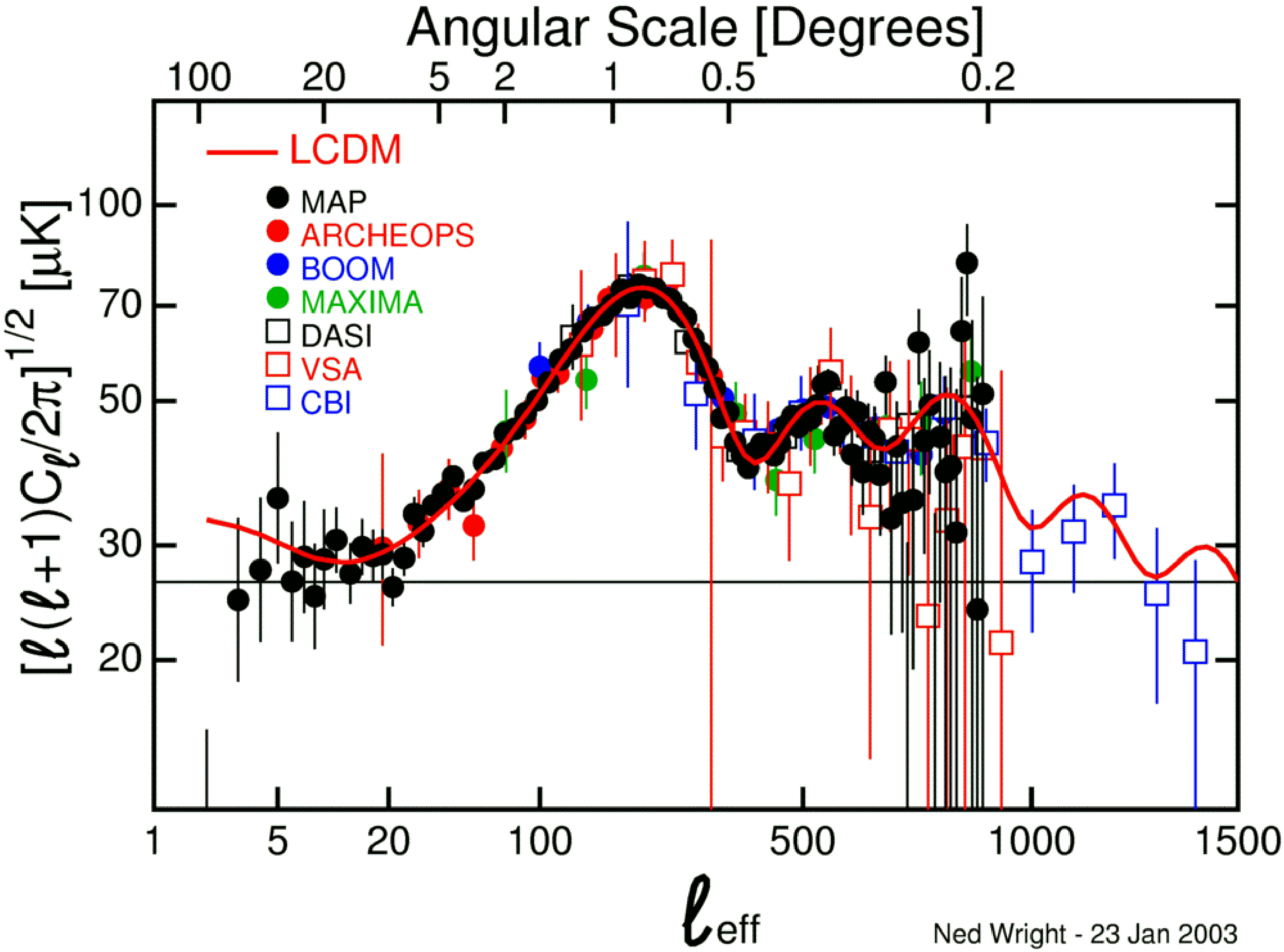


Key to Models

H_o: 30 40 50 60 70 80 90 100

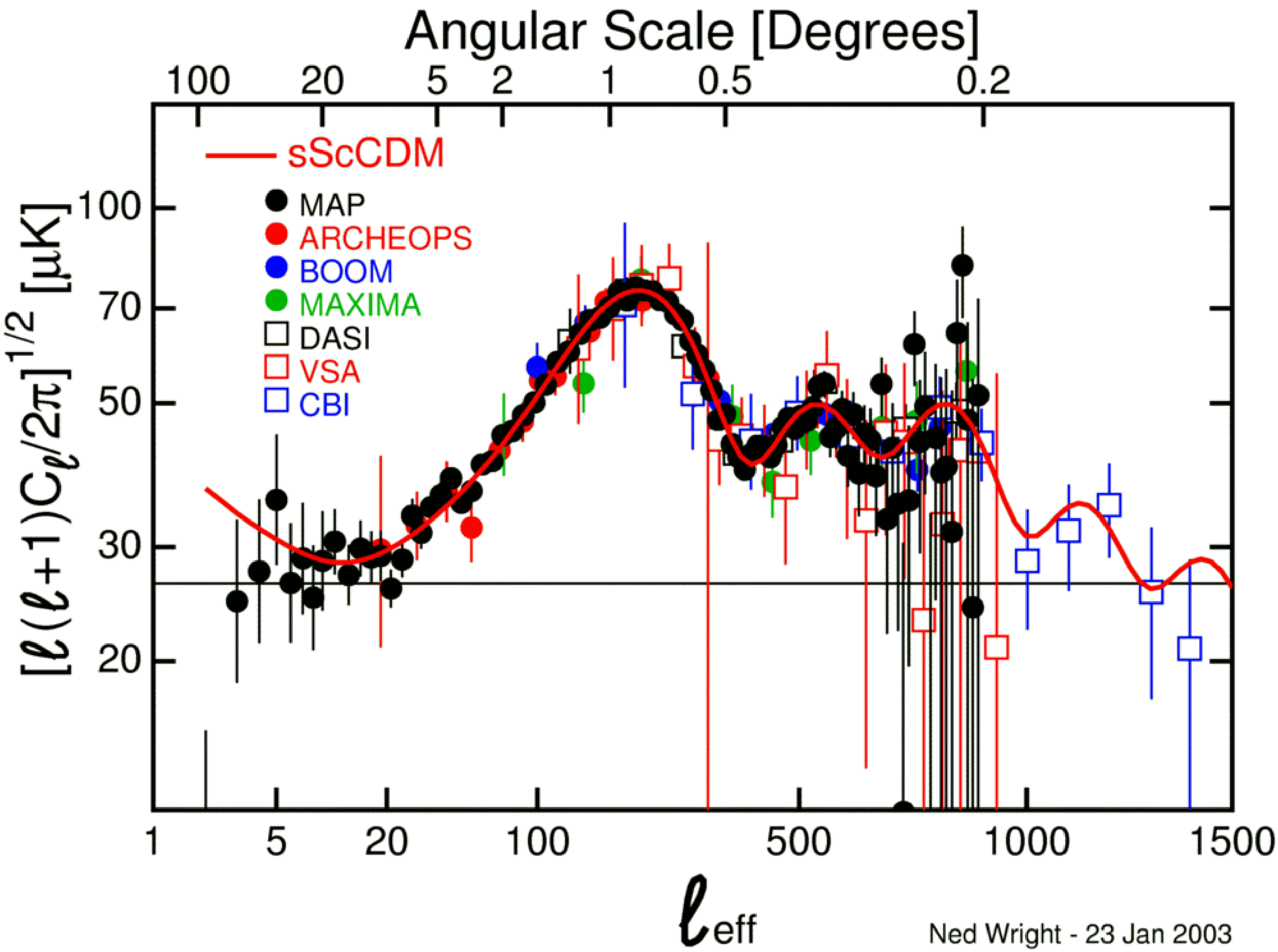


ΛCDM is a Good Fit



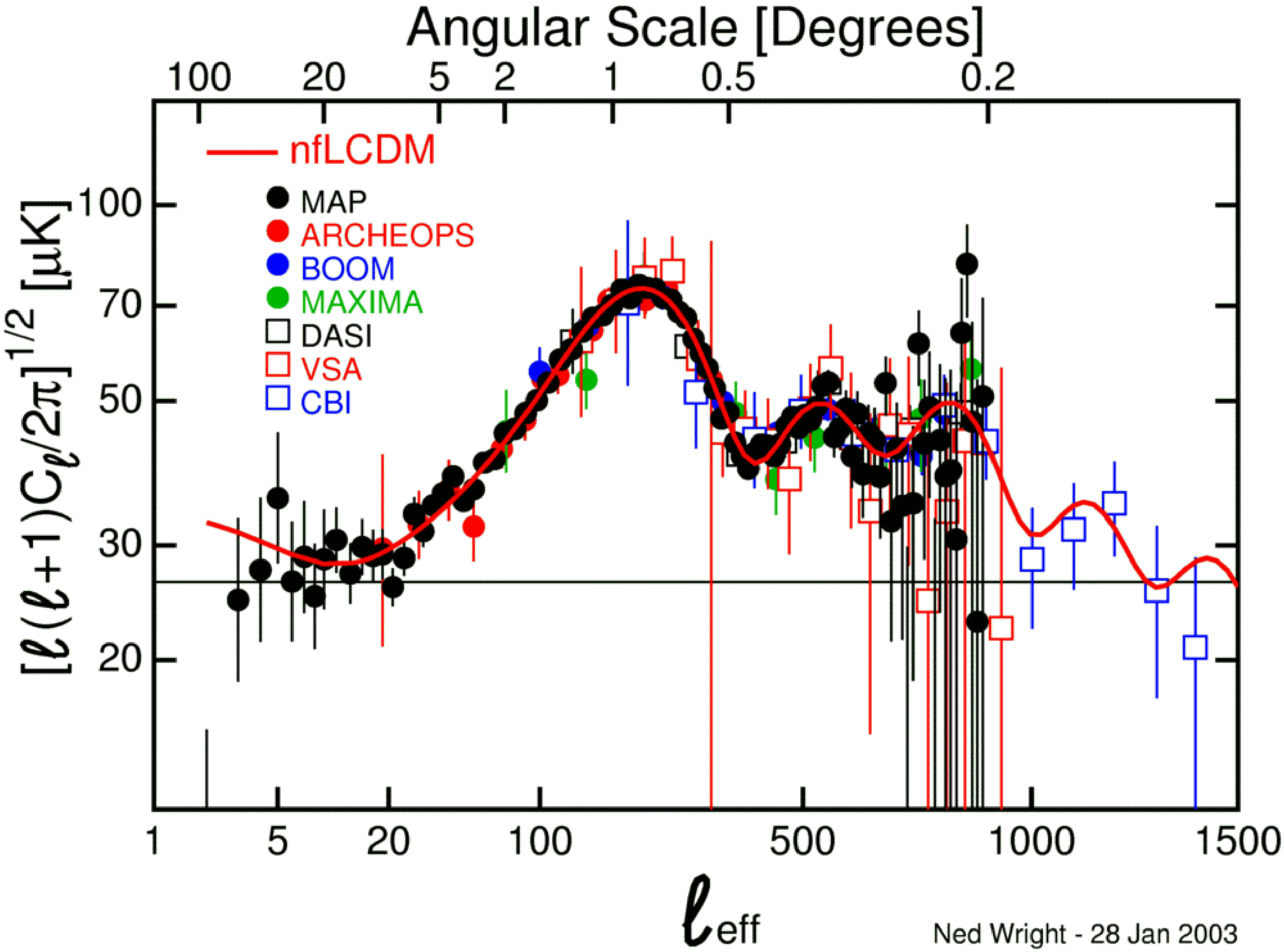
$H_o = 71$, $\Omega_\Lambda = 0.73$, $\Omega_b