CMB Constraints on Cosmology

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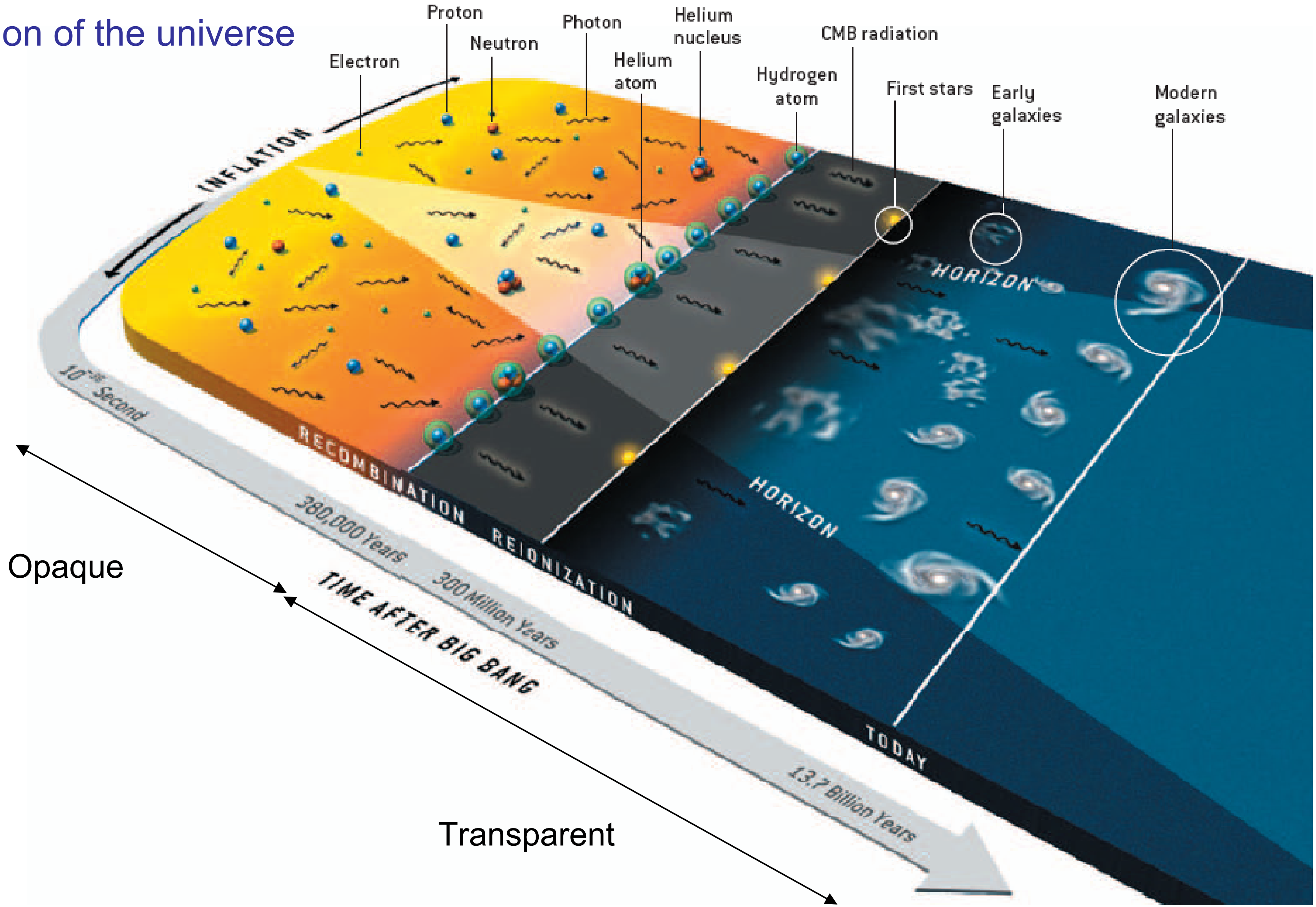
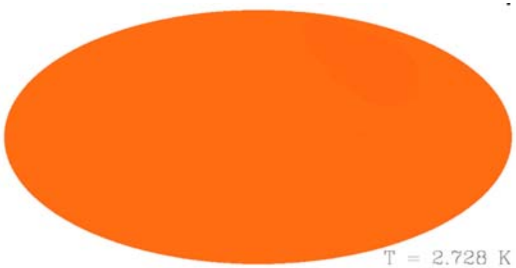
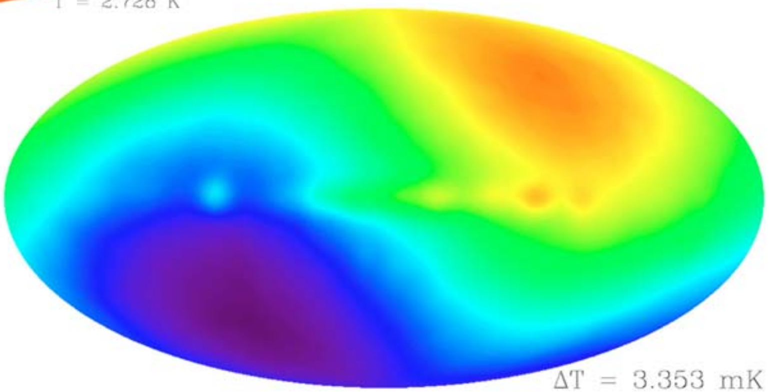
Evolution of the universe



Hu & White, Sci. Am., 290 44 (2004)

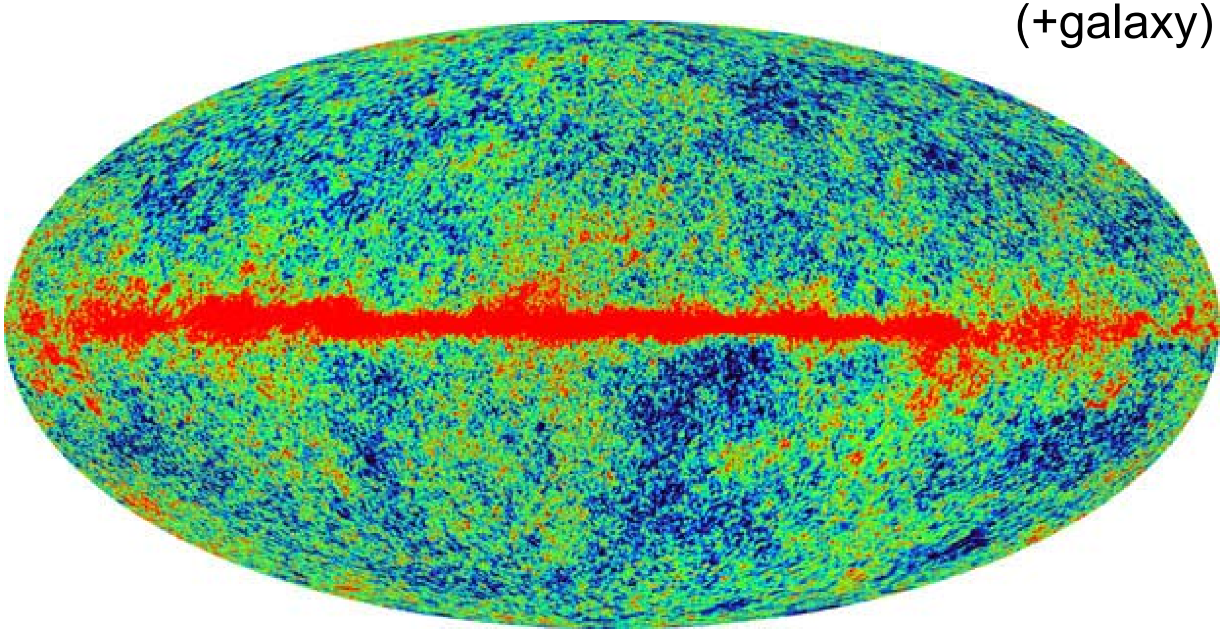


(almost) uniform 2.726K blackbody



Dipole (local motion)

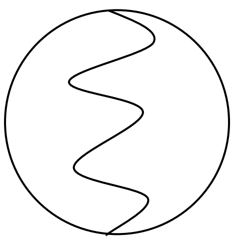
$O(10^{-5})$ perturbations (+galaxy)



Observations: the microwave sky today

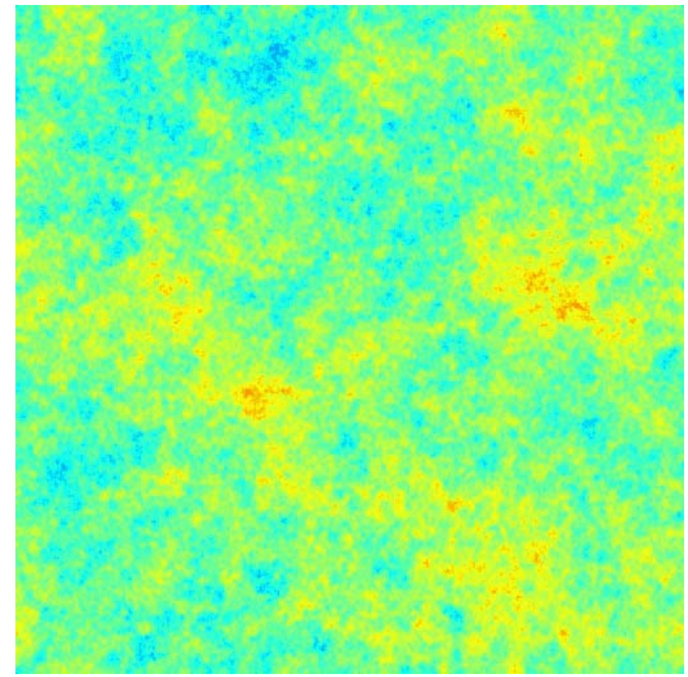
Source: NASA/WMAP Science Team

Where do the perturbations come from?



