Dark Matter

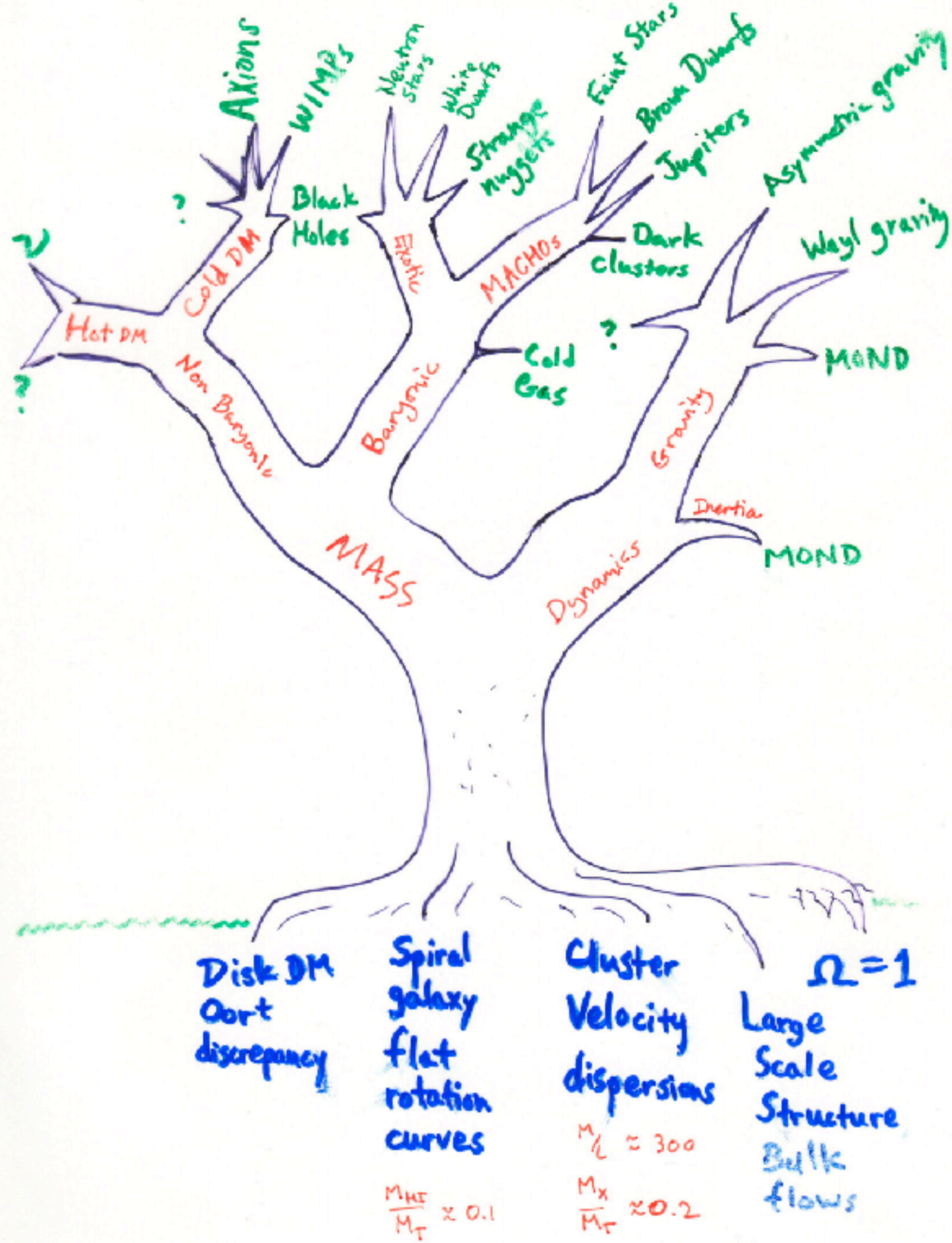
ASTR 333/433

Today

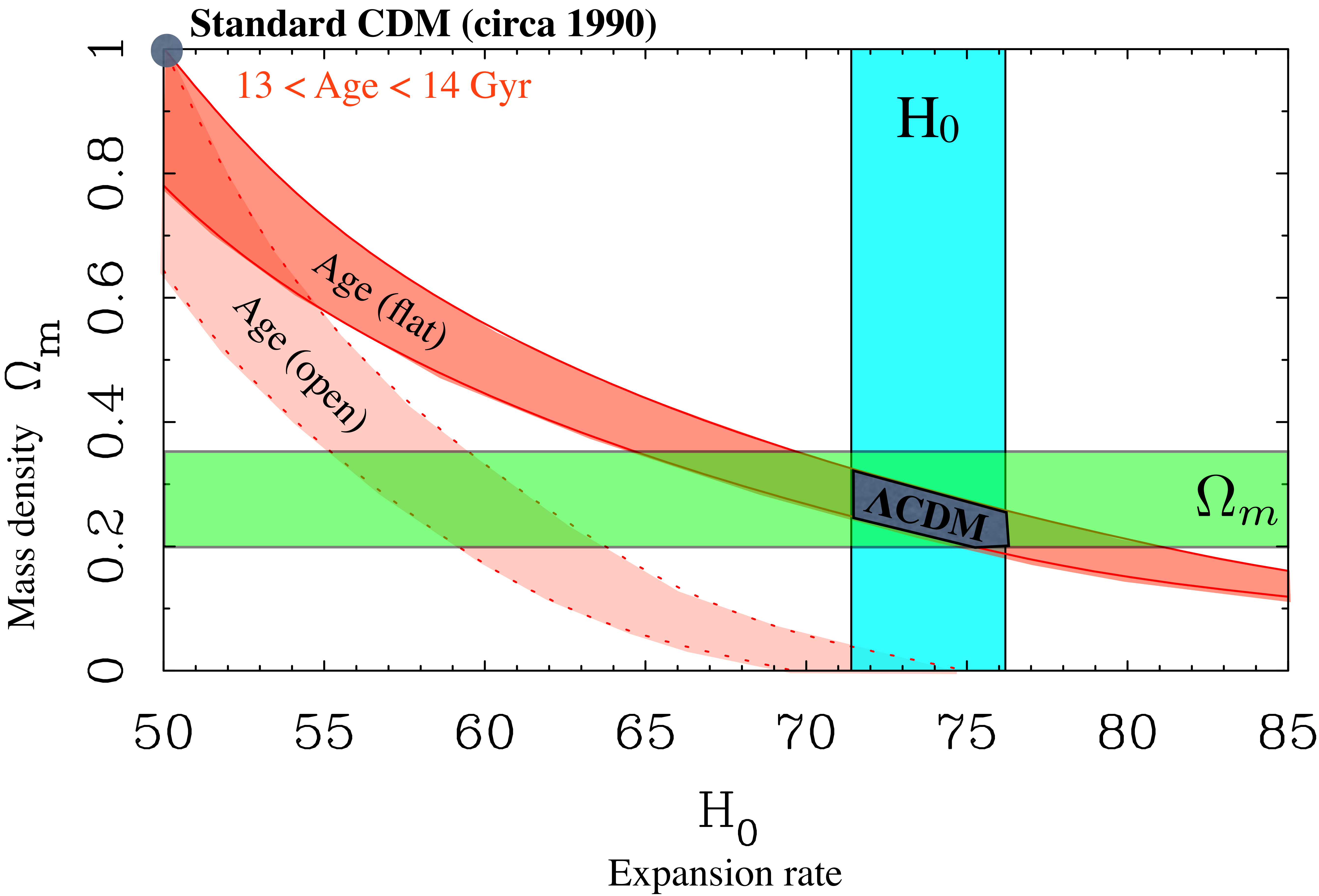
Cosmology (con.)
WIMPS

ASTR 433 Projects
4/17: distribute abstracts
4/19: 20 minute talks

4/24: Homework 4 due
4/26: Exam



Cosmic constraints predating SN, CMB (circa 1995)



CMB temperature fluctuations directly related to density fluctuations

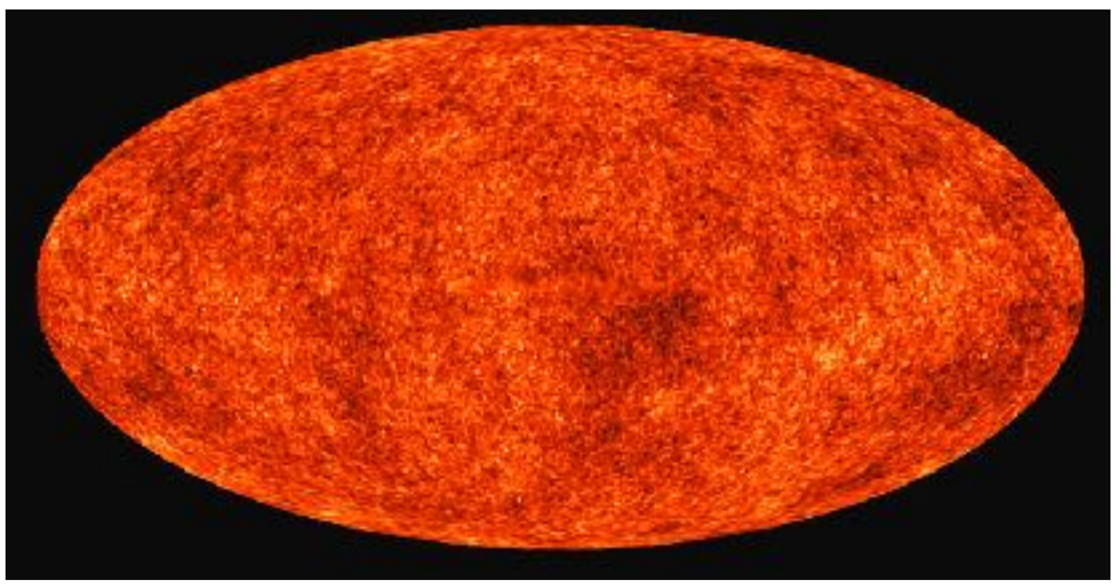
$$\frac{\delta T}{T} = \frac{1}{3}\frac{\delta\rho}{\rho}$$

Basic problem:
not enough time for structure to grow.

Gravity will grow the observed large scale structure, but it works slowly. Can't get here-now from the there-then of tiny CMB fluctuations.

There isn't enough time to form the observed cosmic structures from the smooth initial conditions unless there is a component of mass independent of photons.