h^2 = 0.0224$, $\Omega_m h^2 = 0.135$, $\Omega_{tot} = 1$

Super-Sandage is Closed



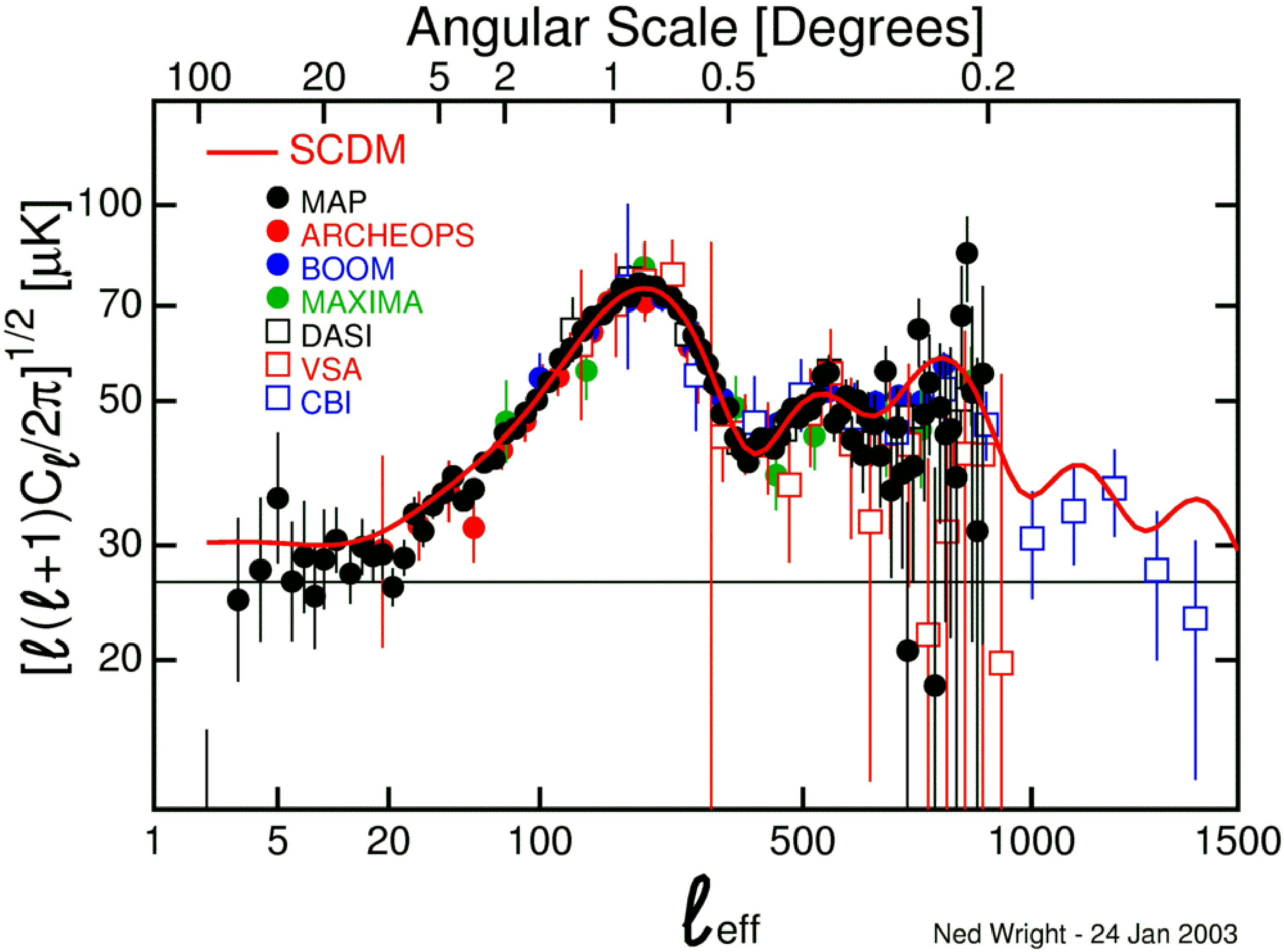
$H_o = 32$, $\Omega_\Lambda = 0$, $\Omega_b h^2 = 0.0232$, $\Omega_m h^2 = 0.139$, $\Omega_{tot} = 1.3$