Quantum Mechanics
"waves in a box"

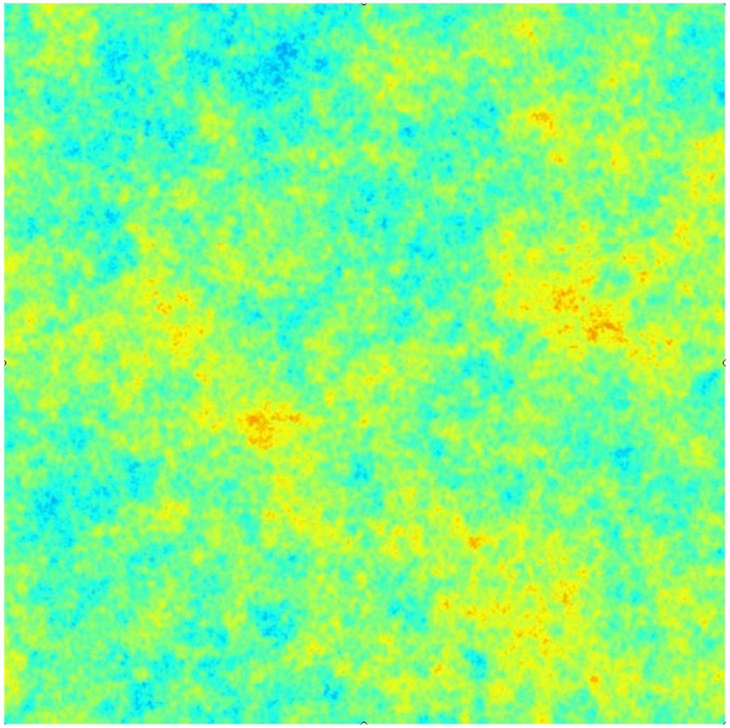
Inflation
make >10^{30} times bigger



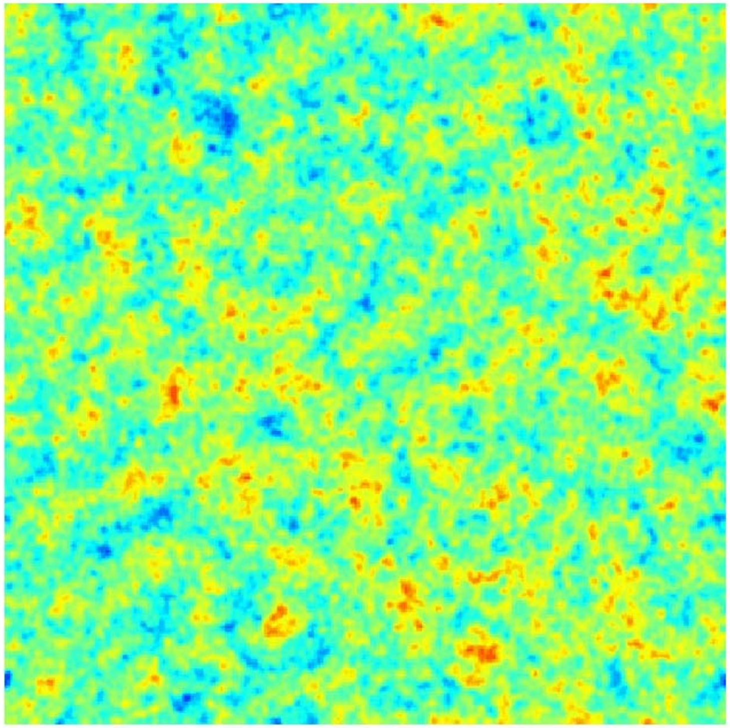
After inflation
Huge size, amplitude ~ 10^{-5}