t = 3.8 x 10^5 yr



very smooth: $\delta\rho/\rho \sim 10^{-5}$

t = 1.4 x 10^{10} yr

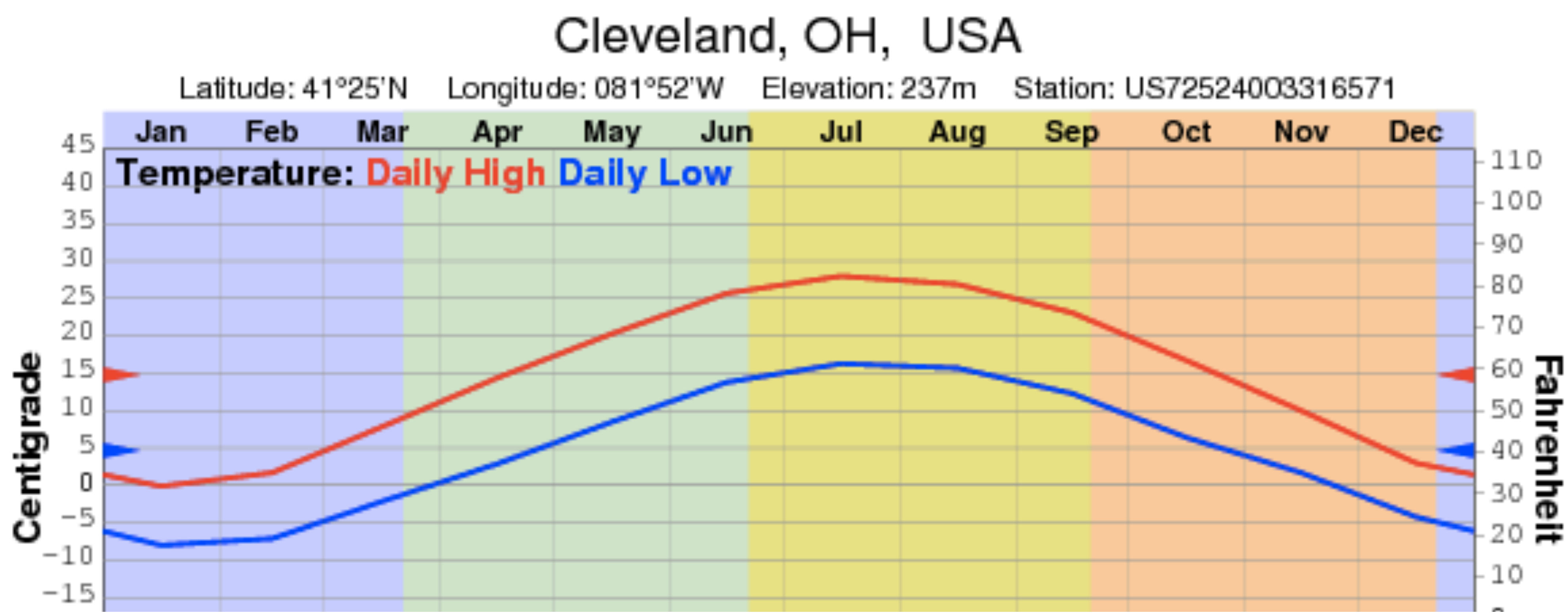
very lumpy: $\delta\rho/\rho \sim 1$

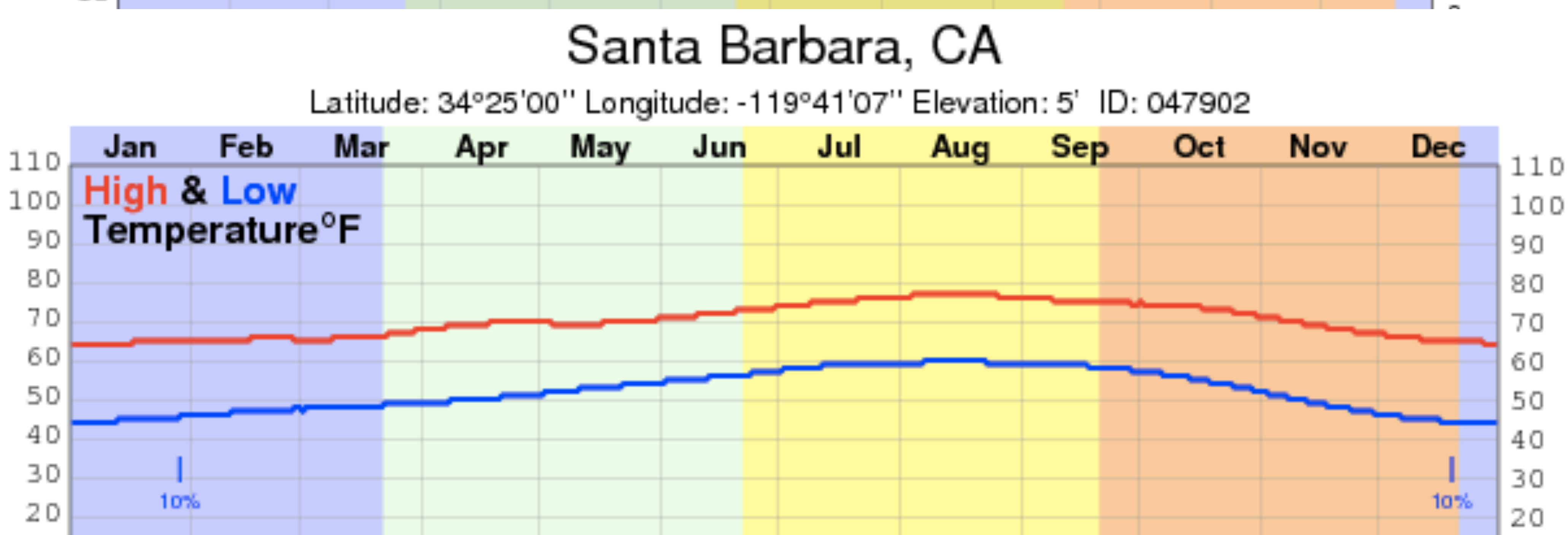
$$\delta\rho/\rho \propto t^{2/3}$$

http://space.mit.edu/home/tegmark/movies.html

Power Spectrum

Example: weather in Cleveland and Santa Barbara
More power on long time scales in Cleveland (seasonal variation)

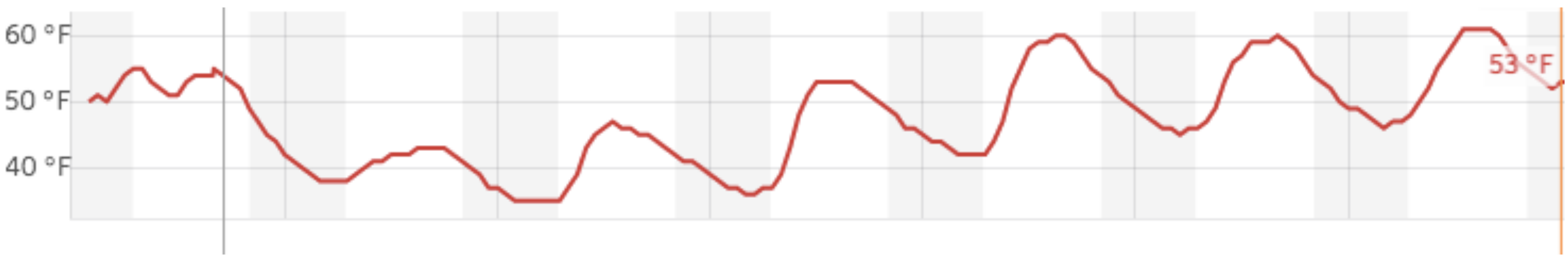




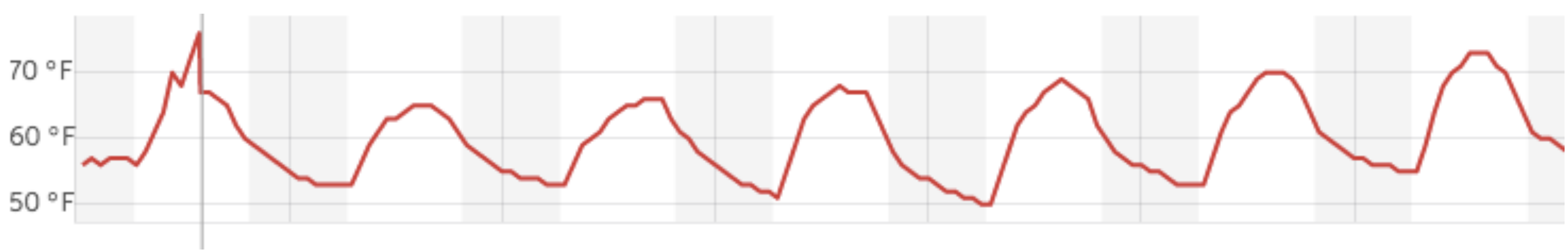
Power Spectrum

Example: weather in Cleveland and Santa Barbara
A little more power on short time scales in Santa Barbara
(diurnal variation)

