Dark Energy Constraints (astro-ph/0701584, ApJ Aug07)

By Ned Wright

UCLA

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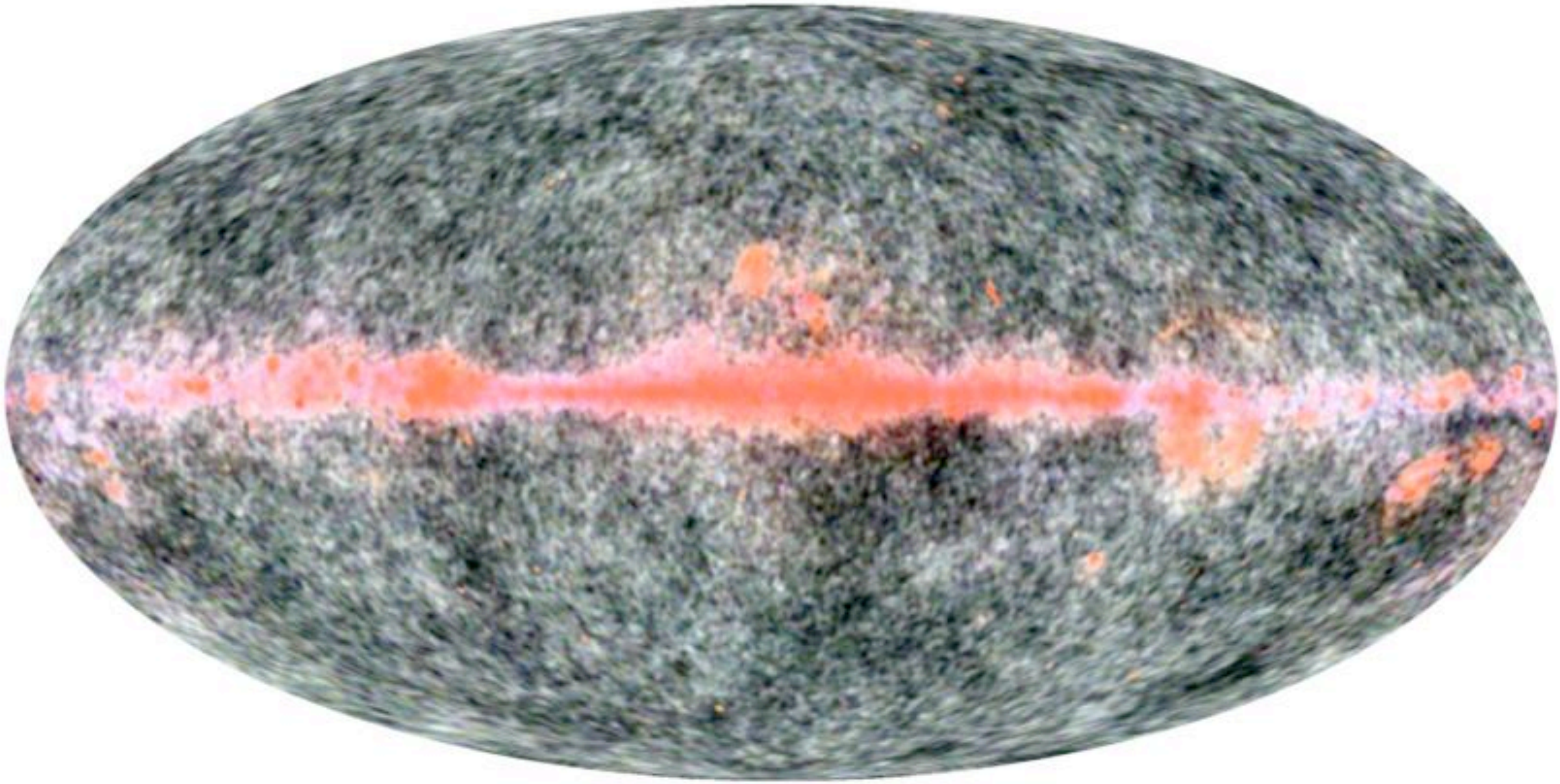
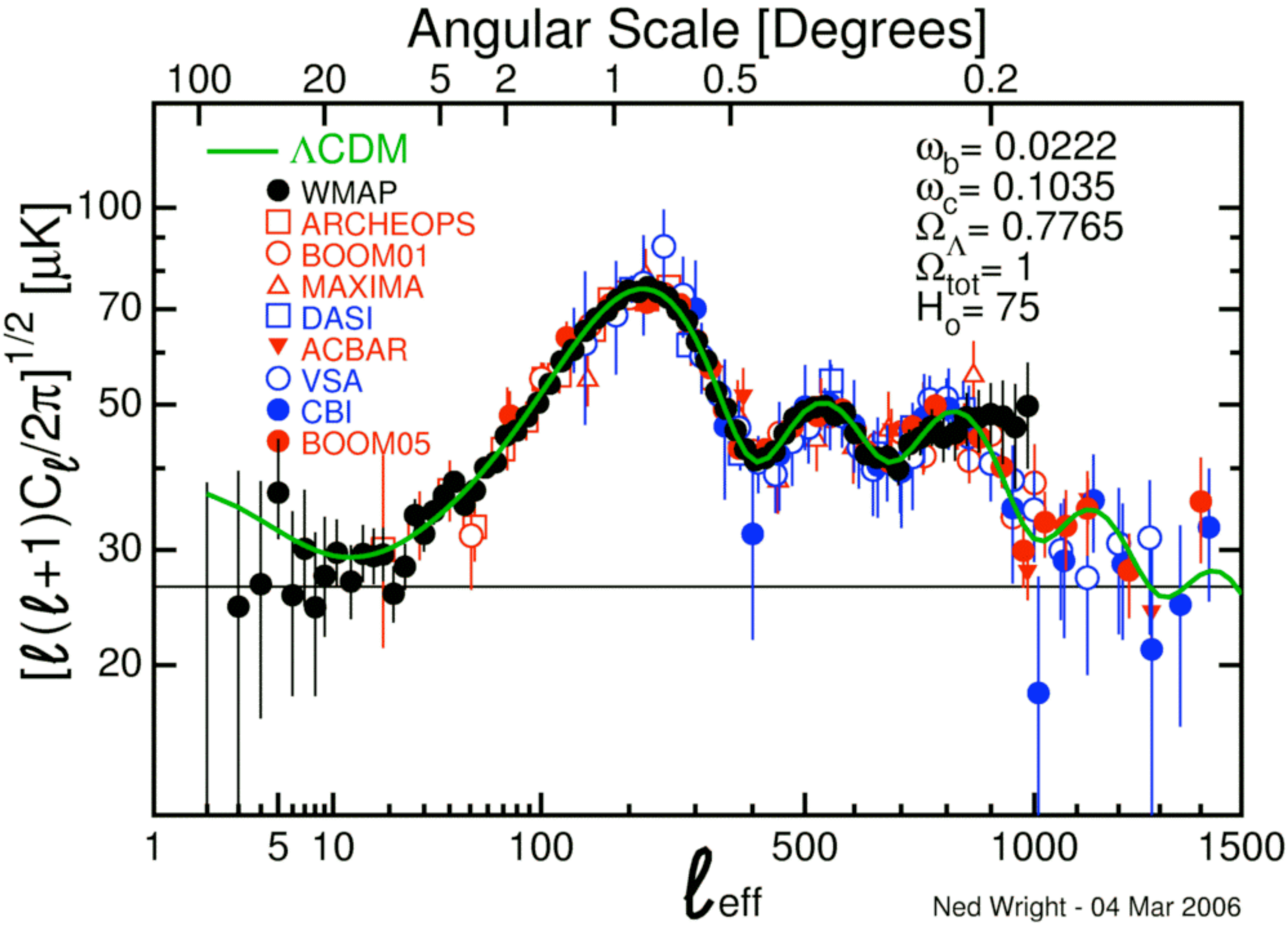
WMAP QVW as RGB