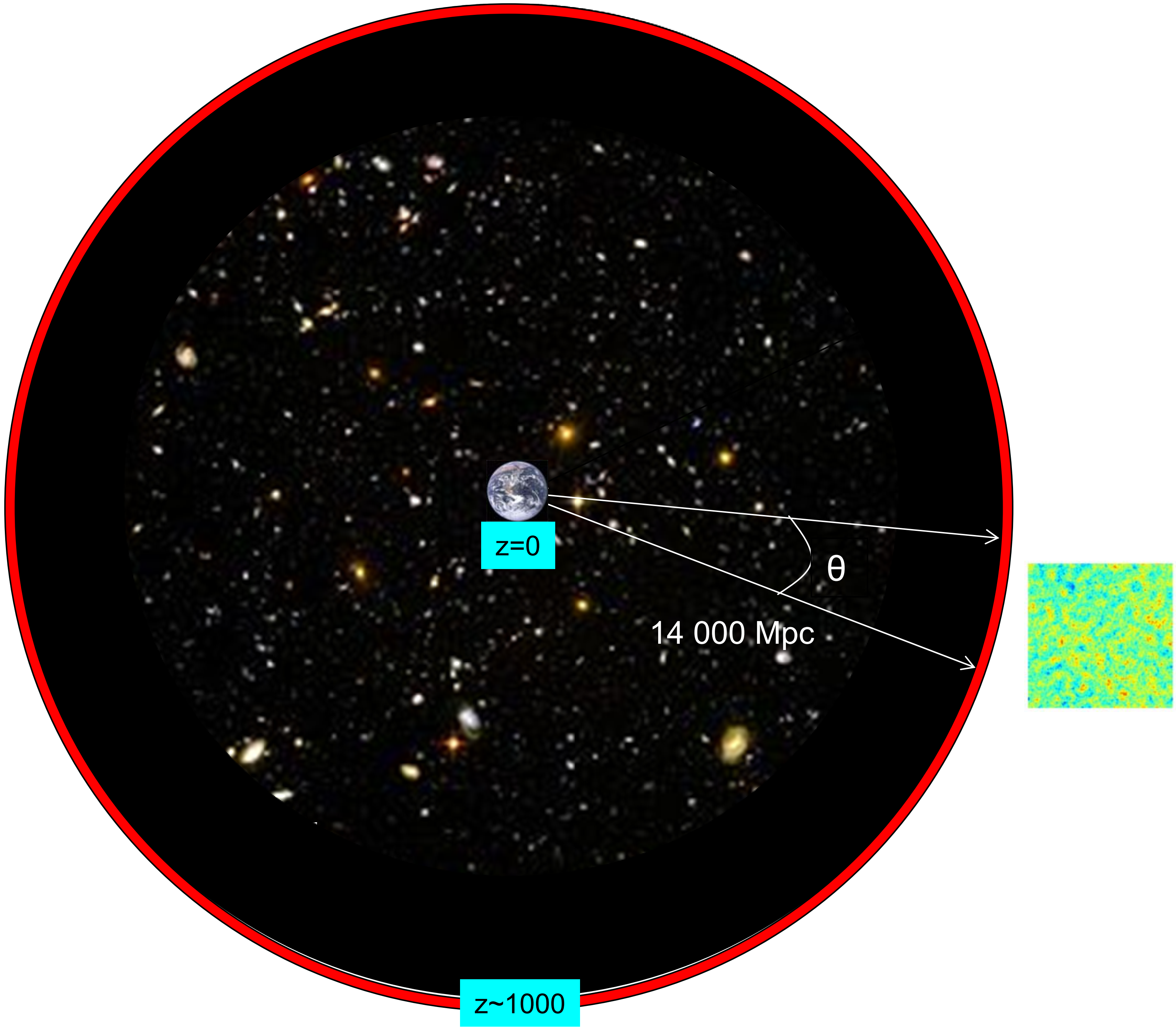
CMB temperature

End of inflation



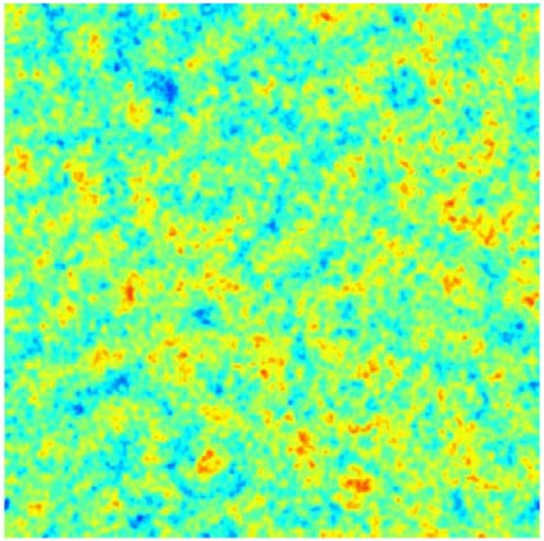
Last scattering surface

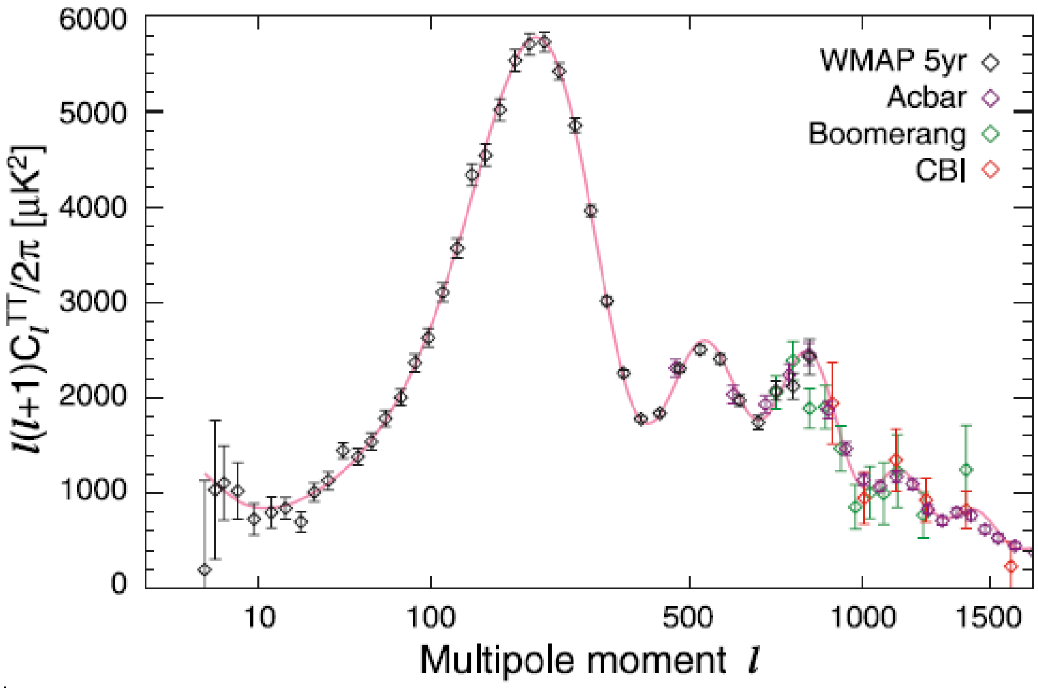



z=0
θ
14 000 Mpc
z~1000

Observed CMB temperature power spectrum

Primordial perturbations + known physics with unknown parameters

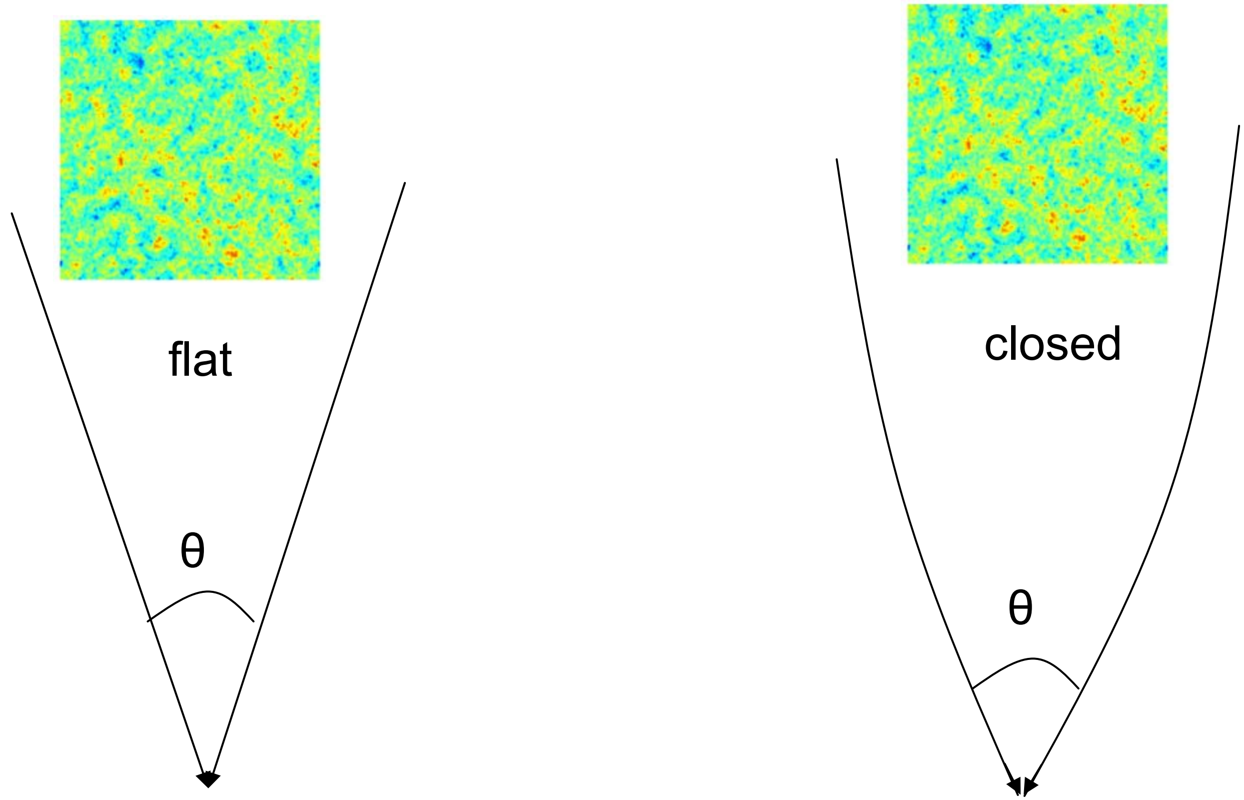




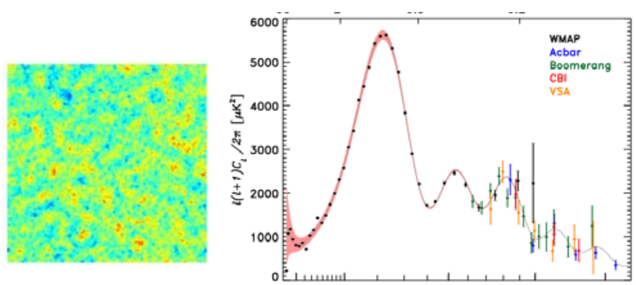
Nolta et al.

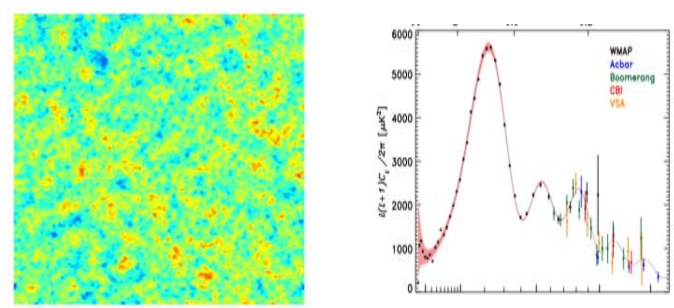
Observations → **Constrain theory of early universe + evolution parameters and geometry**

e.g. Geometry: curvature

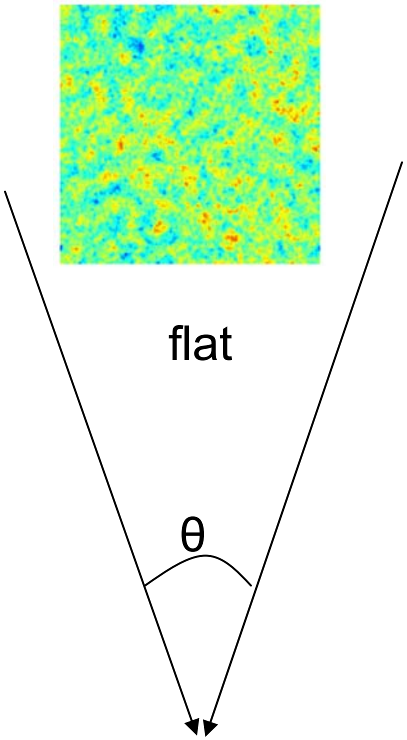


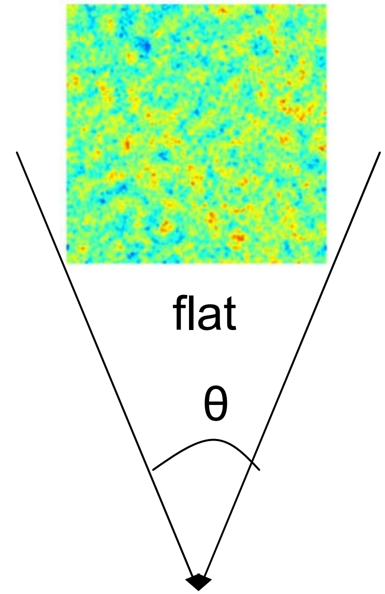
We see:



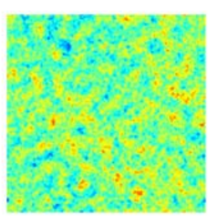


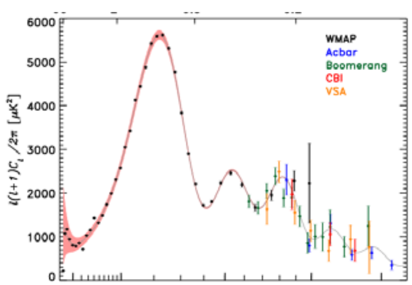
or is it just closer??

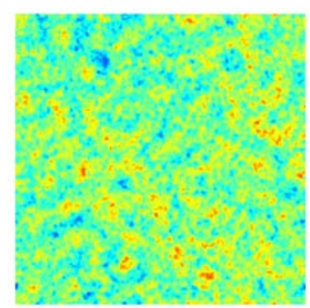


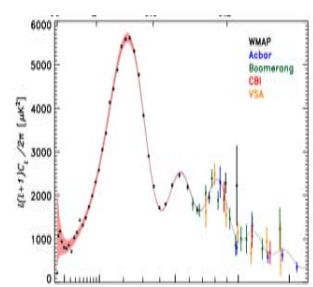


We see:

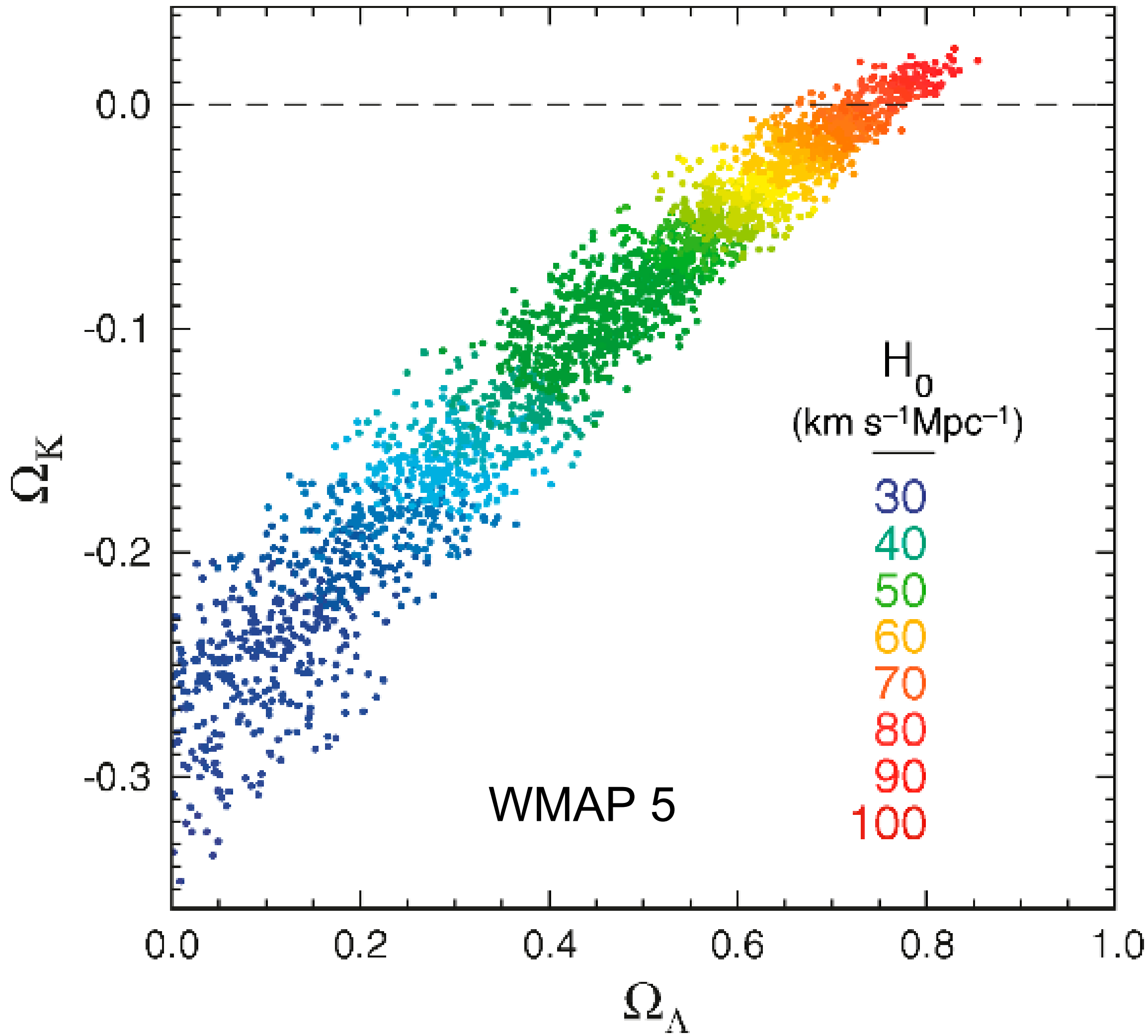








Degeneracies between parameters



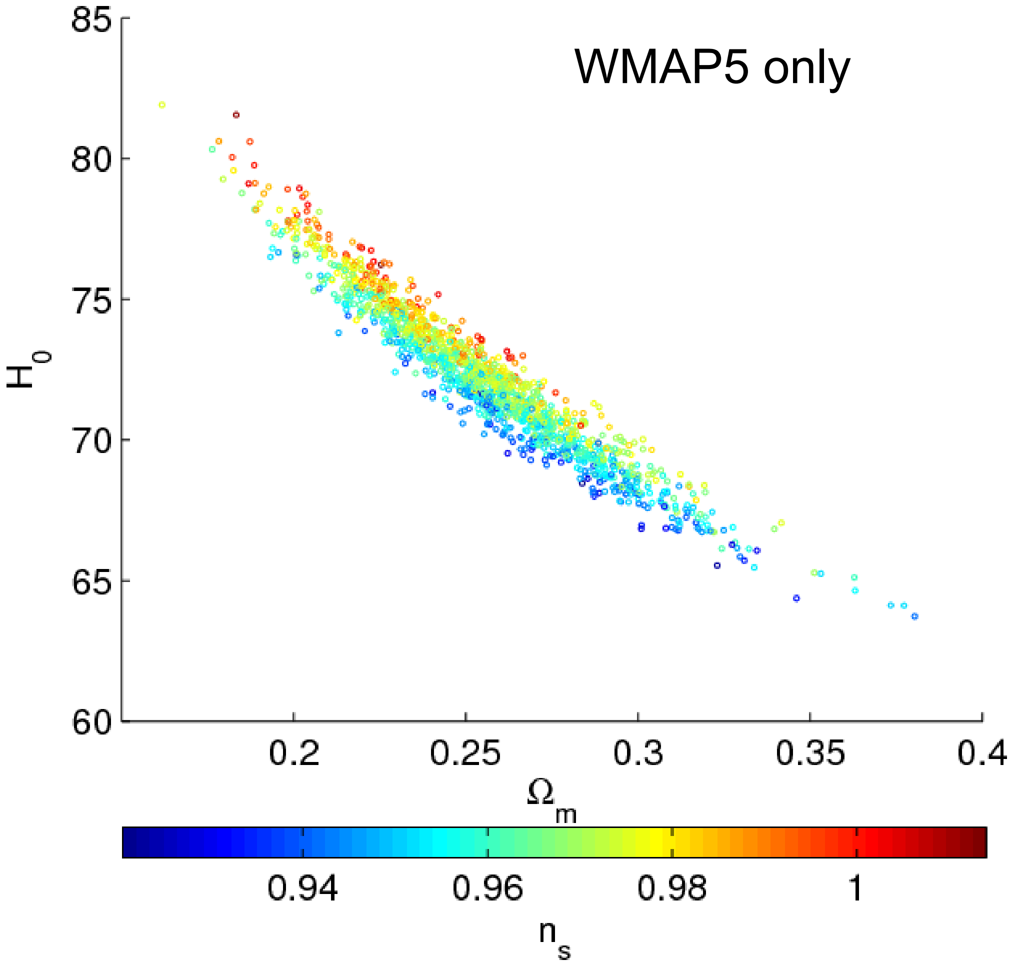
Dunkley et al. 2009

Constrain *combinations* of parameters accurately

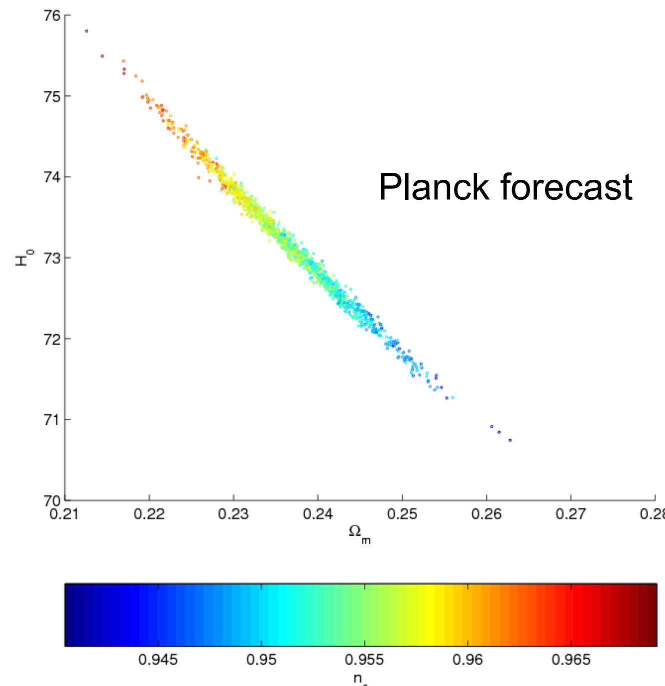
Assume Flat, w=-1

$$\left(\frac{\Omega_m}{0.254}\right)\left(\frac{h}{0.72}\right)^{3.15} = 1.00 \pm 0.03$$

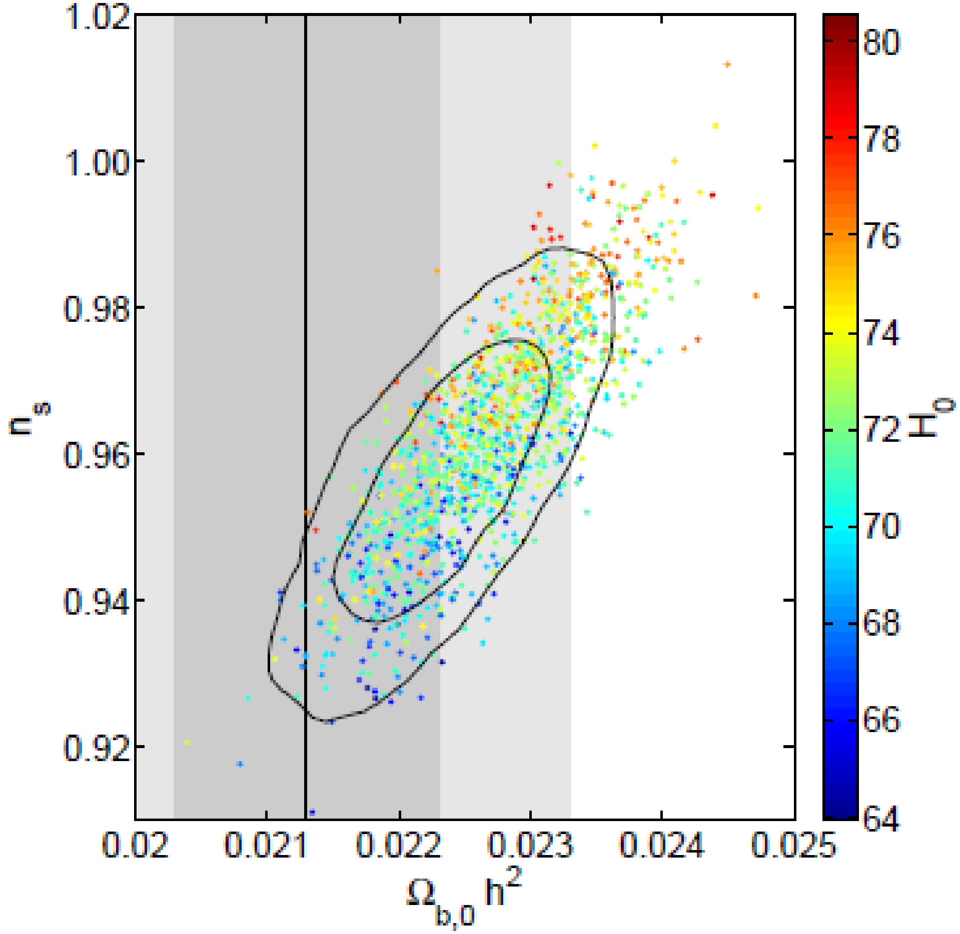
$$\left(\frac{\Omega_m}{0.254}\right)\left(\frac{h}{0.72}\right)^{-3.15} = 1.03 \pm 0.23$$



Use other data to break remaining degeneracies



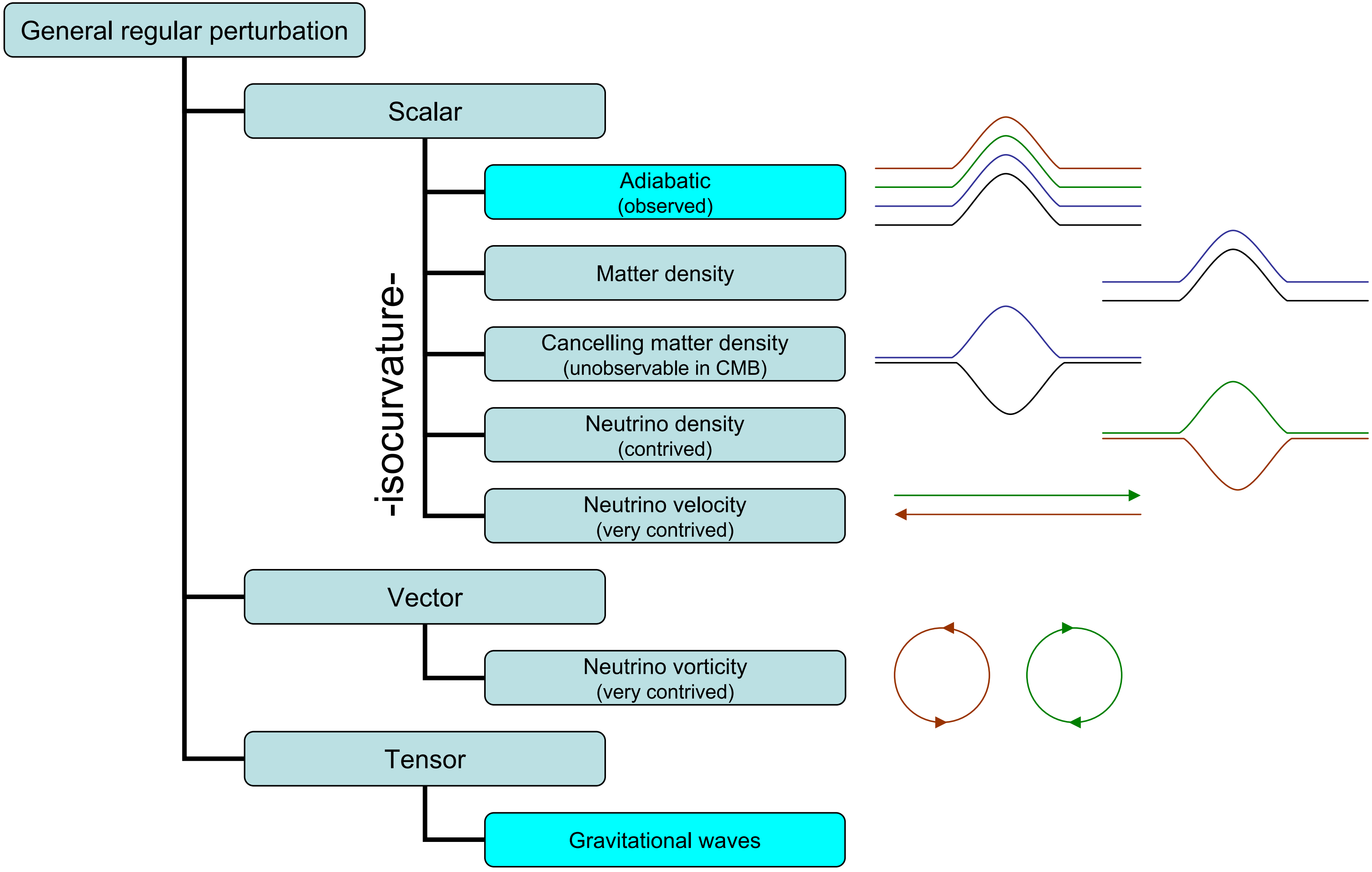
e.g. spectral index from
CMB + baryon abundance (BBN)



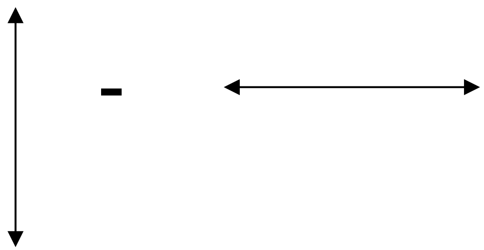
e.g. n_s = 0.956+/-0.013 (1 sigma) and n_s < 0.990 with 99% confidence.

Pettini, Zych, Murphy, Lewis, Steidel (2008).

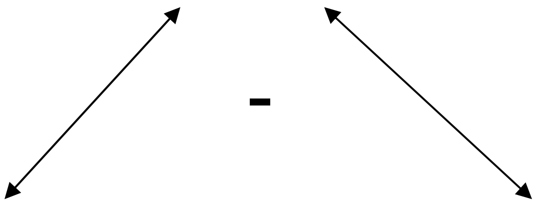
What were the initial perturbations?