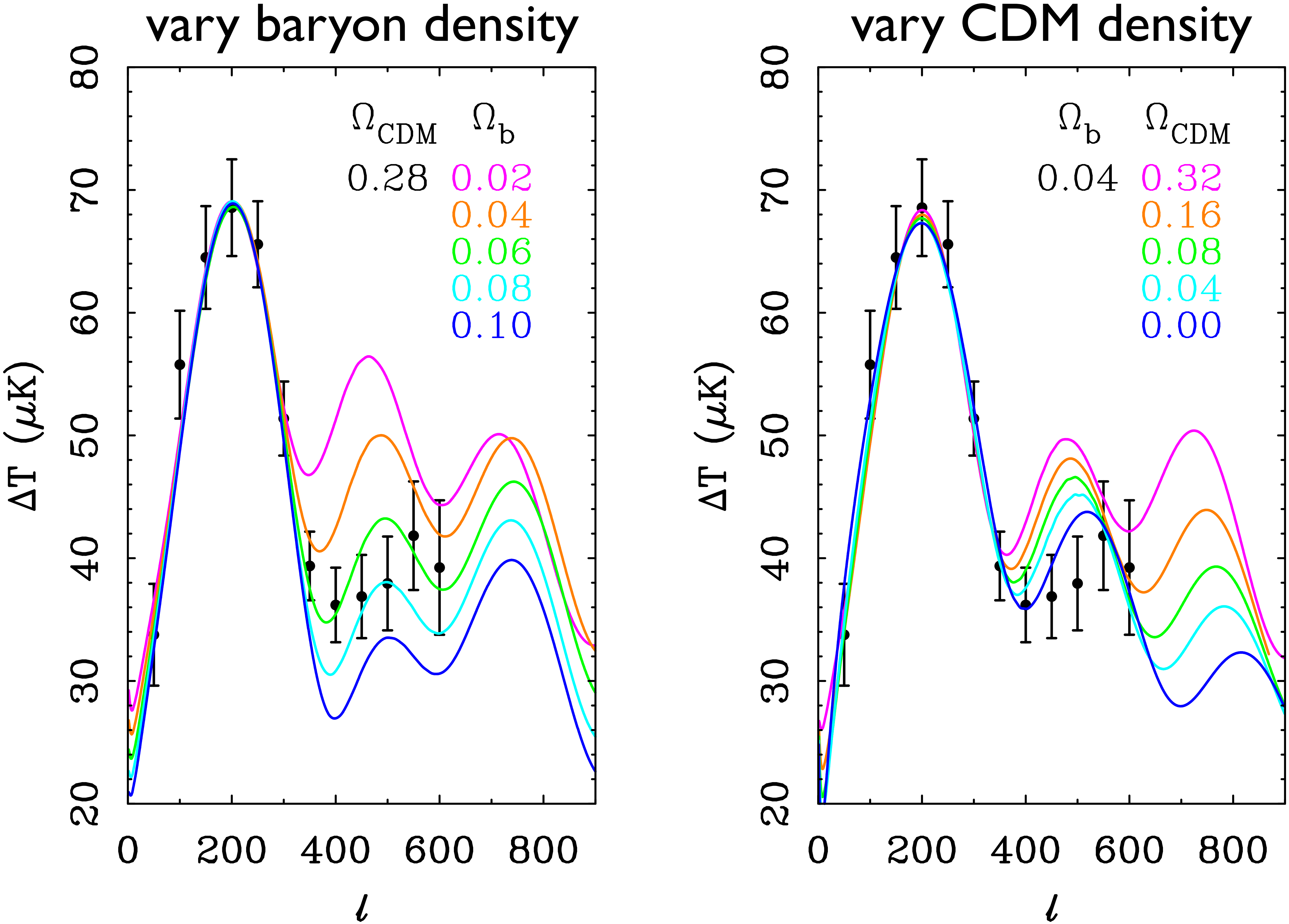
Cleveland forecast



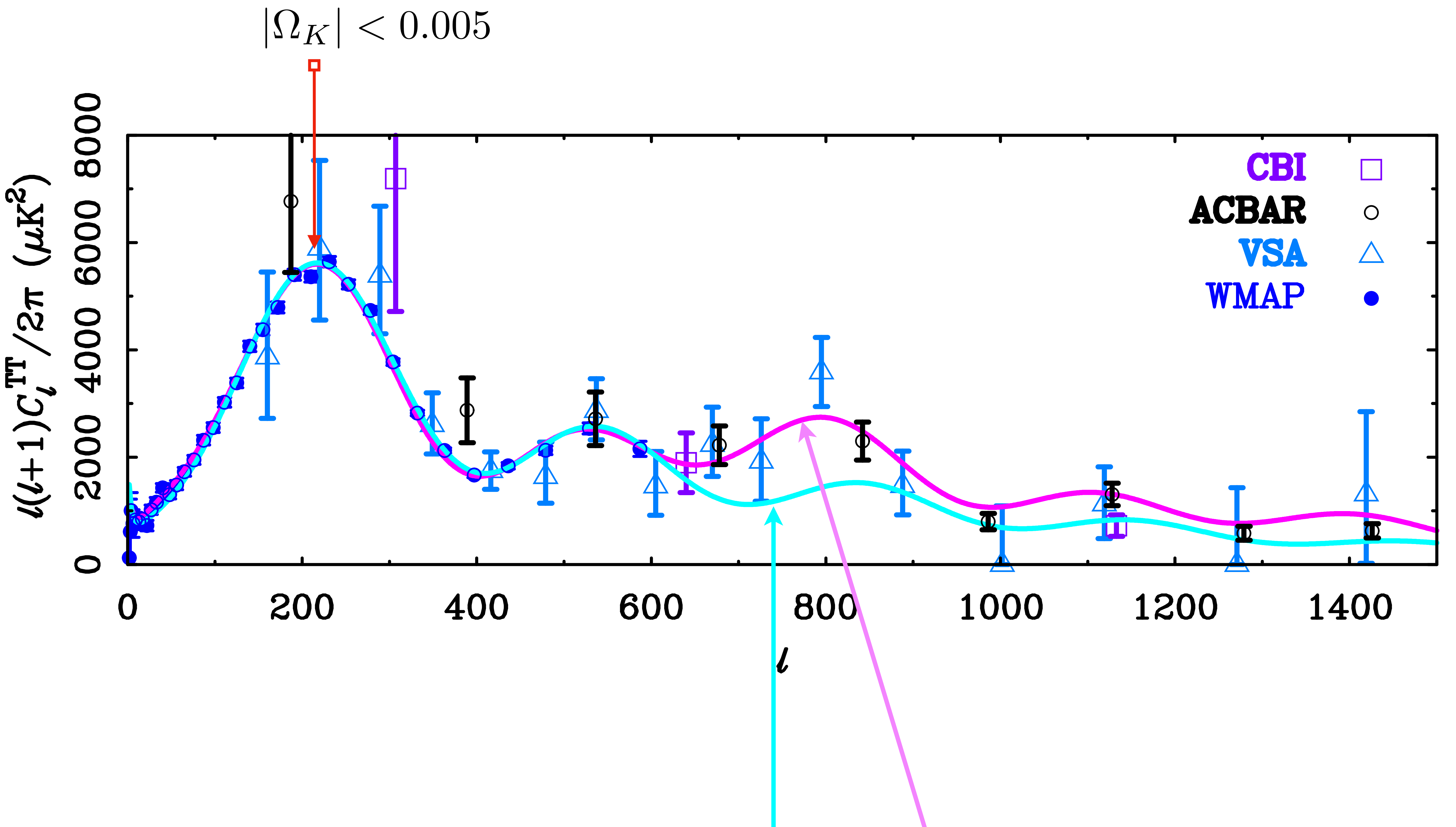
Santa Barbara forecast