Best Fit: Two Many Tooth Fairies



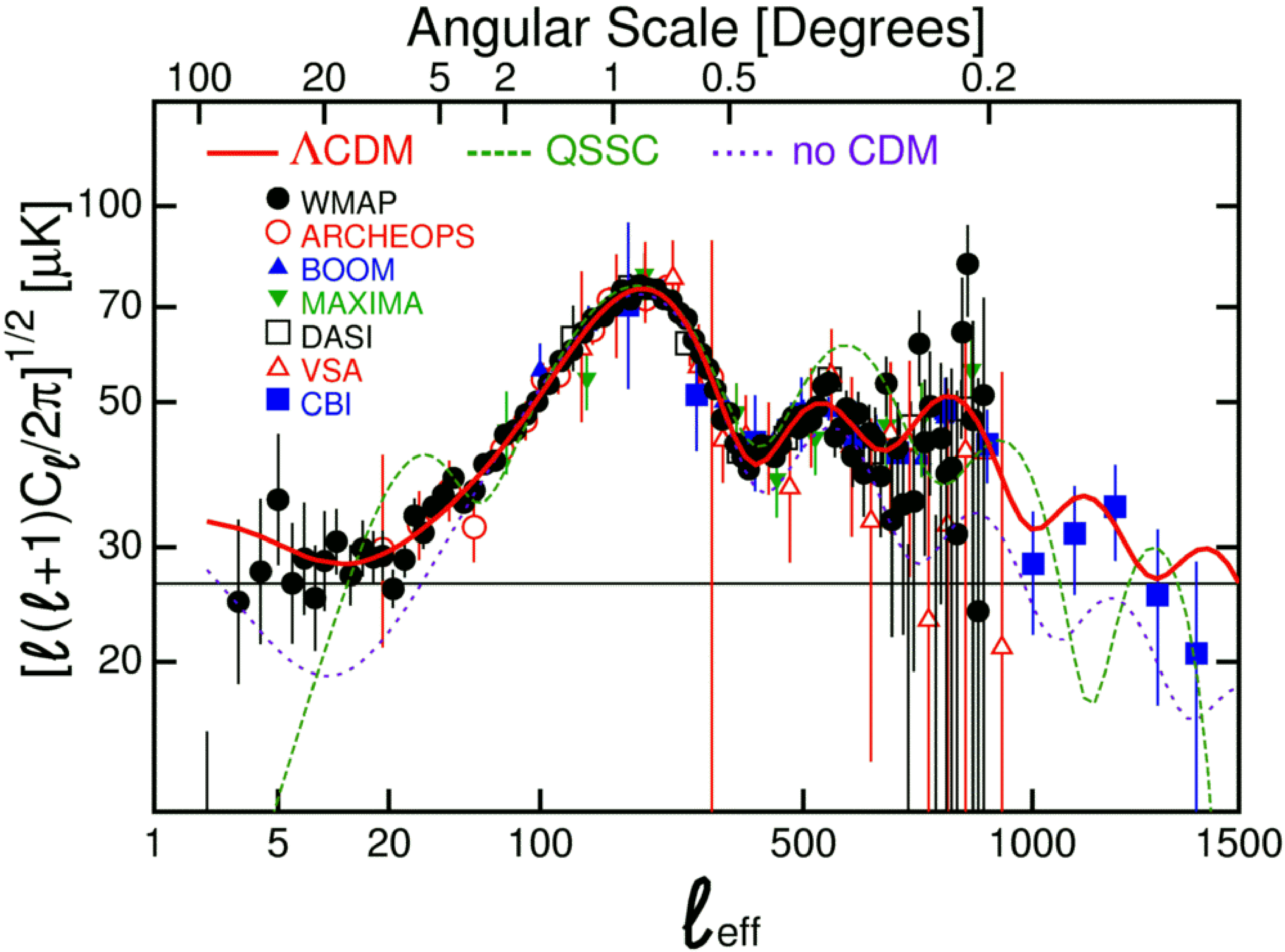
$H_o = 50$, $\Omega_\Lambda = 0.51$, $\Omega_b h^2 = 0.0233$, $\Omega_m h^2 = 0.141$, $\Omega_{tot} = 1.08$

Einstein – de Sitter Model Fails



$H_o = 50$, $\Omega_\Lambda = 0$, $\Omega_b h^2 = 0.0236$, $\Omega_m h^2 = 0.25$, $\Omega_{tot} = 1$

MOND No CDM & QSSC Models Fail

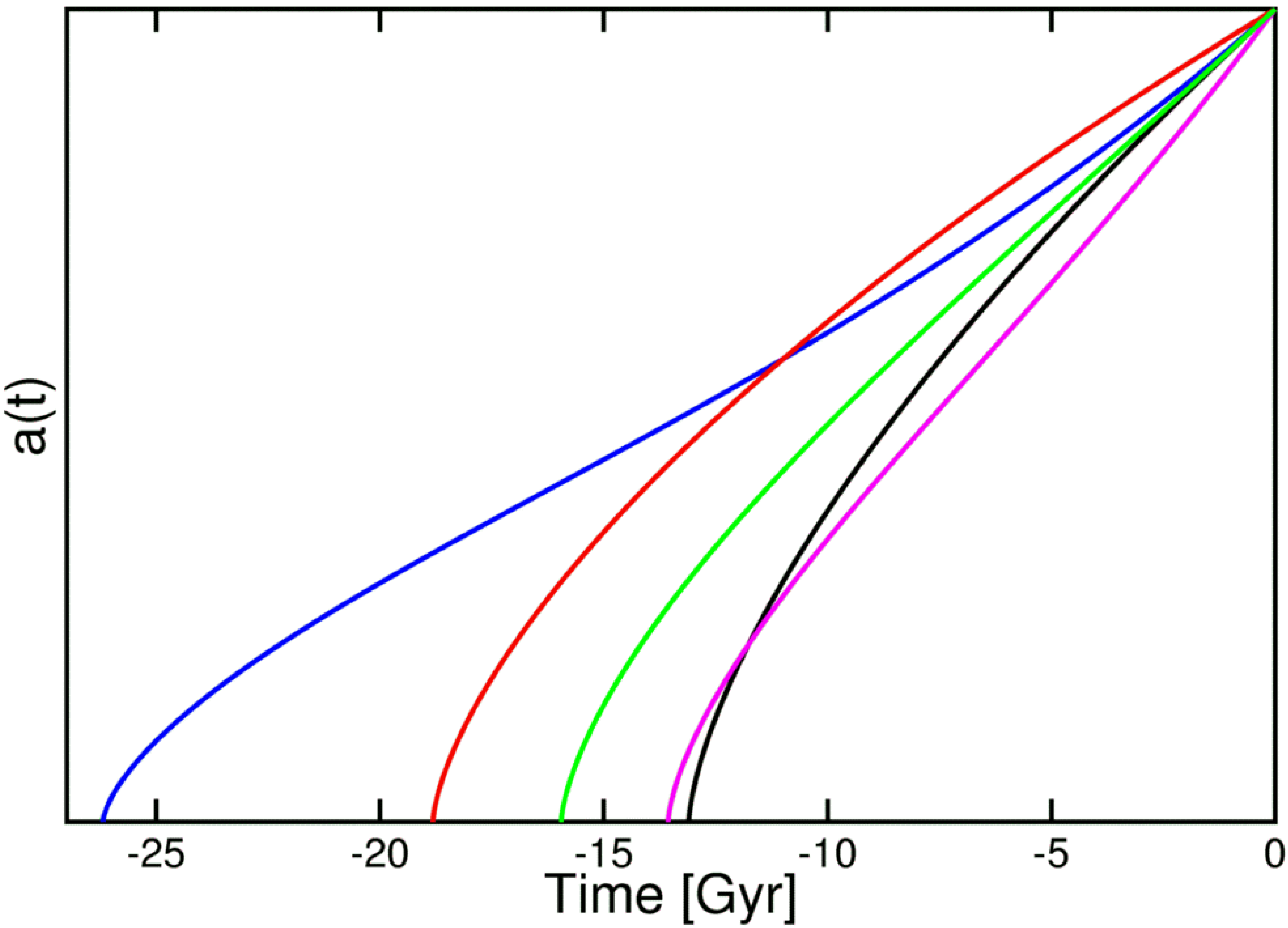


Is the Universe Really Flat?

- CMB data alone give some limits but adding H_o and SNe priors gives much better limits.
- Replacing COBE by WMAP does not dramatically change the limits on Ω_{tot}.

	CMB only	CMB+SNe	CMB+H_o	All
Pre-WMAP	1.18(11)	1.04(4)	1.02(3)	1.02(2)
With WMAP	1.16(9)	1.04(3)	1.03(3)	1.02(2)

Scale factor vs time



More Restrictions on Models

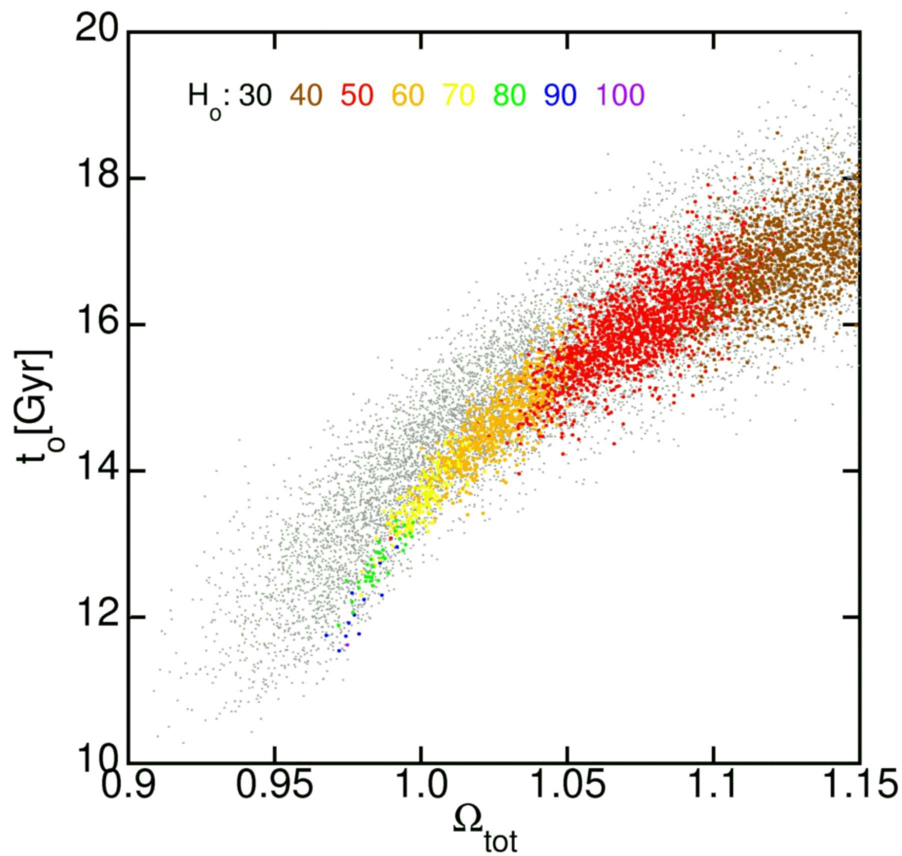
- Quintessence is restricted: $w = P/\rho c^2 \leq -0.78$ in the dark energy
- Neutrino masses add up to less than 0.7 eV
  - $\Delta P/P = -8\ \Omega_\nu/\Omega_m$ (Hu et al. astro-ph/9712057)
  - So this limit, about 7% of the CDM density, gives a 50% reduction in small-scale power

Running Spectral index?