Polarization: Stokes' Parameters



Q



U

Q → -Q, U → -U under 90 degree rotation

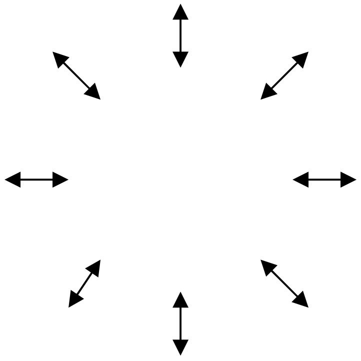
Q → U, U → -Q under 45 degree rotation

Generated by Thomson scattering of anisotropic unpolarized light

CMB polarization: E and B modes

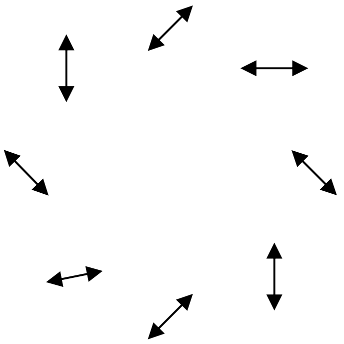
“gradient” modes
E polarization

e.g.



e.g. cold spot

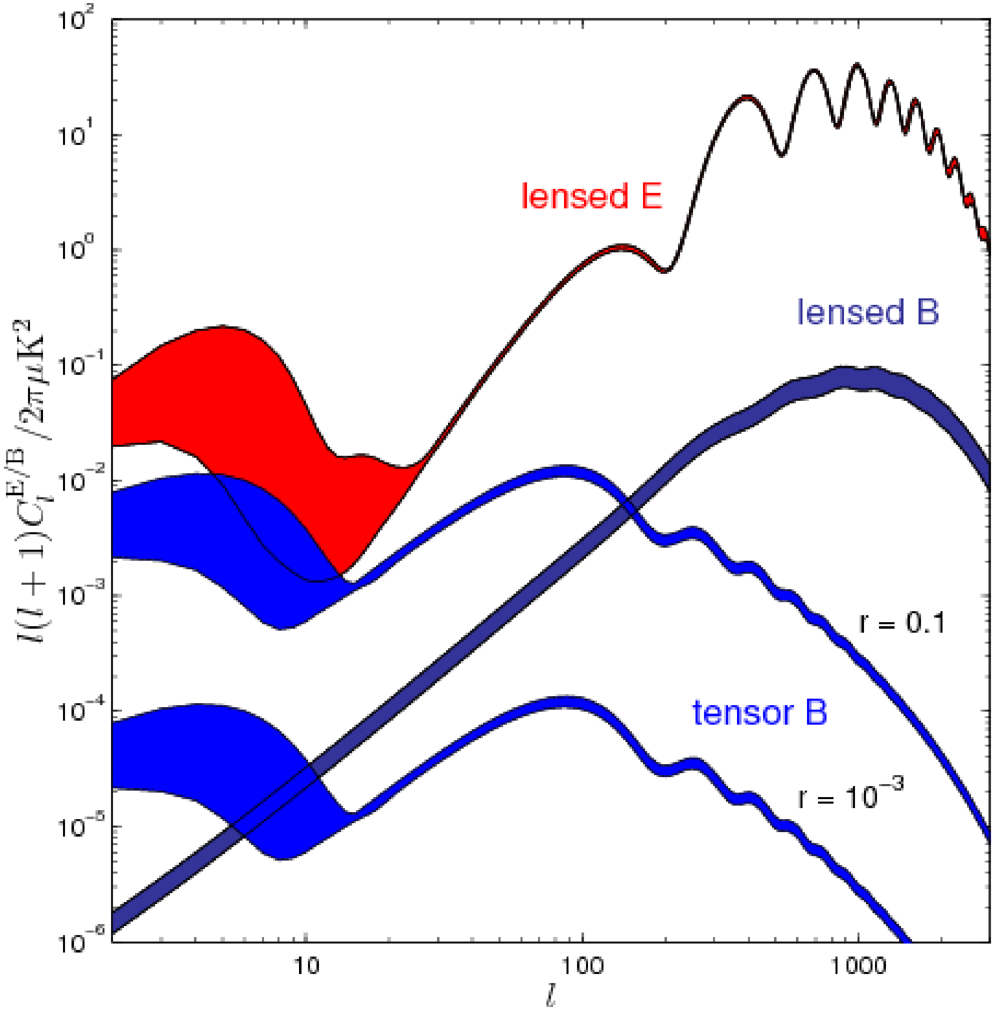
“curl” modes
B polarization



B modes only expected from gravitational waves and CMB lensing

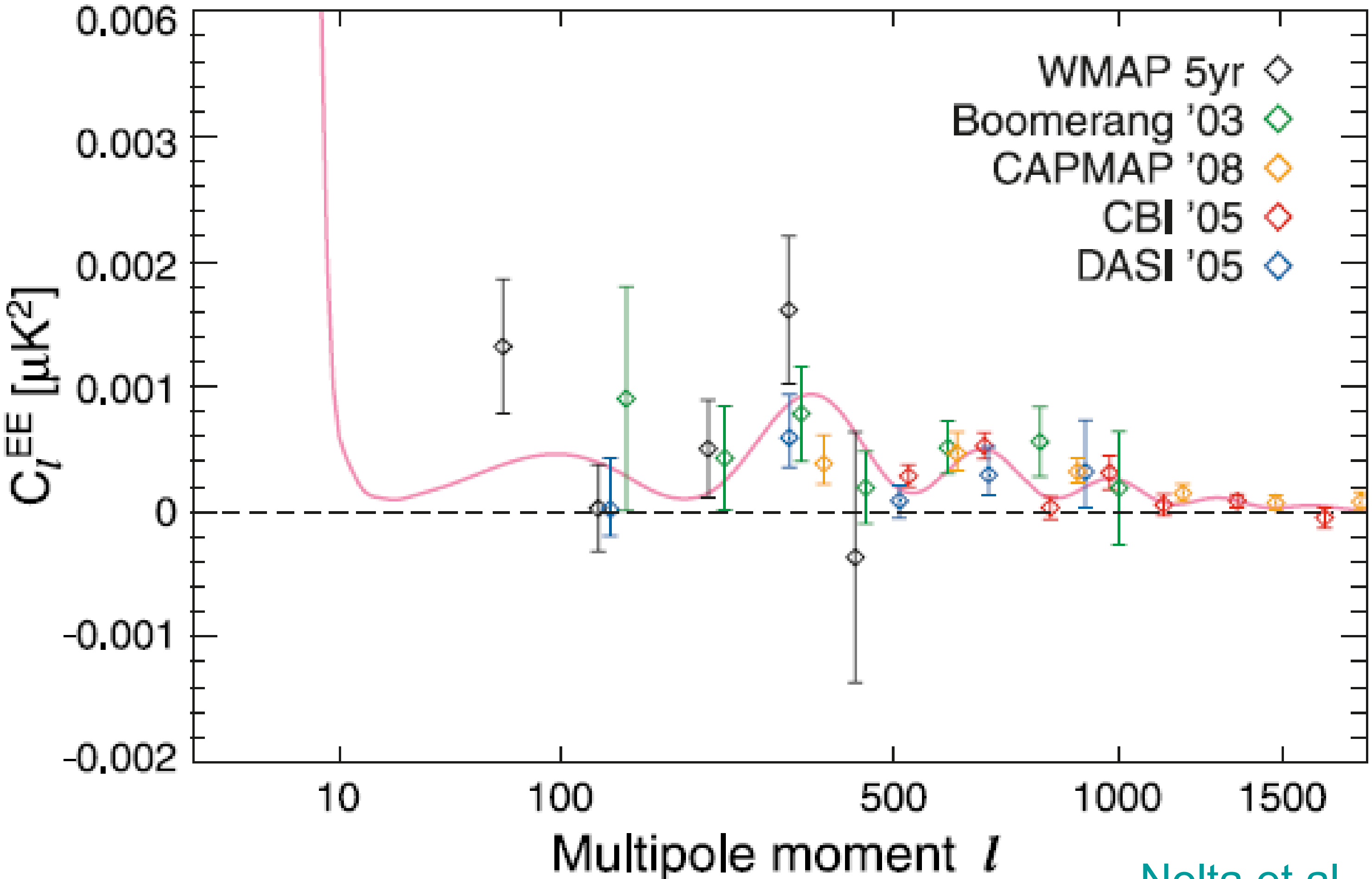
CMB Polarization

95% indirect limits for LCDM given WMAP+2dF+HST+z_{re}>6



WMAP3ext

Lewis, Challinor : astro-ph/0601594

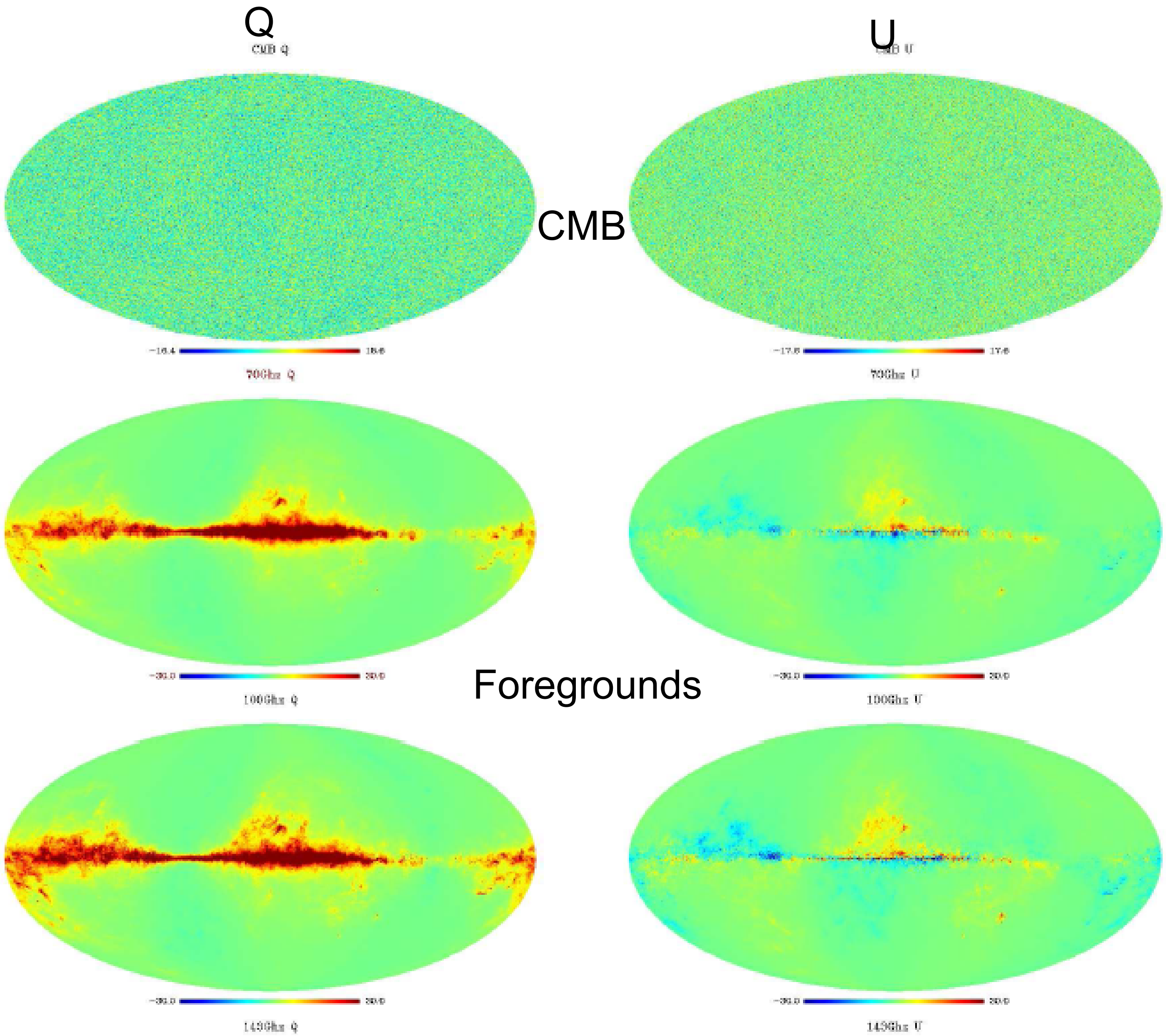


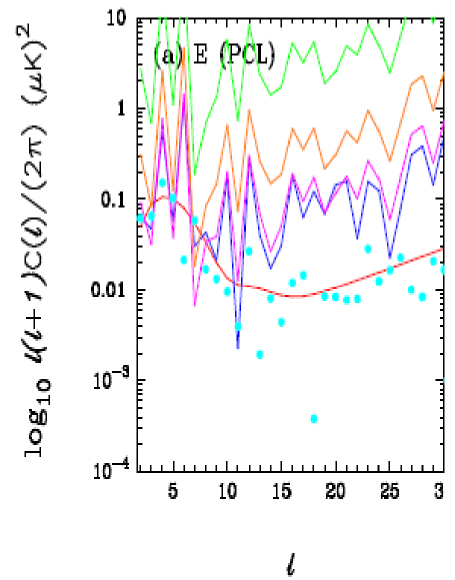
Nolta et al.