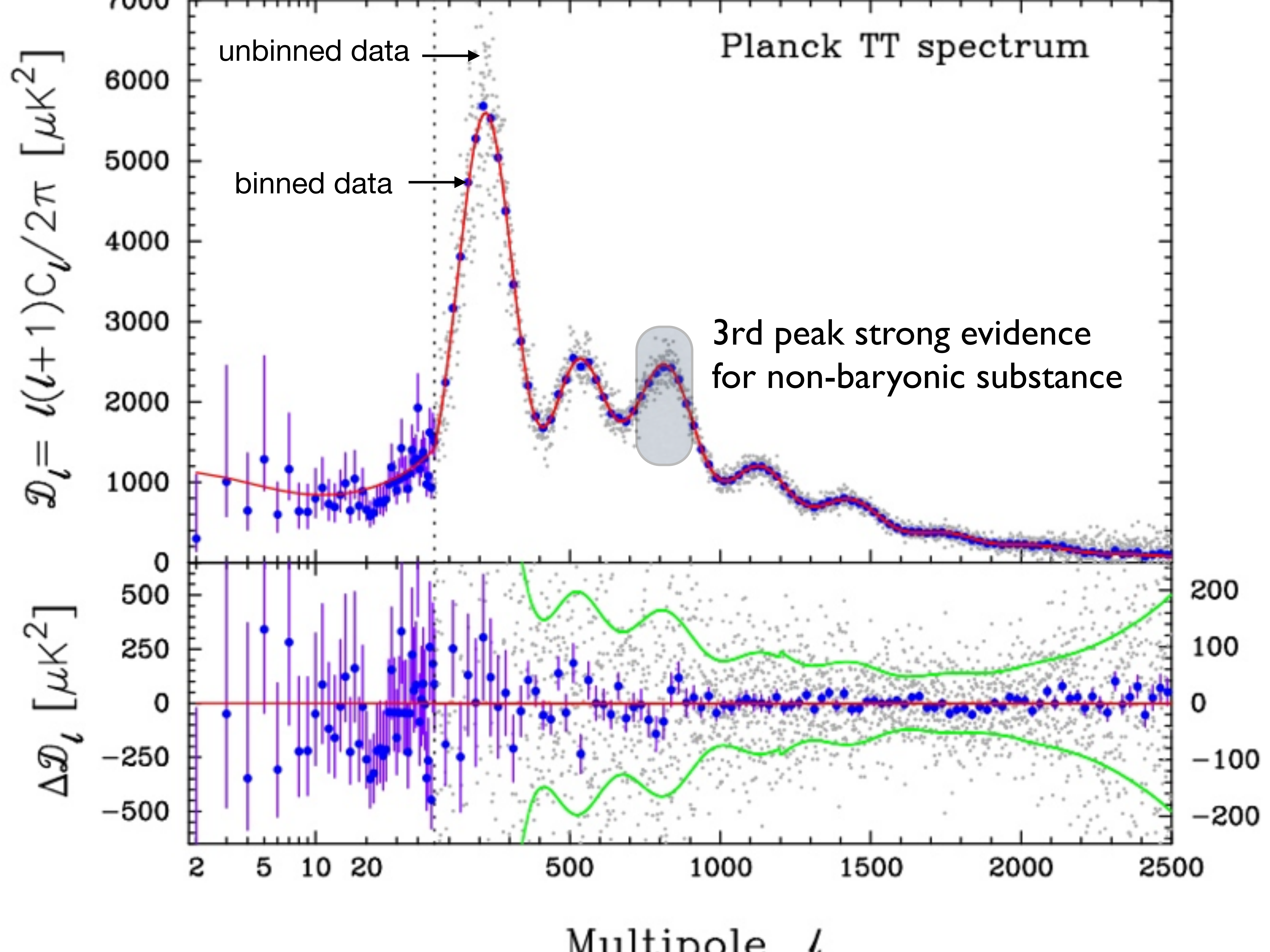
A power spectrum is a Fourier transform that quantifies the relative variability on different scales