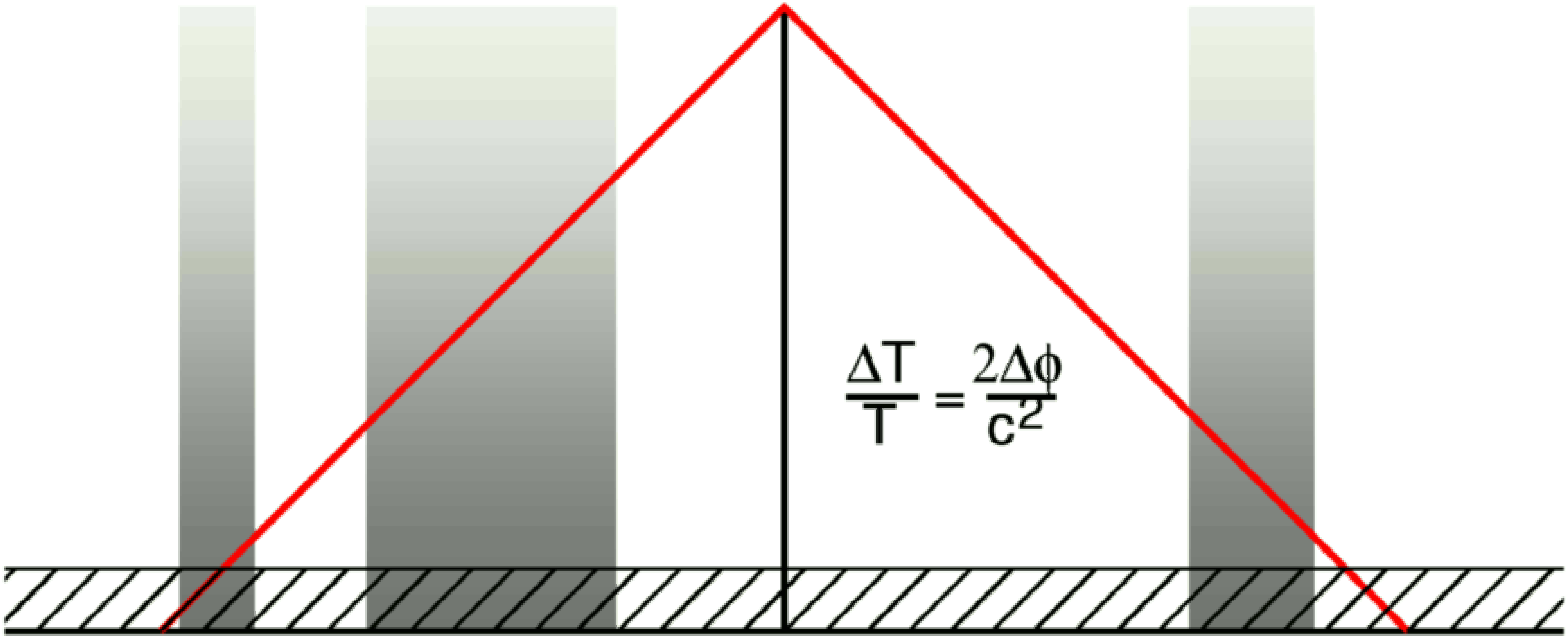
- 2σ using LSS & Croft *et al.* “Keck” Lyα:
  - $dn_s/d\ln k = -0.031 \pm 0.016$
  - $n = 0.93 \pm 0.03$ at $k = 0.05/\mathrm{Mpc}$
- Two separate analyses of “SDSS” Lyα:
  - $dn_s/d\ln k = +0.015 \pm 0.020$, $n = 0.99 \pm 0.04$ (Dodelson)
  - $dn_s/d\ln k = -0.027 \pm 0.007$, $n = 0.97$ (Seljak)

Going Flat Out with LSS & Lyα

- Assuming a flat, Ω_{tot} = 1, Universe gives:
  - H_o = 71 ± 3.5 km/s/Mpc
  - t_o = 13.7 ± 0.2 Gyr
  - Ω_Λ = 0.73 ± 0.04
  - $\Omega_b h^2$ = 0.0224 ± 0.001 or 0.25 baryons/m^3
  - $\Omega_m h^2$ = 0.135 ± 0.009 or 2.54 yoctograms/m^3
  - Running index: $dn_s/d\ln k$ = -0.031±0.016 n = 0.93 ± 0.03 at k = 0.05/Mpc
  - σ_8 = 0.84 ± 0.04