Currently only large scales useful for parameters

(+ consistency check on small scales)

BUT: Big foregrounds on large scales



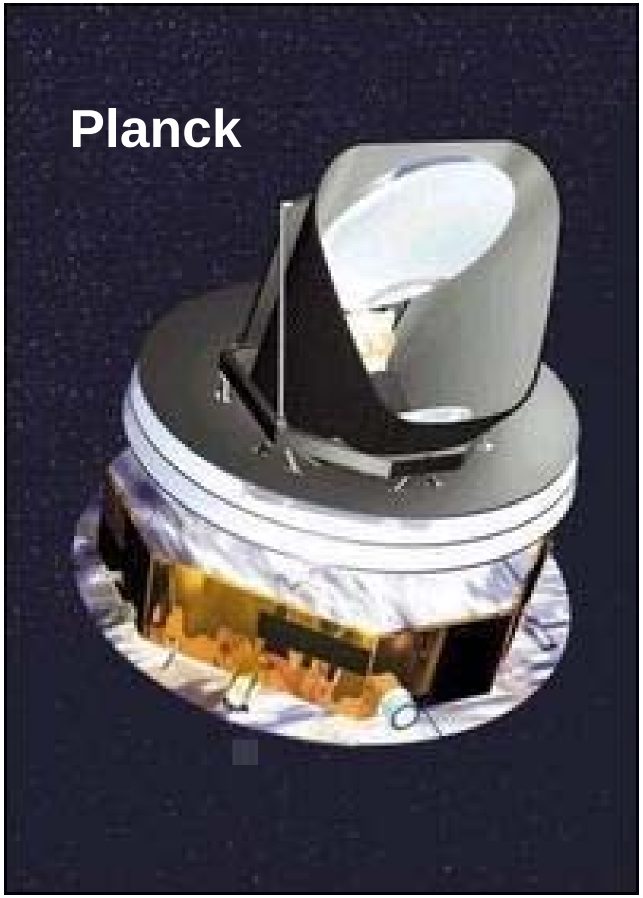


Efstathiou et al 2009

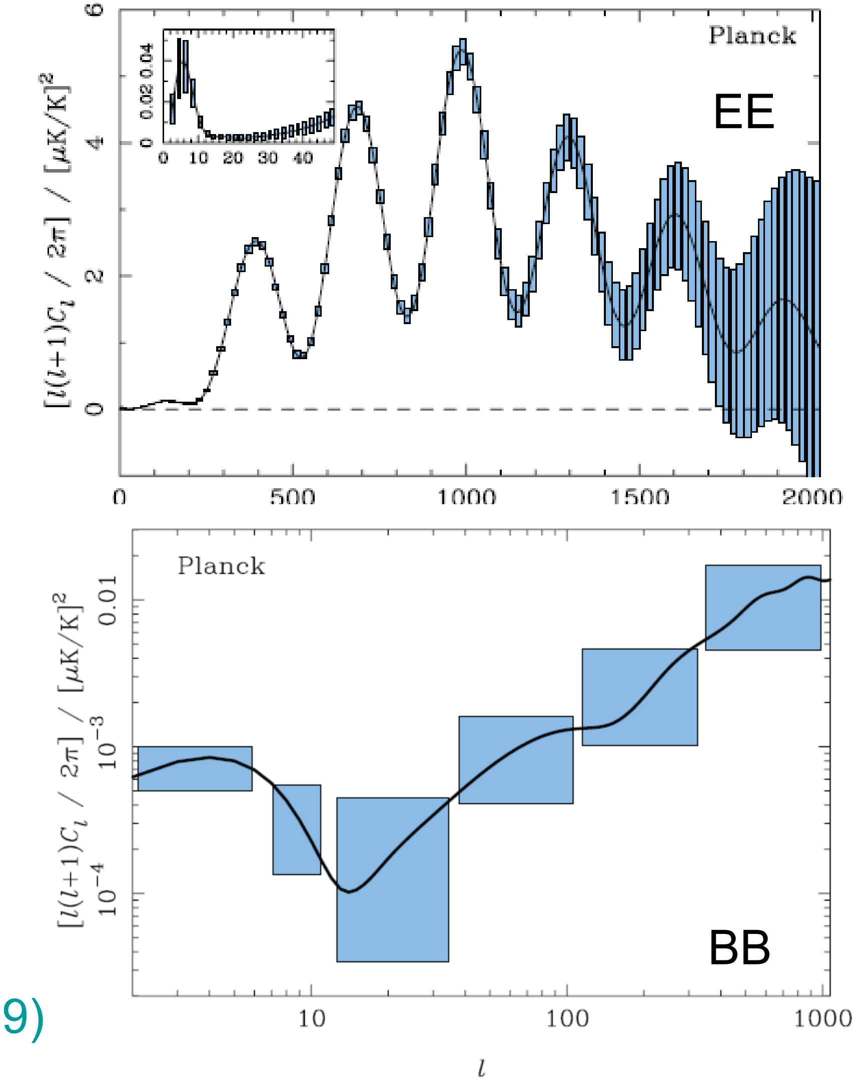
Planck and the future

Blast off 6th May?

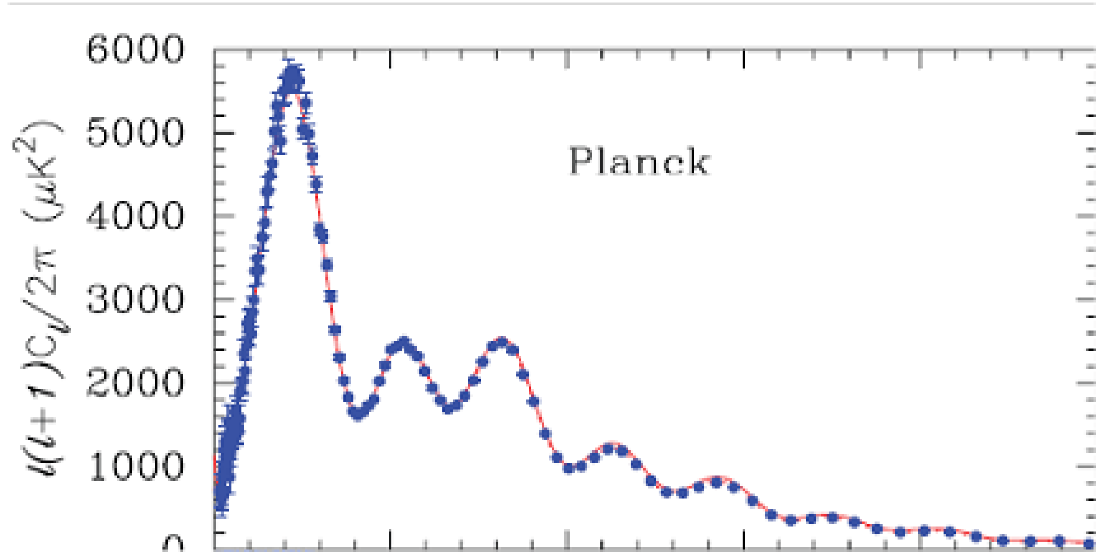
High sensitivity and resolution temperature and polarization



Planck blue book



B-mode constraint:
r ~ 0.1 in 14 months
r ~ 0.05 if 28 months (Efstathiou, Gratton 09)



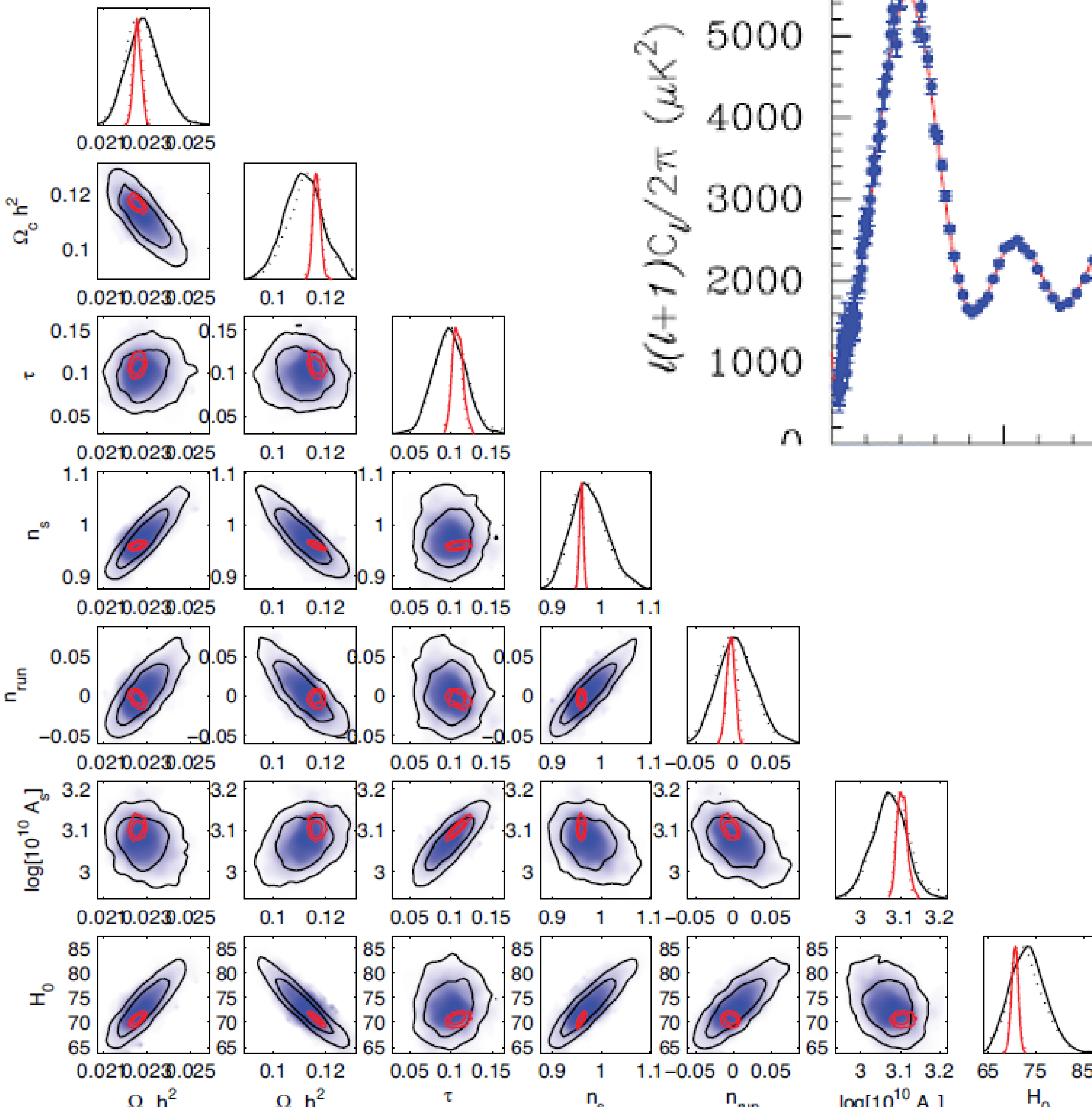
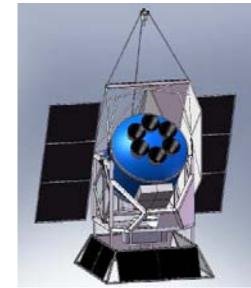