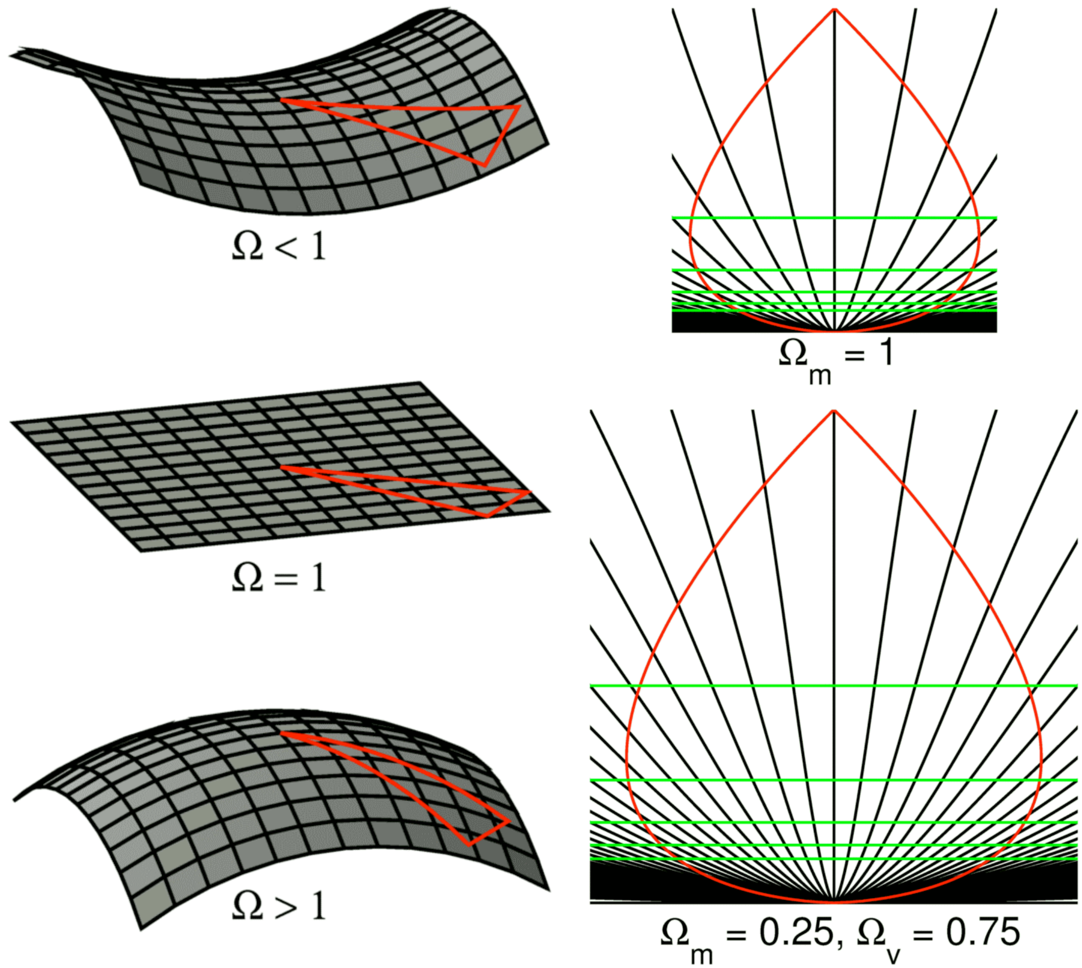
Note the characteristic spot size away from Milky Way: $l_{pk} \approx 180/\theta$