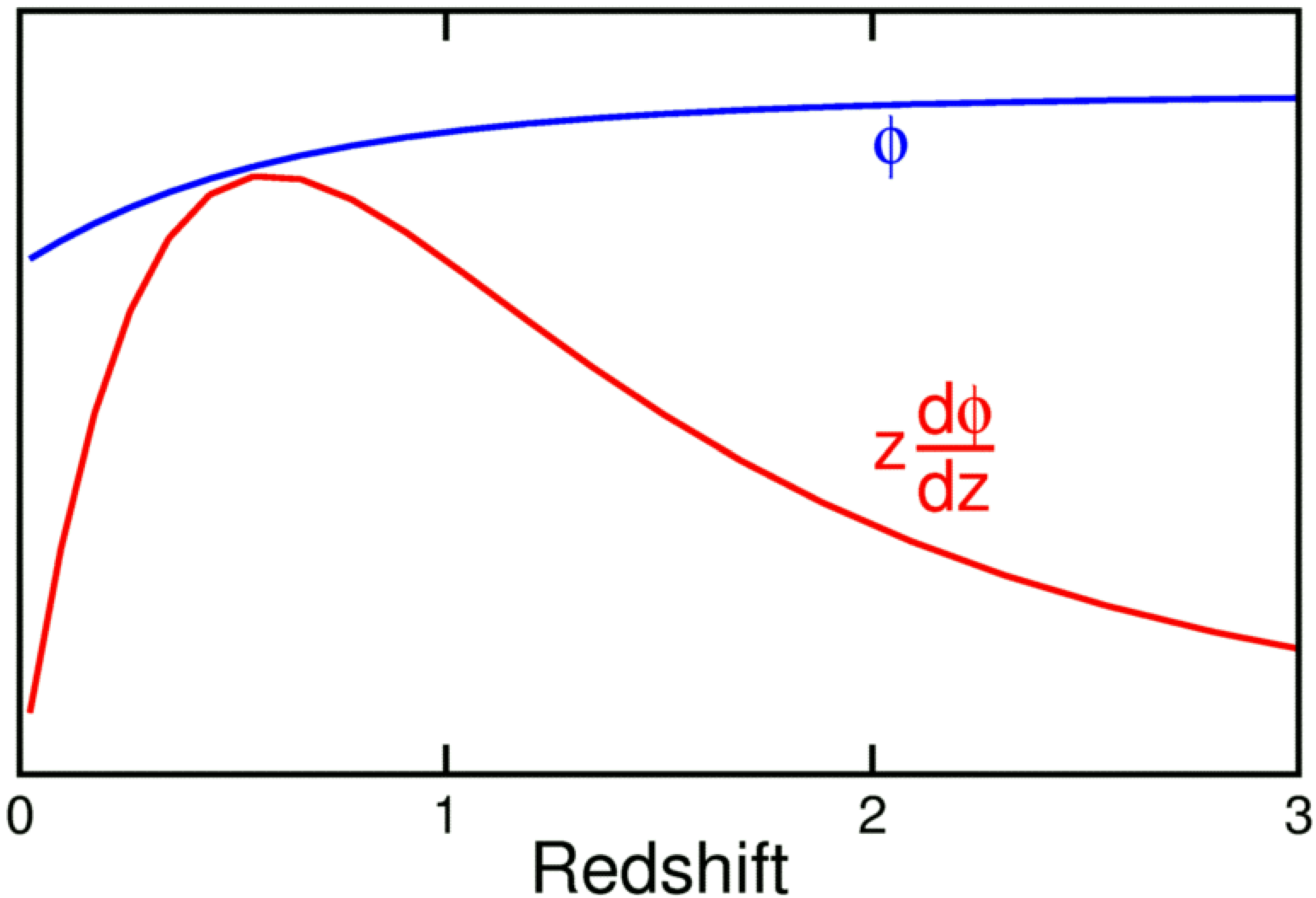


Late ISW Effect



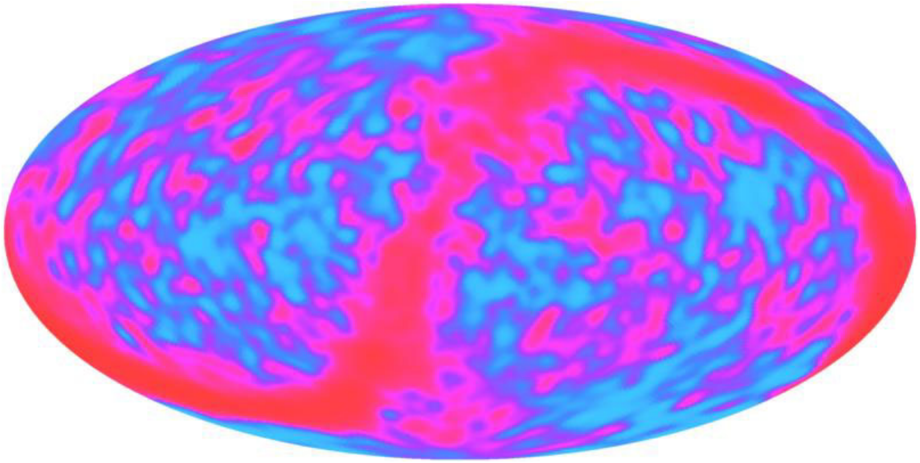
Potential only changes if $\Omega_m \neq 1$ (or in non-linear collapse, but that's another story [Rees-Sciama effect]).

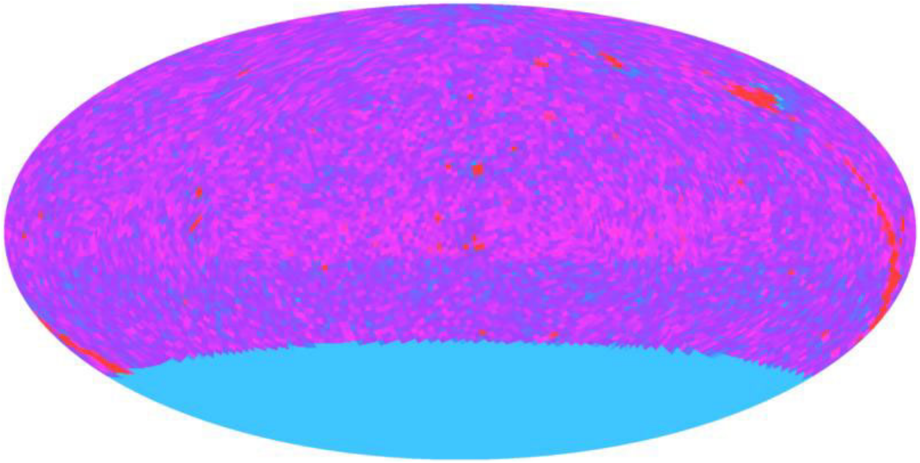
Potential decays at z ≈ 0.6



Correlated with Observed LSS

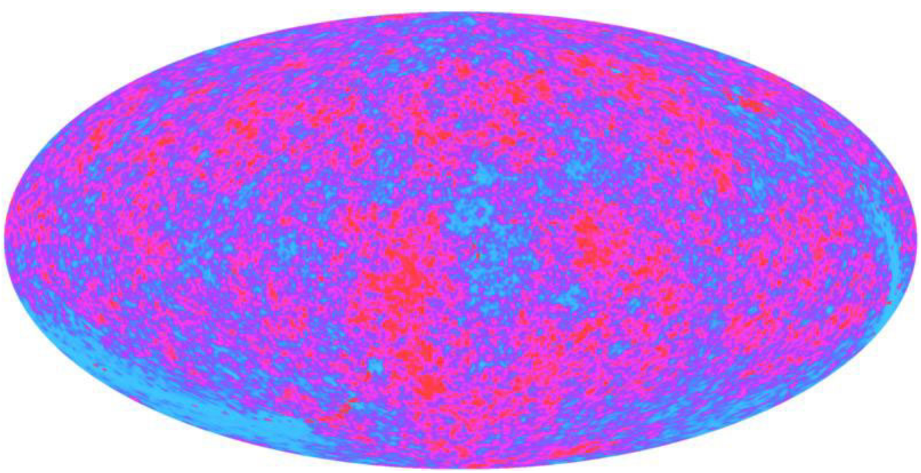
- This late ISW effect occurs on our past light cone so the ΔT we see is due to structures we also see.
- Search for correlation between LSS at z=0.6 and the CMB anisotropy: see Boughn & Crittenden, astro-ph/0111281
  - Expected 0.035 cross-correlation between NVSS sources and COBE DMR
  - observed -0.003 ± 0.025

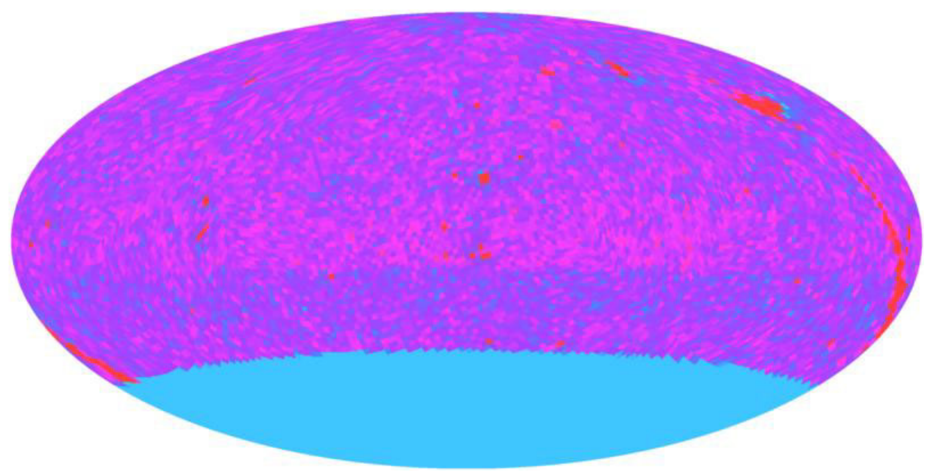




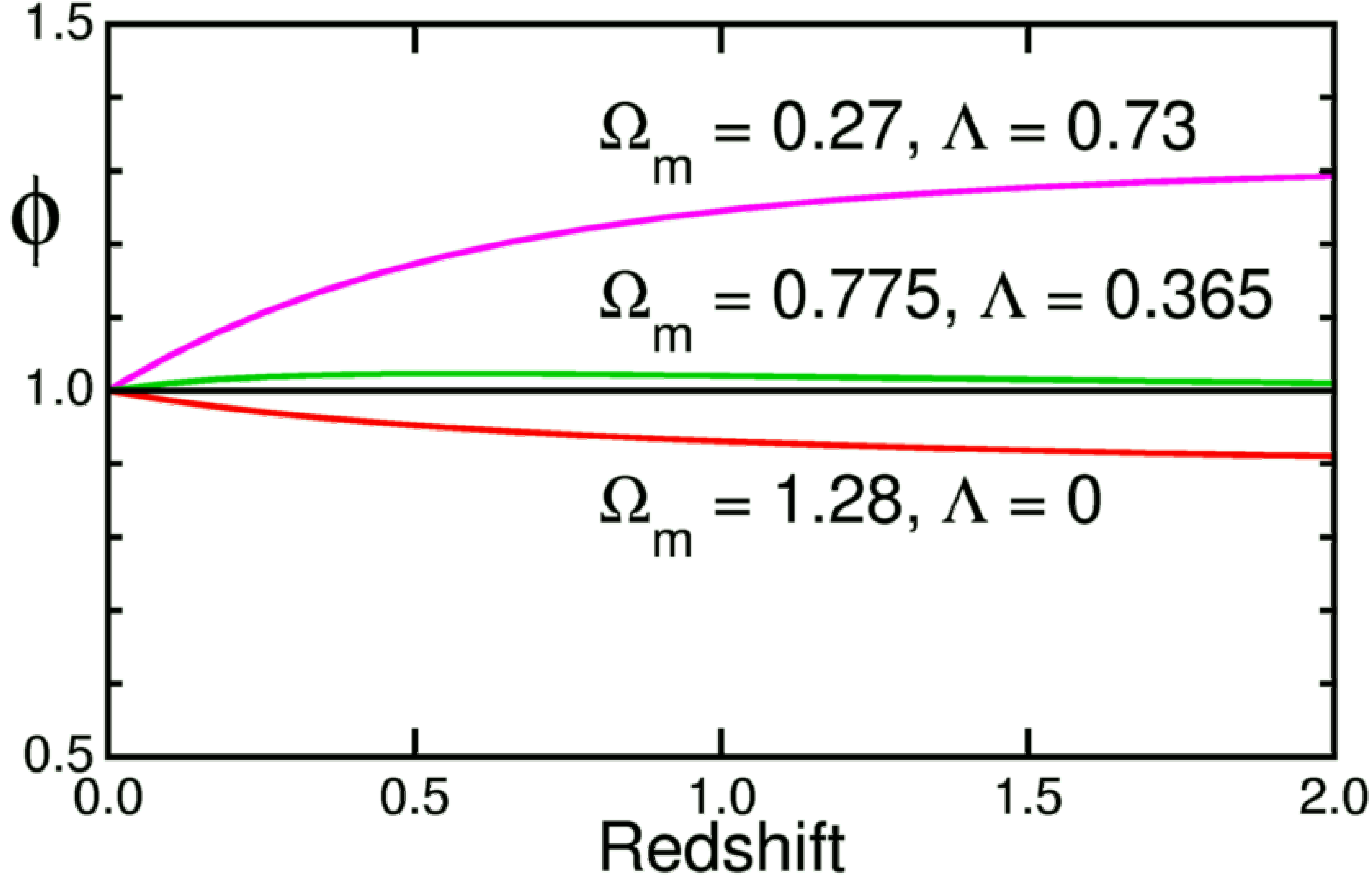
Correlation is seen with WMAP

- Correlation between WMAP and LSS seen by:
  - Boughn & Crittenden (astro-ph/0305001) at 2.75σ with hard Xray background and 2.25σ with NVSS
  - Nolta et al. (astro-ph/0305097) at 2σ with NVSS