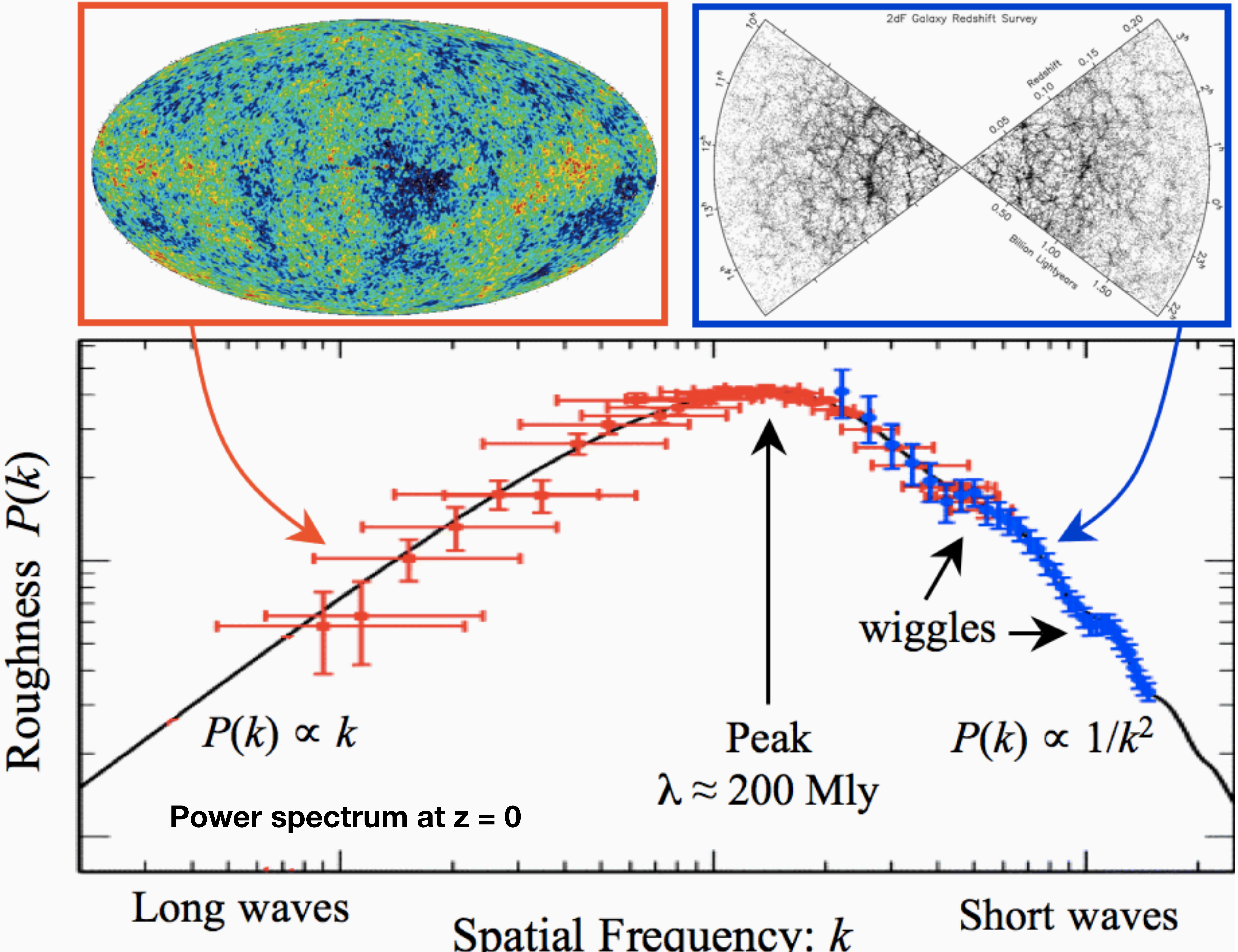


CMB power spectra



$$k^2\Phi = 4\pi G(\rho_b\delta_b + \rho_\gamma\delta_\gamma + \rho_{CDM}\delta_{CDM})$$


Planck TT spectrum
unbinned data
binned data
3rd peak strong evidence
for non-baryonic substance
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
$\Delta\mathcal{D}_\ell\ [\mu K^2]$
Multipole ℓ



2dF Galaxy Redshift Survey
Redshift
0.05
0.10
0.15
0.20
0.50
1.00
1.50
Billion Lightyears
Roughness $P(k)$
$P(k) \propto k$
Peak
$\lambda \approx 200$ Mly
wiggles
$P(k) \propto 1/k^2$
Power spectrum at z = 0
Long waves
Spatial Frequency: k
Short waves

From an accident report in the *Boston Driver's Handbook*:
"The guy was all over the road. I had to swerve several times before I hit him."

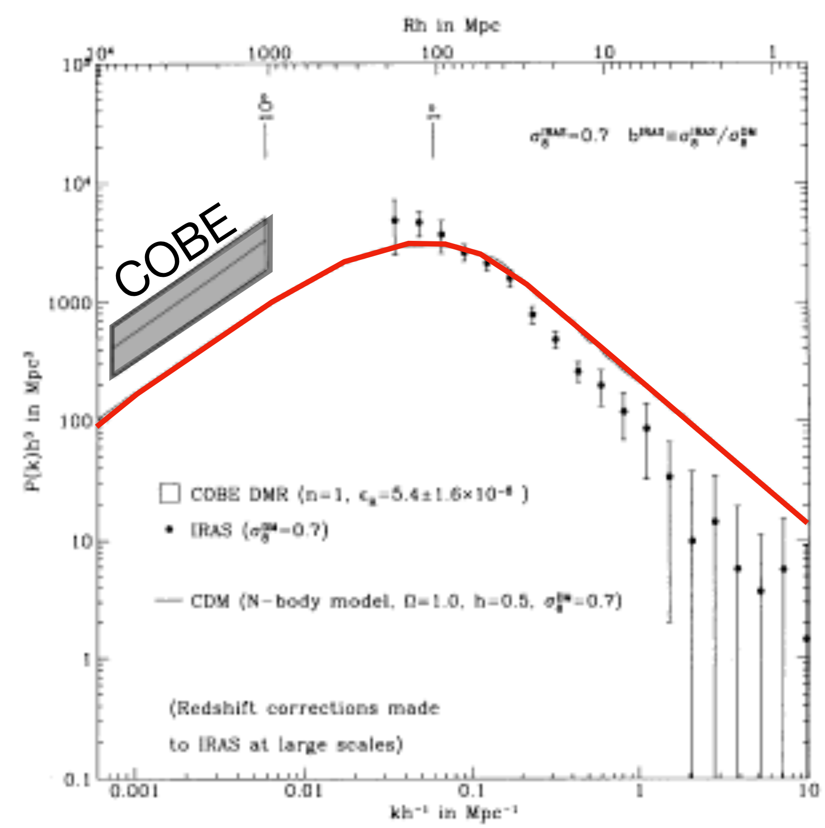
The power spectrum of SCDM missed badly:
too much power on small scales;
too little power on large scales.

<u>SCDM</u> ("Standard" CDM)

$$\Omega_m = 1$$

$$H_0 = 50$$

$$\Omega_m h = 0.5$$



SCDM
$\Omega_m h = 0.5$
$\sigma_8 = 0.7$

FIG. 10.—Solid curve is the real space power spectrum of the full nonlinear CDM *N*-body simulation (as in Fig. 3) normalized to the real space variance of *IRAS* galaxies ($\sigma_8 = 0.7$). The points are the *IRAS* redshift space $\tilde{P}(k)$ from Fig. 4, rescaled by eq. (17) with $\Omega = 1$ and $b = 1$; this is then, apart from the effects of the convolution in eq. (14), an approximation to the power spectrum of *IRAS* galaxies in *real* space on large scales if the *IRAS* galaxies are unbiased. The box indicates the power spectrum inferred from the *COBE* DMR measurements, assuming a $n = 1$ spectral index and $\epsilon_H = (5.4 \pm 1.6) \times 10^{-6}$ (Smoot et al. 1992; Wright et al. 1992). Note that when the CDM model is normalized to the *IRAS* variance, it produces excessive power on small scales while simultaneously failing to produce sufficient power on large scales to match the *COBE* results.