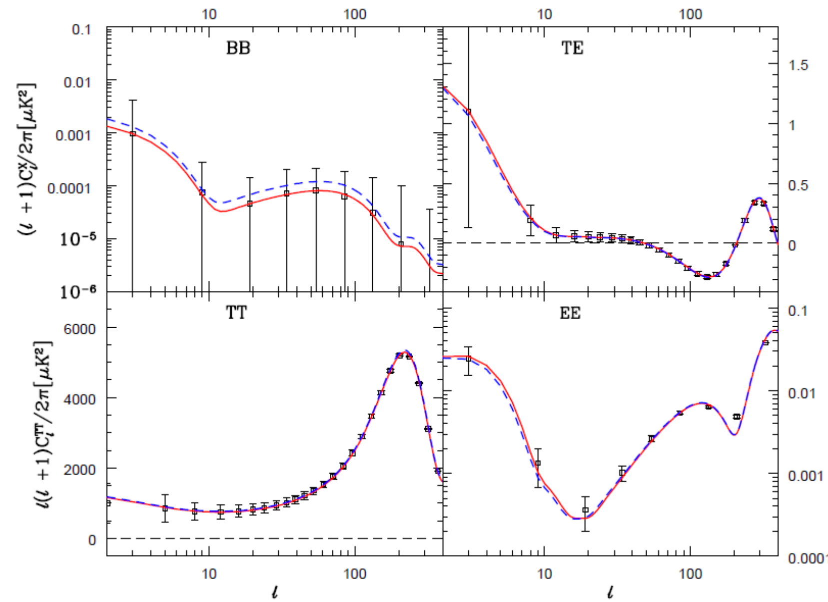
FIG 2.18.—Forecasts of 1 and 2σ contour regions for various cosmological parameters when the spectral index is allowed to run. Blue contours show forecasts for *WMAP* after 4 years of observation and red contours show results for *Planck* after 1 year of observations. The curves show marginalized posterior distributions for each parameter.

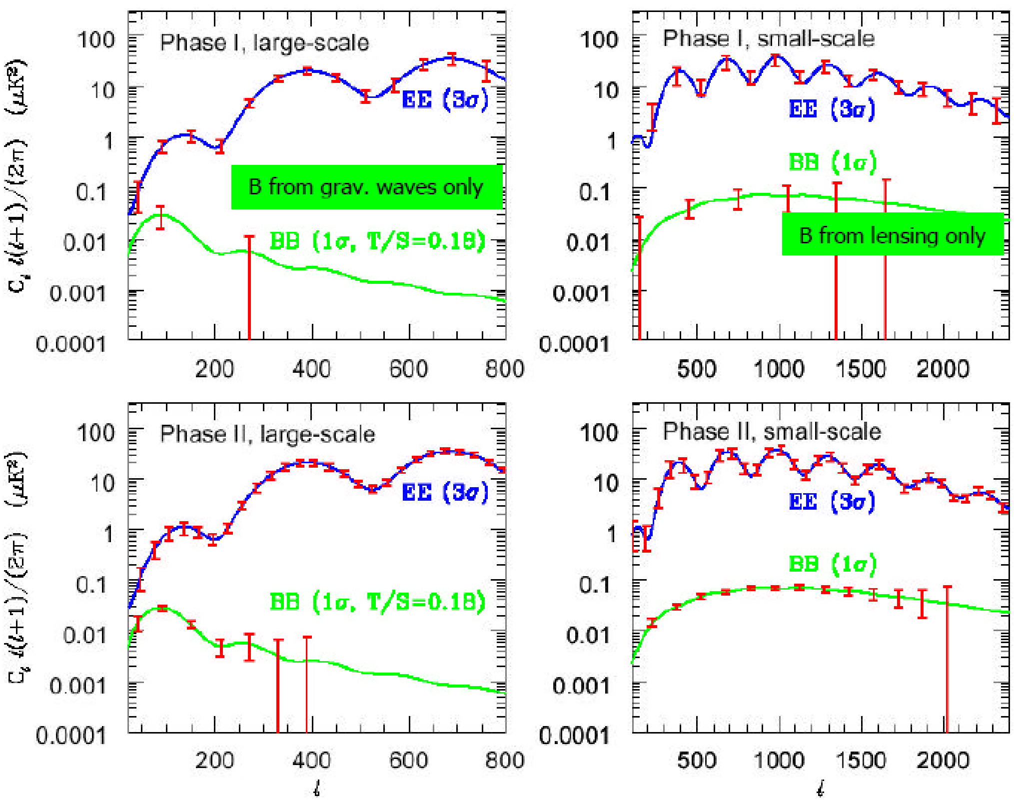
CℓOVER

Measuring gravitational-waves from Inflation

SPIDER





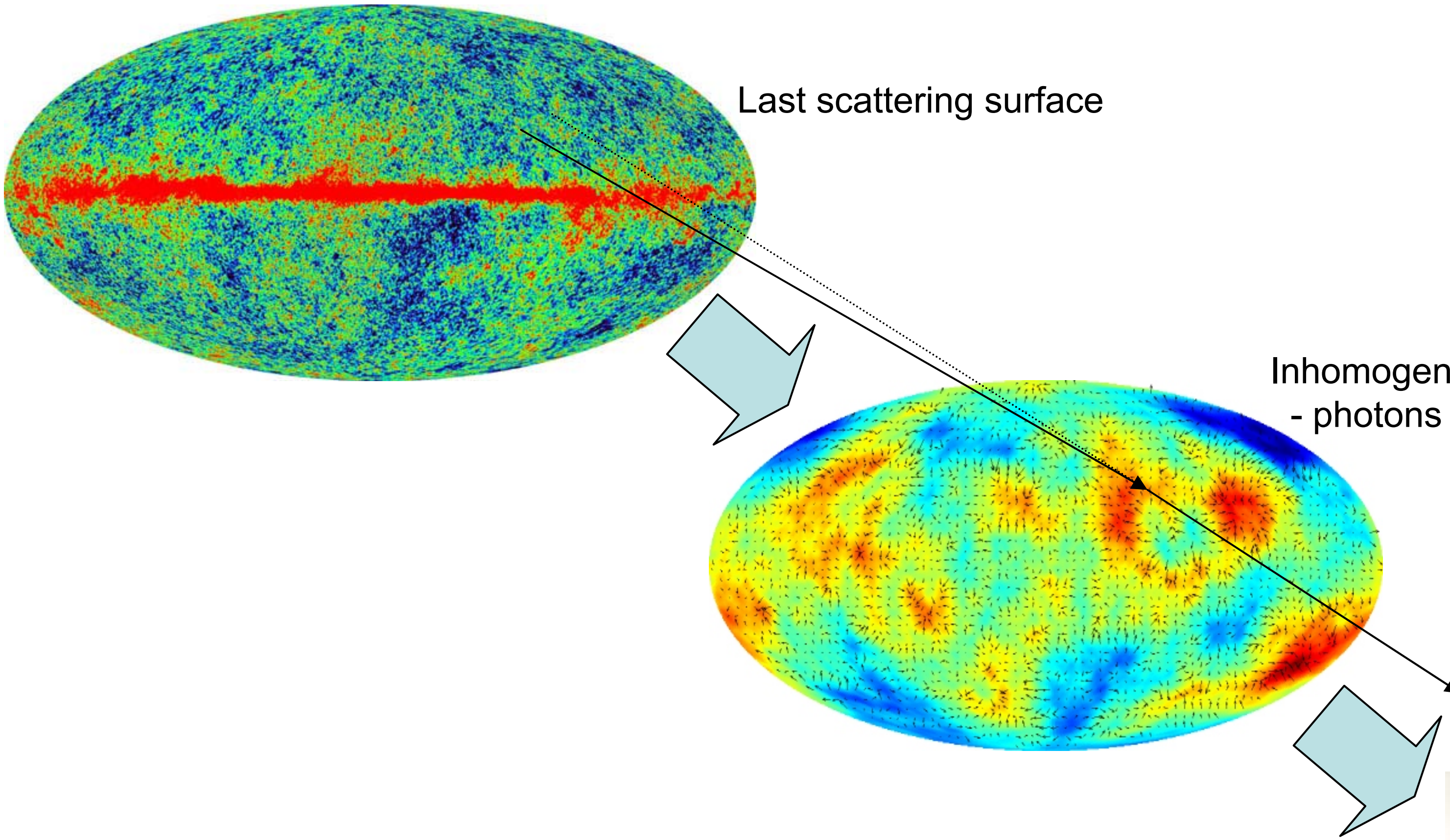


+ ACT, SPT, EBEX, PolarBear…

+ CMBPol ??

Beyond linear order

Weak lensing to break CMB degeneracies

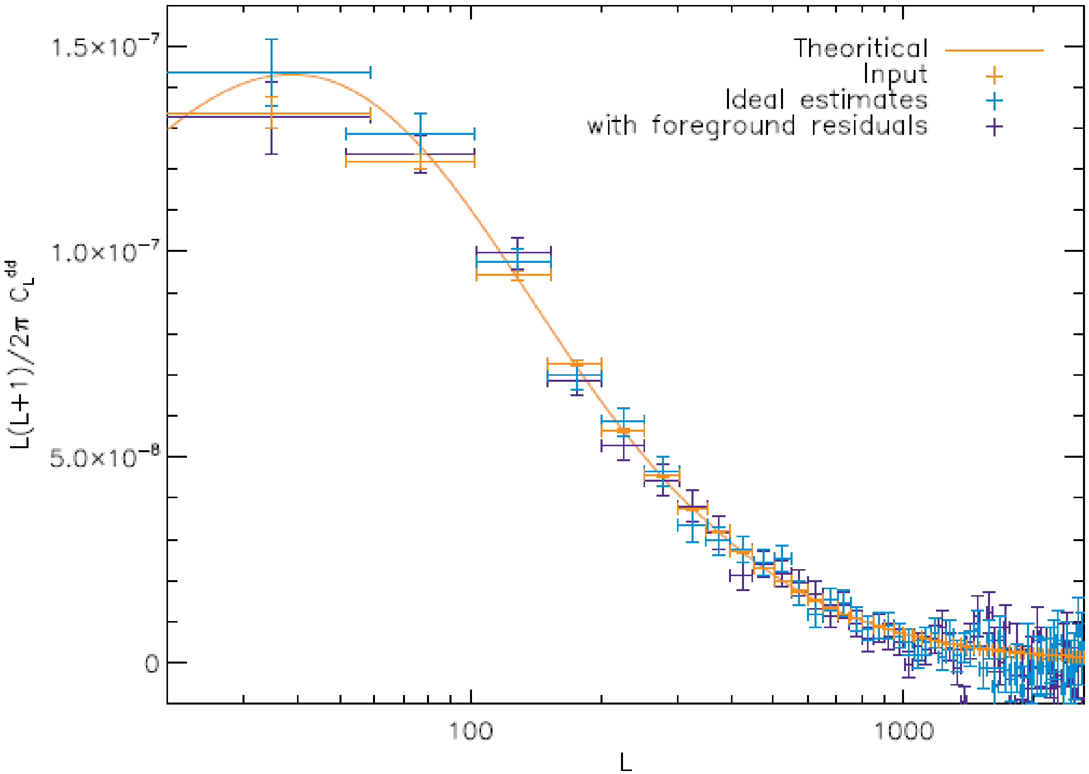


Changes power spectrum,
new B modes, induces non-Gaussianity

Review: Lewis & Challinor *Phys. Rept . 429, 1-65 (2006)*: astro-ph/0601594

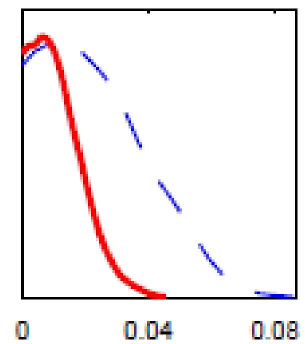
Probe 0.5<~ z <~ 6: depends on geometry and matter power spectrum