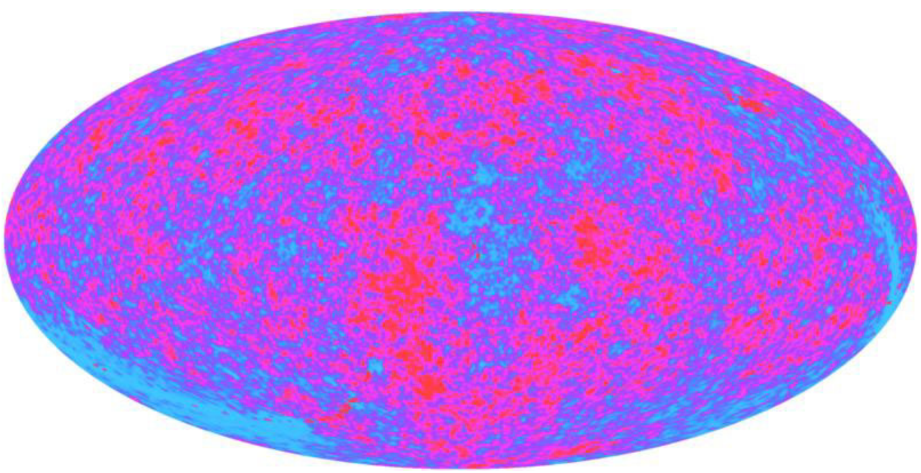
ΛCDM is OK, sSCDM fails at 3σ

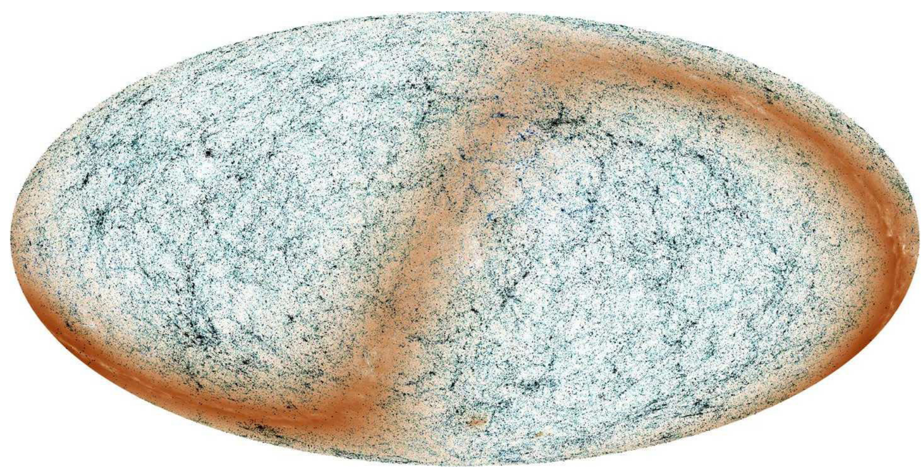


Possible Improvements?

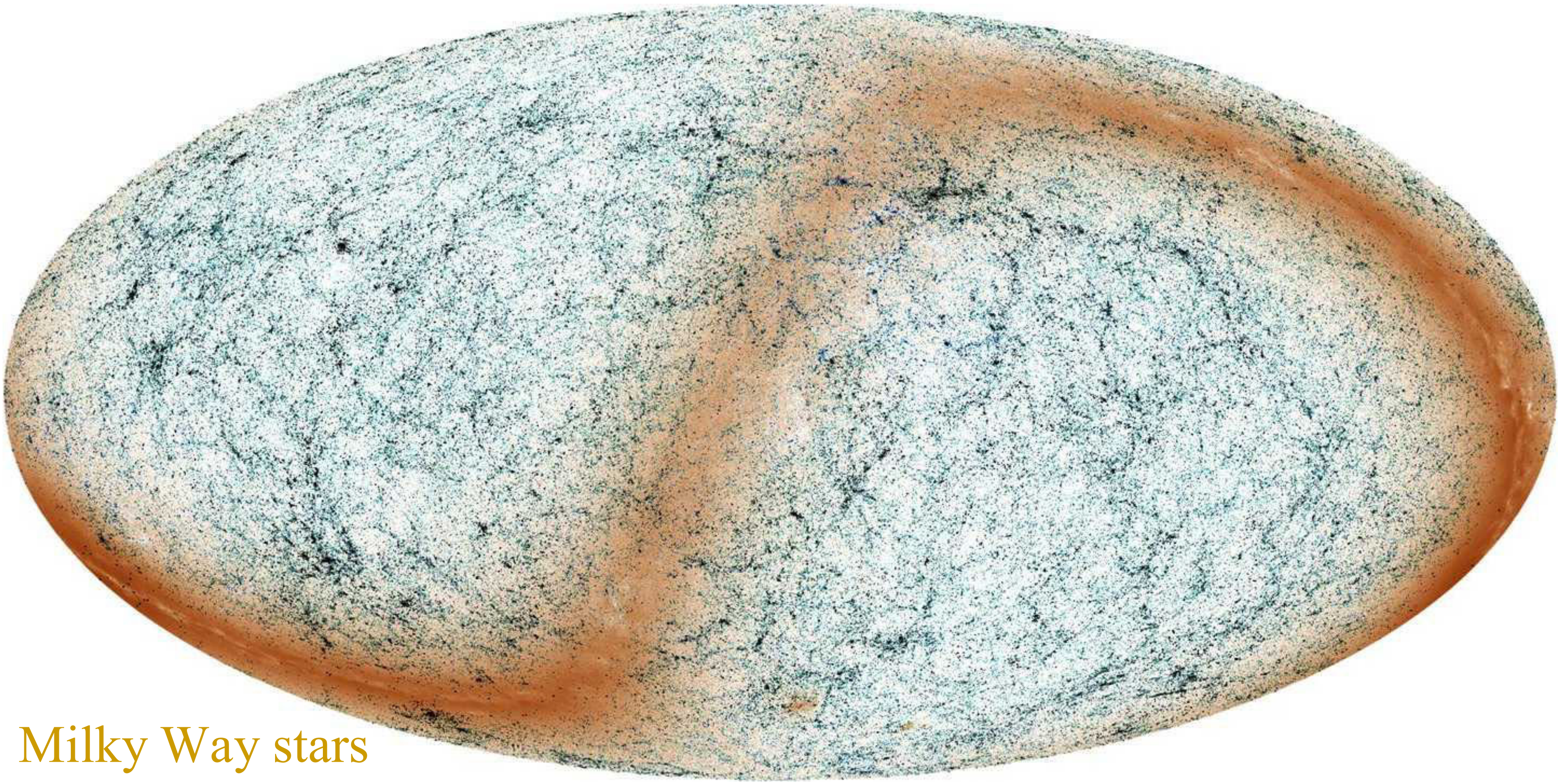
✓ Less noisy and higher resolution CMB data.

- Use a better tracer of LSS. IR surveys trace old stars and thus are close to a mass survey.