Flat ΛCDM fits all CMB data

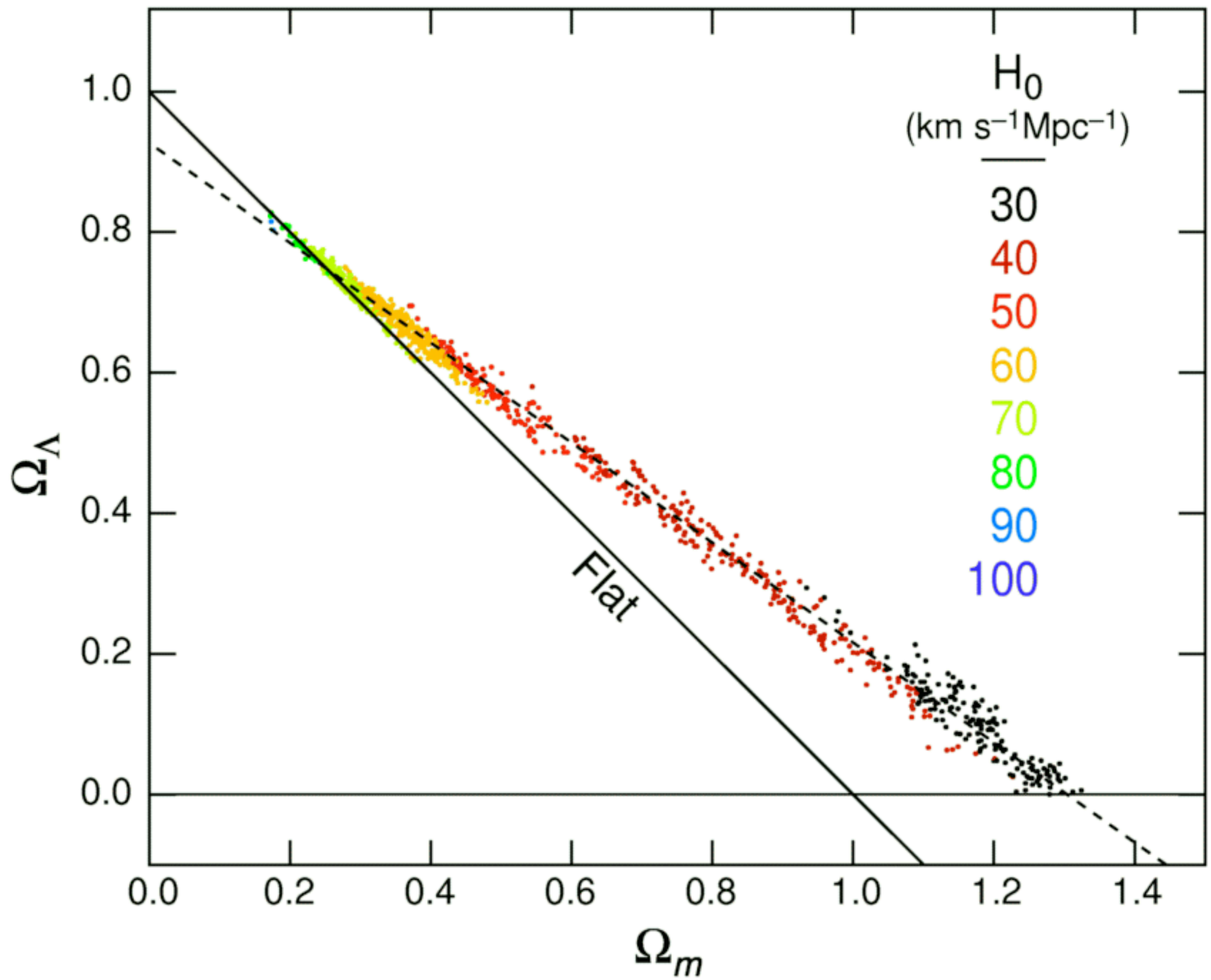


Effects on Peak Position: l_{pk}

- + Open or vacuum dominated Universes give larger distance to last scattering surface
- + High matter density gives smaller wavelength