Already helps with Planck



Perotto et al. 2009

Neutrino mass fraction with and without lensing (Planck only)

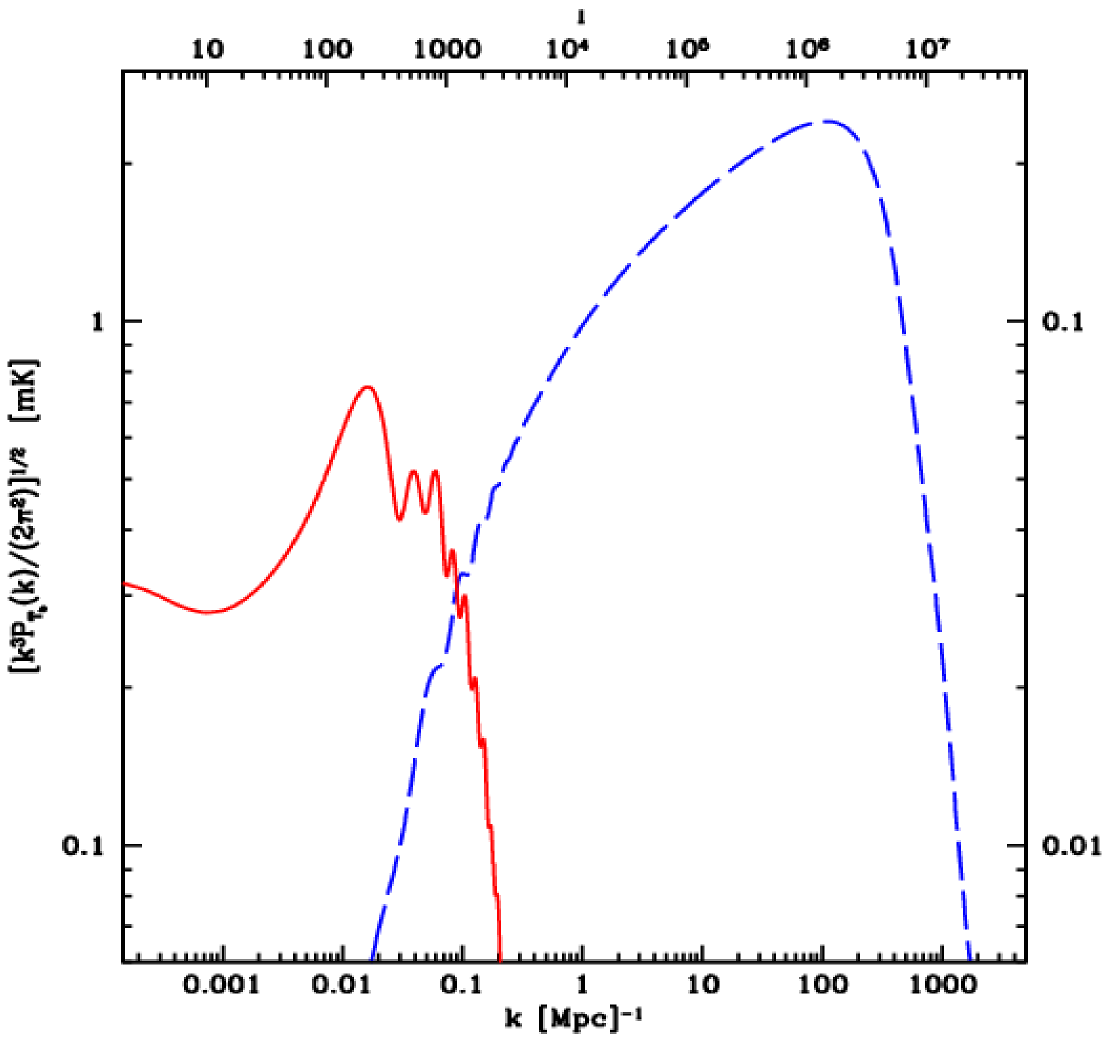


Perotto et al. 2006

Also: SZ clusters – e.g. cluster counts to constrain dark energy

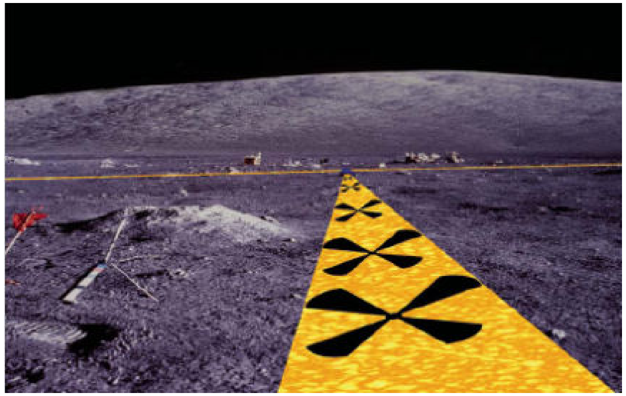
Beyond blackbody

- Measure CMB at low frequencies as function of frequency: 21cm absorption from high redshift neutral hydrogen



Kleban et al. hep-th/0703215

Scott, Rees, Zaldarriaga, Loeb, Barkana, Bharadwaj, Naoz, …

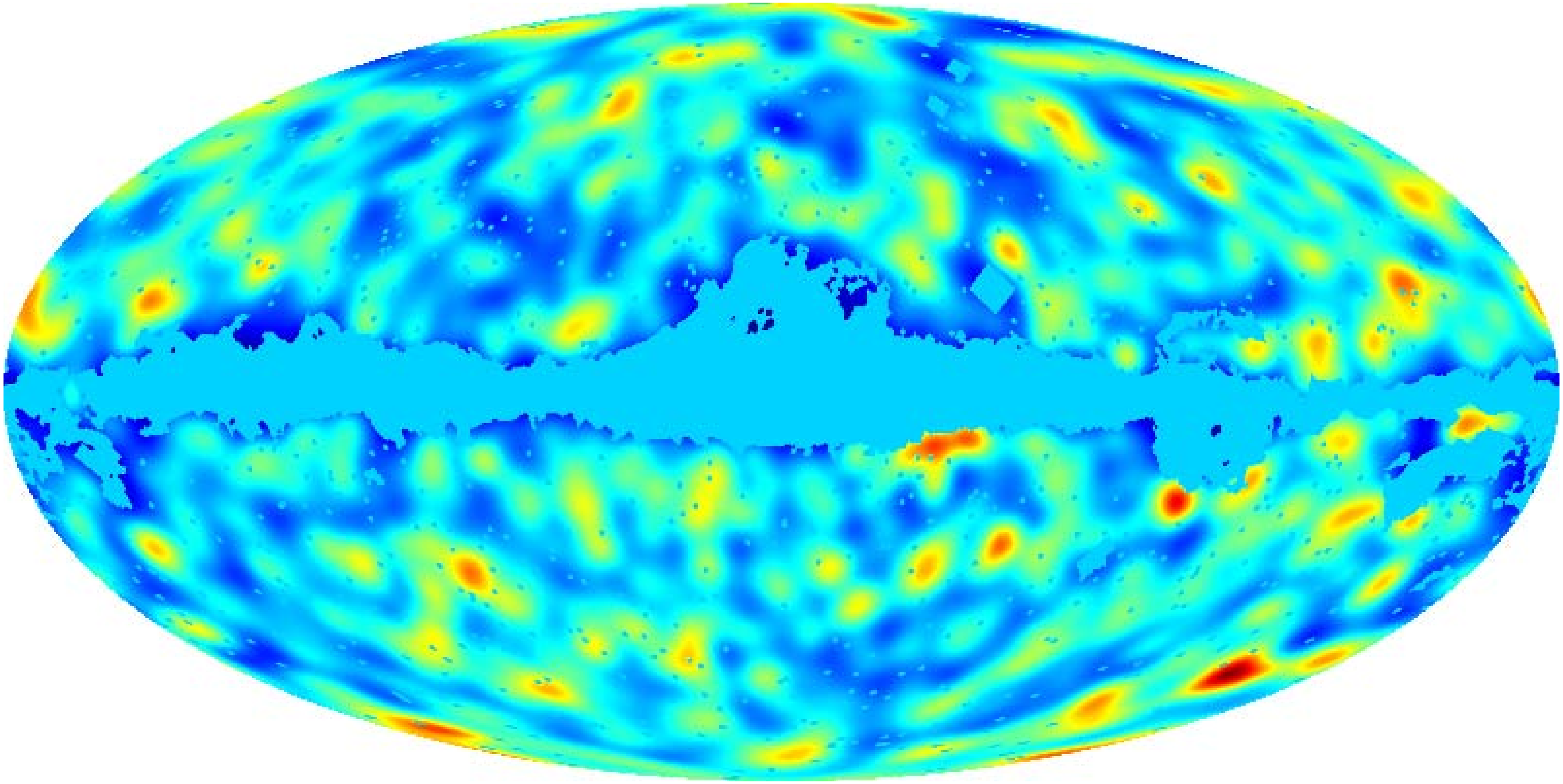


RADIO DAYS. Future astronauts lay out a carpet of simple dipole antennas, embedded in plastic, that will hunt for radio signals associated with the first stars in the universe.
NASA Goddard

BUT *very* challenging to observe

Caveat: if we use the wrong model, we'll get the wrong/meaningless parameters

- is the universe more complicated than we might prefer to think?



Smoothed map of large scale CMB temperature power

Low quadrupole, alignments, power asymmetries, cold spot, non-Gaussianities….

Conclusions

- CMB very clean way to measure many combinations of parameters very accurately

- Extra data needed to break degeneracies (or CMB lensing/SZ)

- Precision cosmology, and maybe answer more interesting qualitative questions:

  - were there significant primordial gravitational waves?
  - is the universe non-flat?
  - is n_s <1
  - is n_s constant

- BUT: depends on the right model – wait for Planck data to check anomalies

- Future:

  - large scale polarization B modes
  - precision cosmology
  - secondaries
  - 21cm