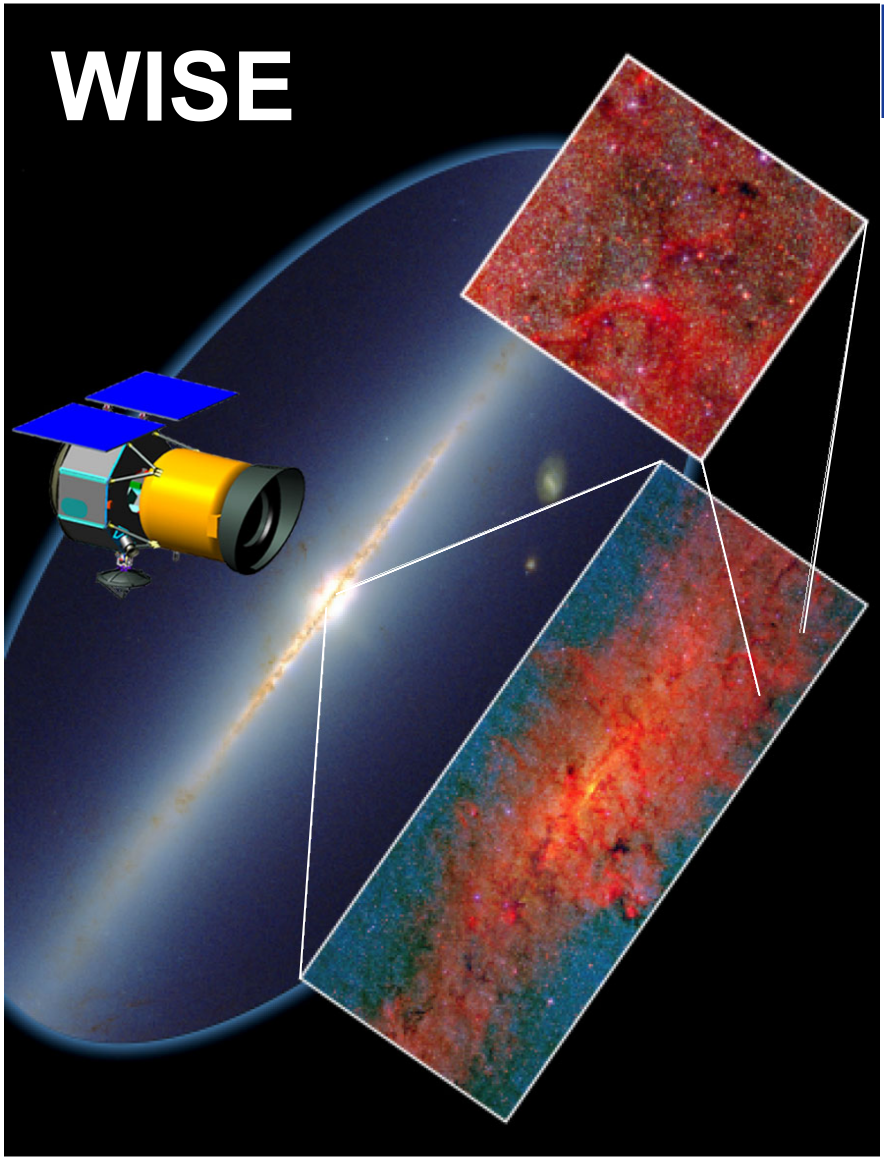




2MASS Galaxies at $z \approx 0.15$



To get a deeper sample, use:



WIDE-FIELD INFRARED SURVEY EXPLORER

WISE will provide an all-sky survey from 3.5 to 23 μm with over 500,000 times the sensitivity of COBE/DIRBE and 1,000 times that of IRAS. The survey will help search for the origins of planets, stars, and galaxies and is the necessary precursor forJWST.

WISE will

- *Find the most luminous galaxies in the Universe.*
- *Find the closest stars to the sun.*
- *Detect most main belt asteroids larger then 3km.*

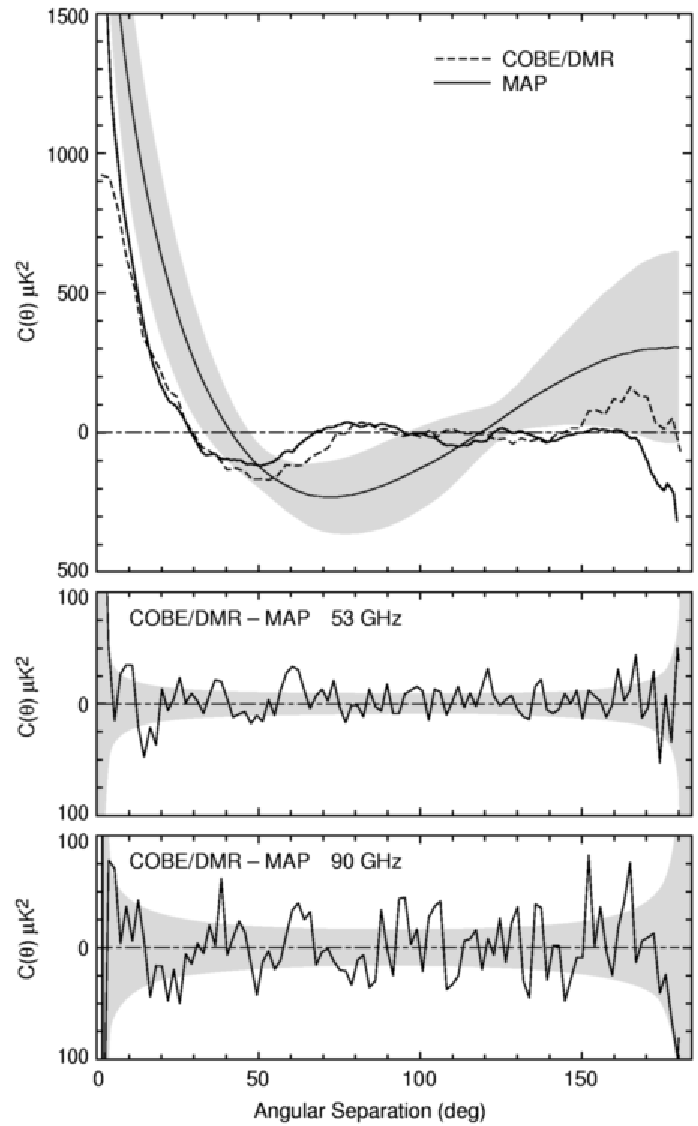
Mission Overview

- *Circular 500-km Sun-synchronous orbit.*
- *7-month mission including a 1-month checkout.*
- *Four 1024^2 focal plane arrays.*
- *50-cm telescope cooled by a two-stage solid-hydrogen cryostat.*
- *Scan mirror to stabilize the line-of-sight while the spacecraft scans the sky.*

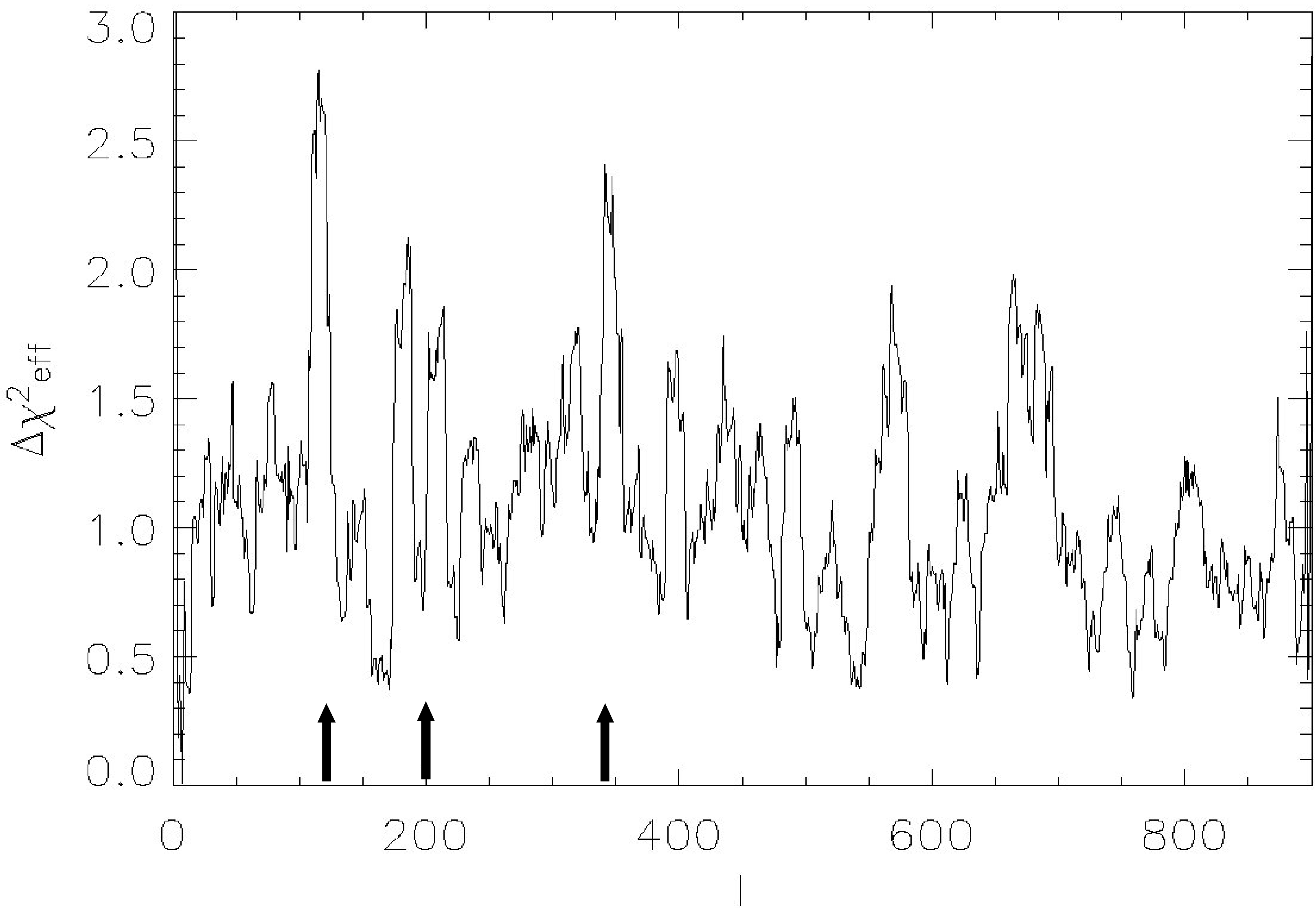
NASA · UCLA · SDL USU · SSG, Inc. · Rockwell Scientific · Orbital · DRS Technologies · Ball · Lockheed Martin · JPL