Fisher et al. (1993) ApJ, 402, 42

LCDM

$\Omega_m = 0.3$

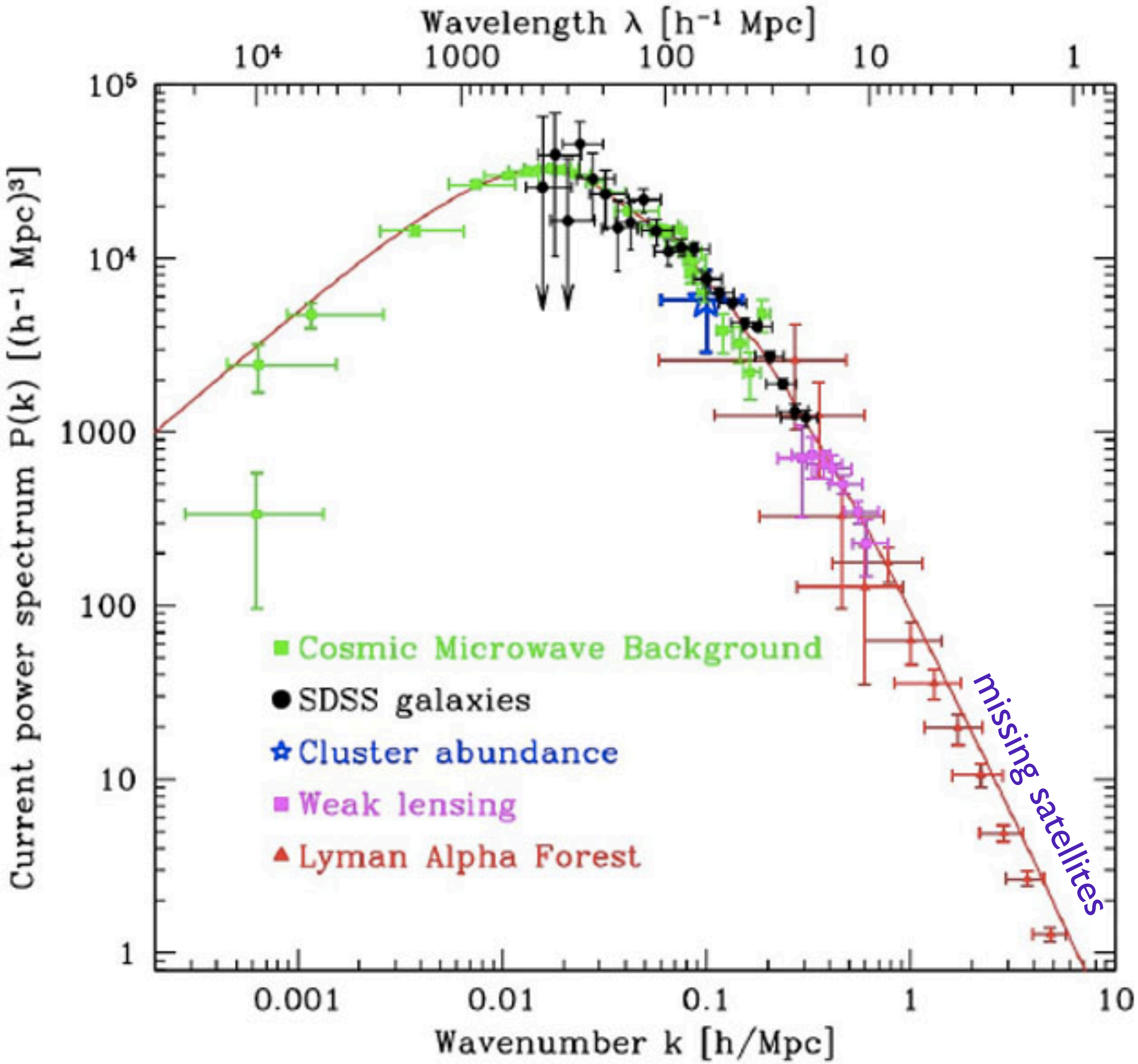
$H_0 = 70$

$\Omega_\Lambda = 0.7$

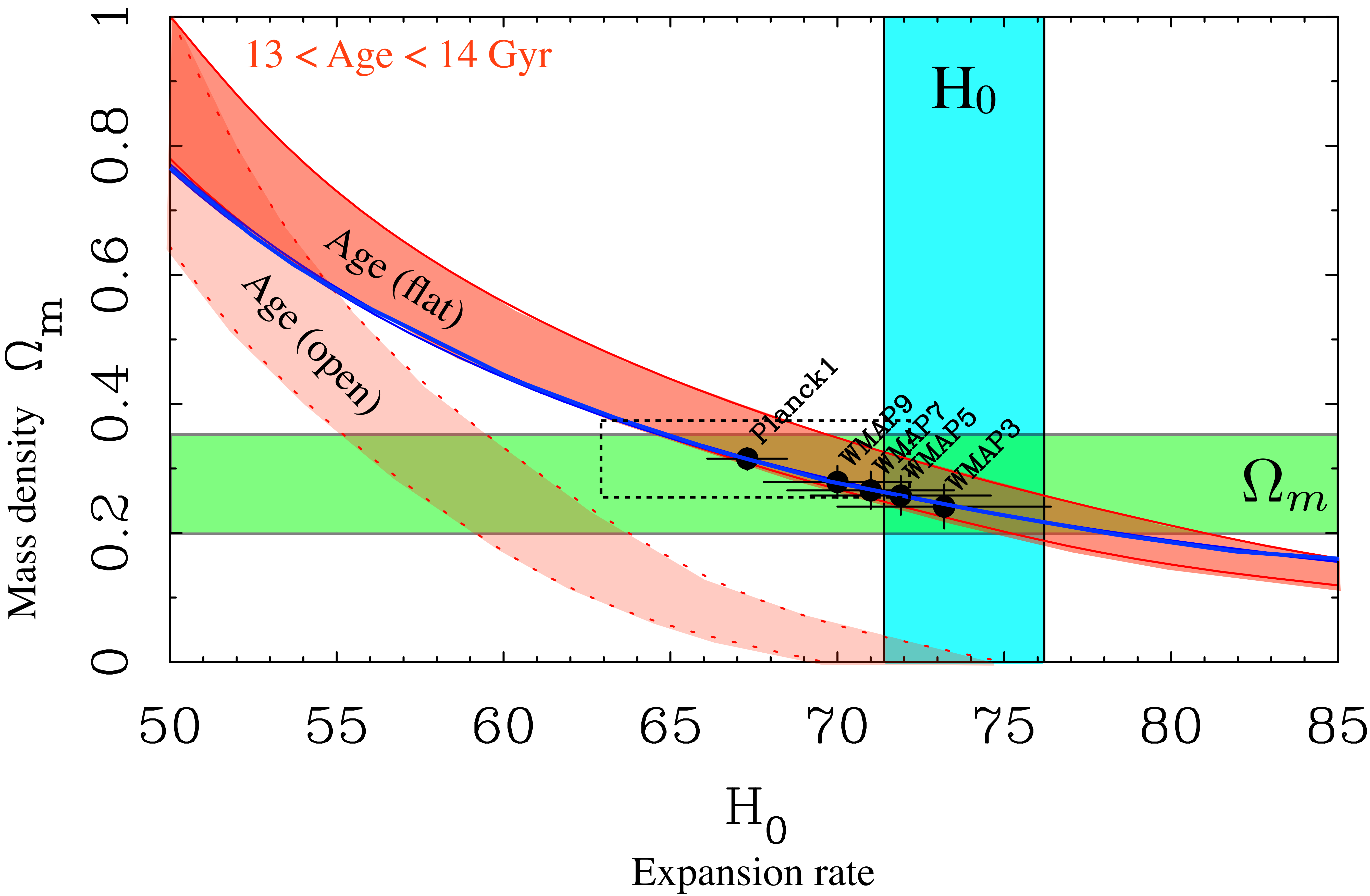
$\Omega_m h = 0.21$

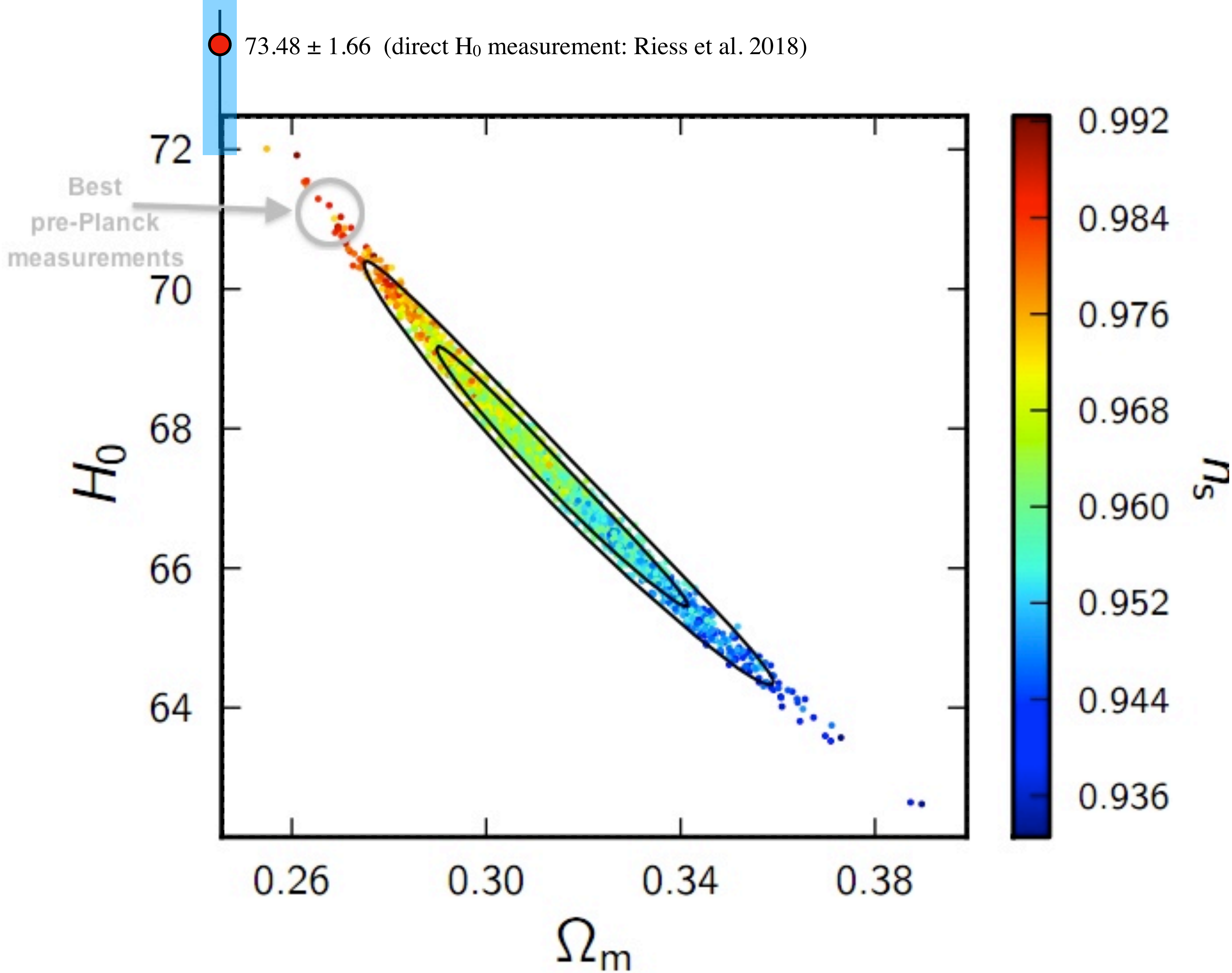
$\sigma_8 = 0.83$

$n_s = 0.965$



Planck constraint: $\Omega_m h^3 = 0.0959 \pm 0.0006$





73.48 ± 1.66 (direct H0 measurement: Riess et al. 2018)
Best
pre-Planck
measurements
72
70
68
66
64
H0
0.26
0.30
0.34
0.38
Ωm
0.992
0.984
0.976
0.968
0.960
0.952
0.944
0.936
ns

"Cosmologists are often wrong, but never in doubt"

- Lev Landau

Things we know for sure in cosmology:

quantity	c. 1990	WMAP5 2008	Planck 2013
Ω_m	1	0.258±0.027	0.315±0.017
Ω_Λ	0	0.742	0.685
$\Omega_b h^2$	0.0125	0.02273 ±0.00062	0.02205 ±0.00028
$H_\circ$	50	71.9±2.7	67.3±1.2
dark matter	CDM	CDM	CDM