Something Funny

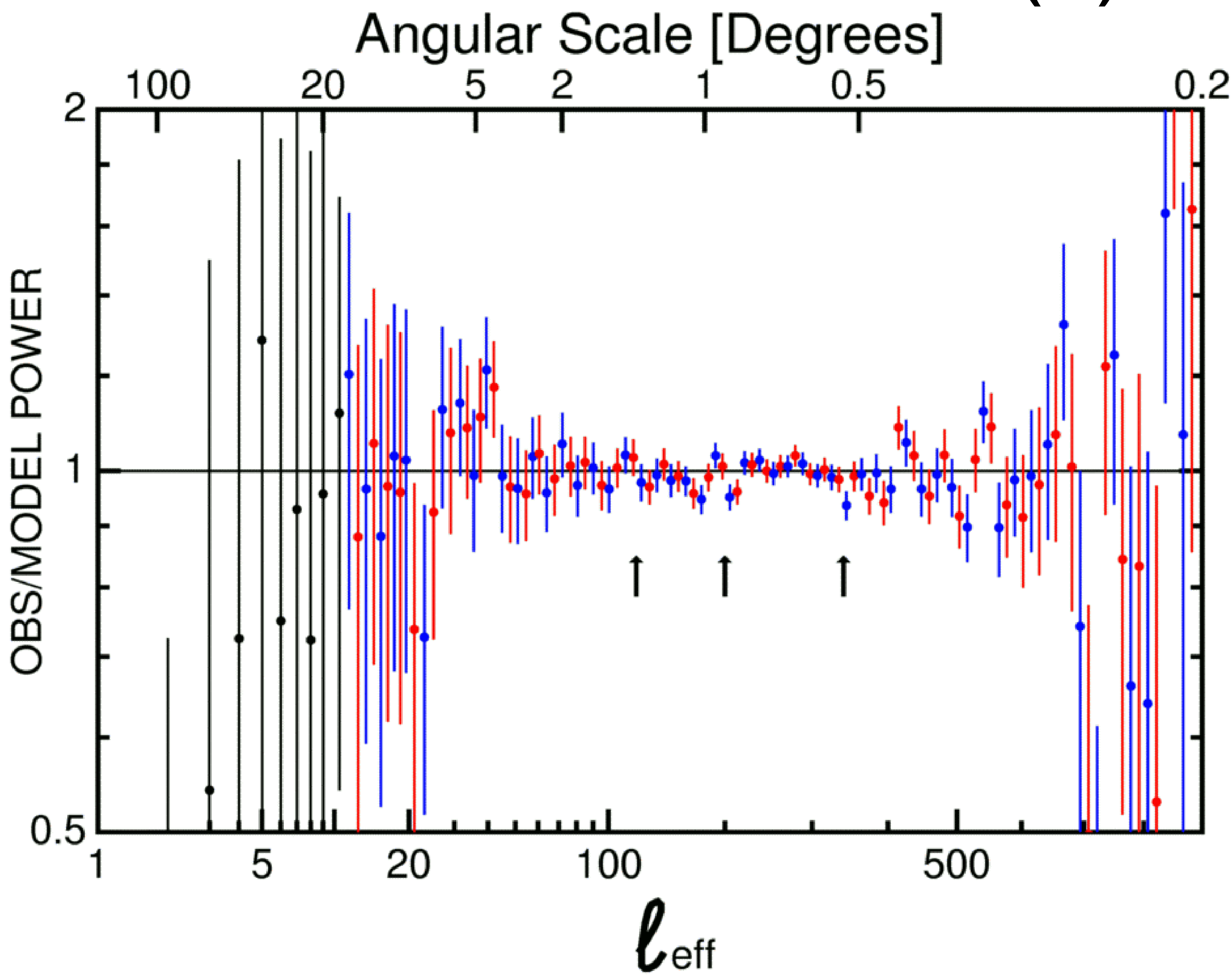
- The TT autocorrelation function is extremely flat for separations greater than 70 degrees.
- This agrees perfectly with COBE.
- The low observed quadrupole is a necessary part of this but not sufficient to explain the whole effect.



“Dents” in the power spectrum



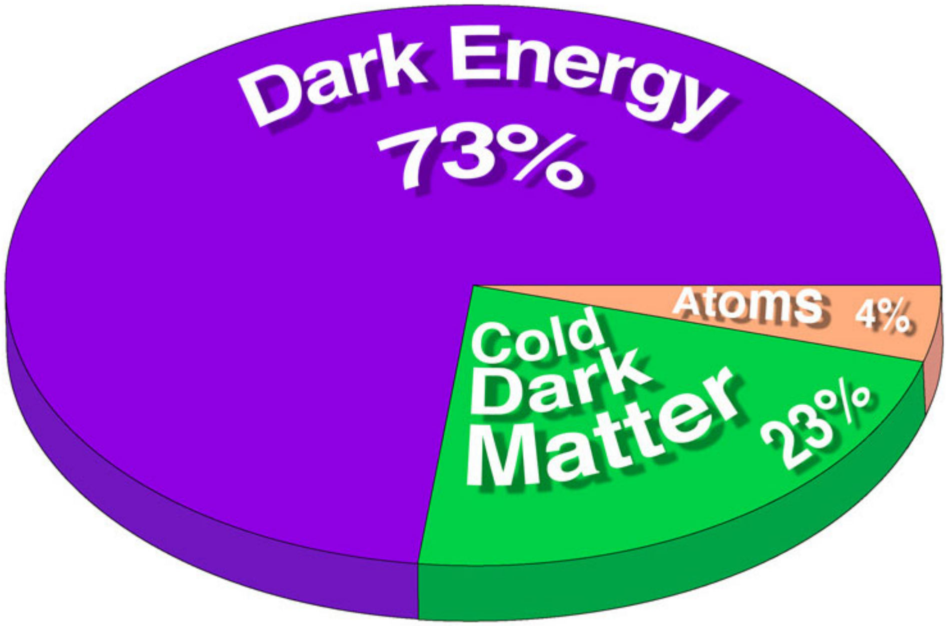
Too narrow to be in P(k)

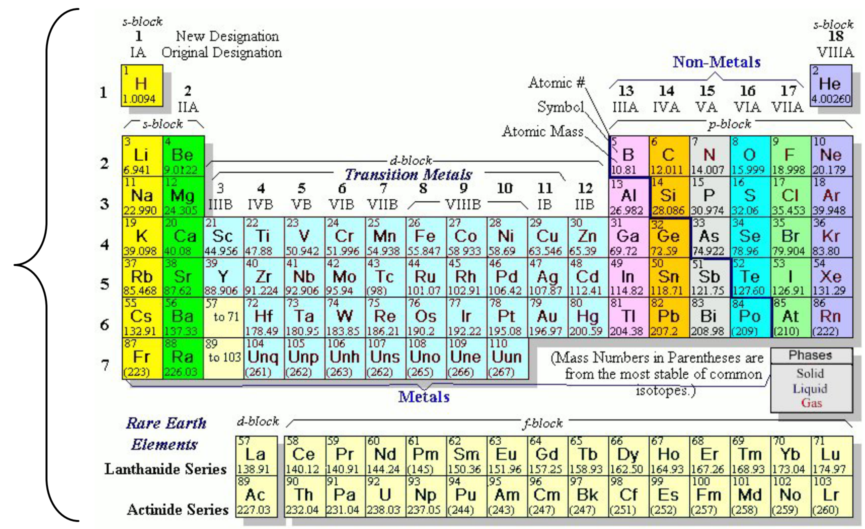


“Nothing” really funny

- Where the hell does it all come from?
- And where does the vacuum energy come from?
- Why 3.9 keV/cc?

We (and all of chemistry) are a small minority in the Universe.





CONCLUSION

- MAP is now the Wilkinson Microwave Anisotropy Probe.
- Early reionization has been seen.
- The basic ΛCDM model for the Big Bang with inflation is confirmed:
  - The baryon density is measured to an accuracy of 4% from the CMB and agrees with the value from BBNS (9% accuracy) to within 5%.
  - Flat model fit only to CMB data matches the Hubble constant, supernova and large scale structure data.
  - Age of the Universe in flat model is 13.7 ± 0.2 Gyr
- Get more information at http://map.gsfc.nasa.gov