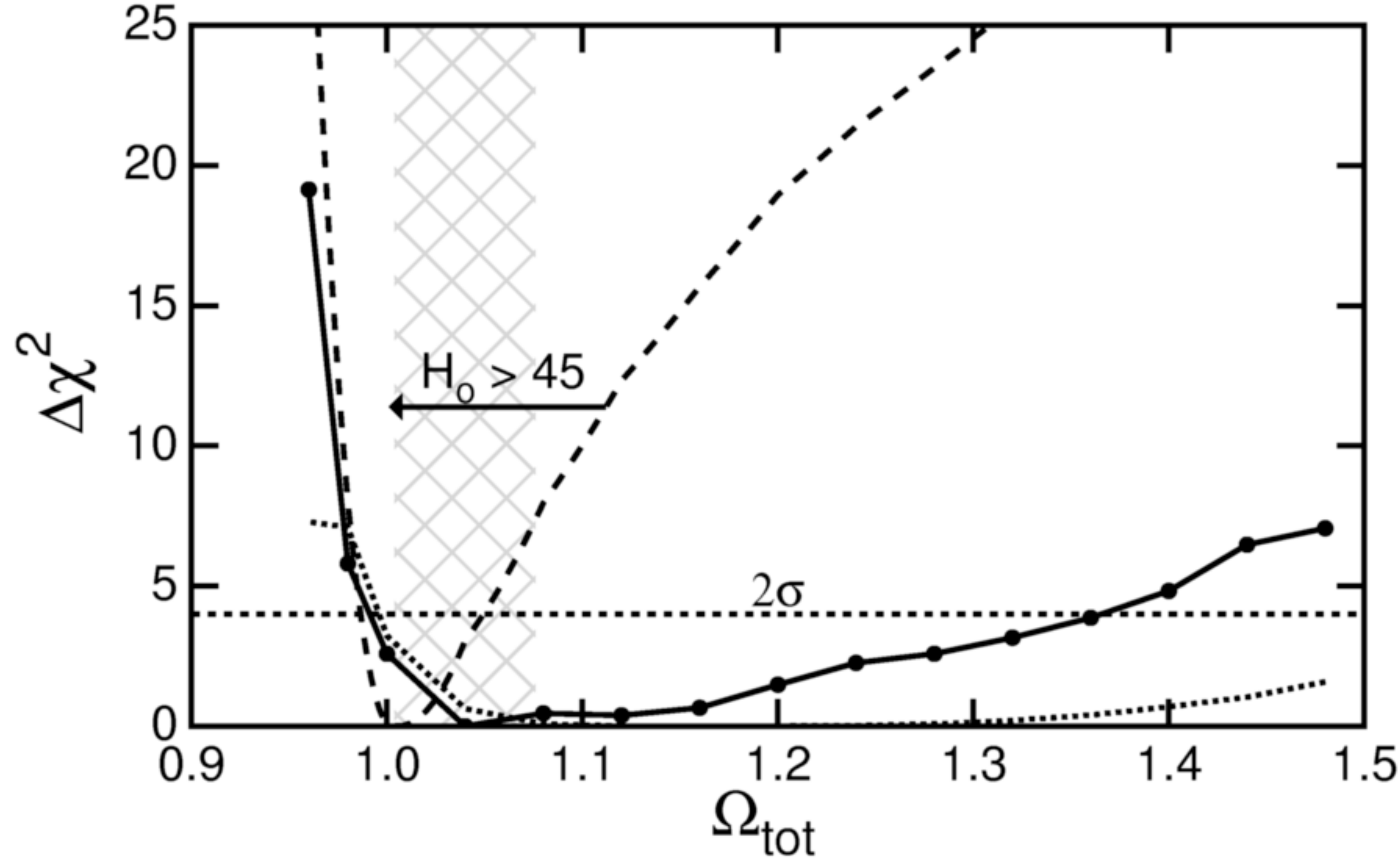


The CMB does not imply flatness

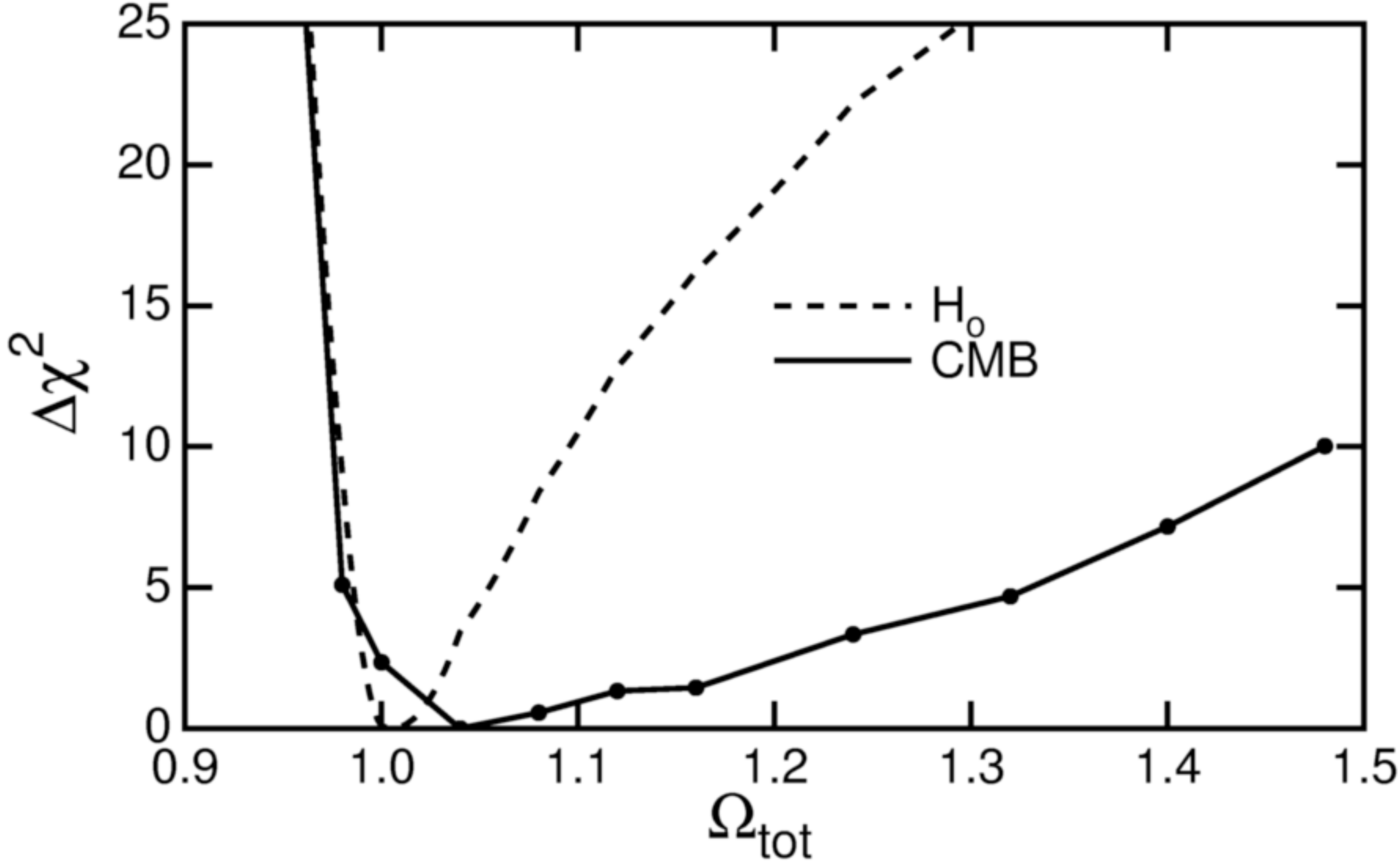


- But CMB + H_o (or other data) do imply flatness.

Minimum χ^2 vs Ω_{tot}: 1year



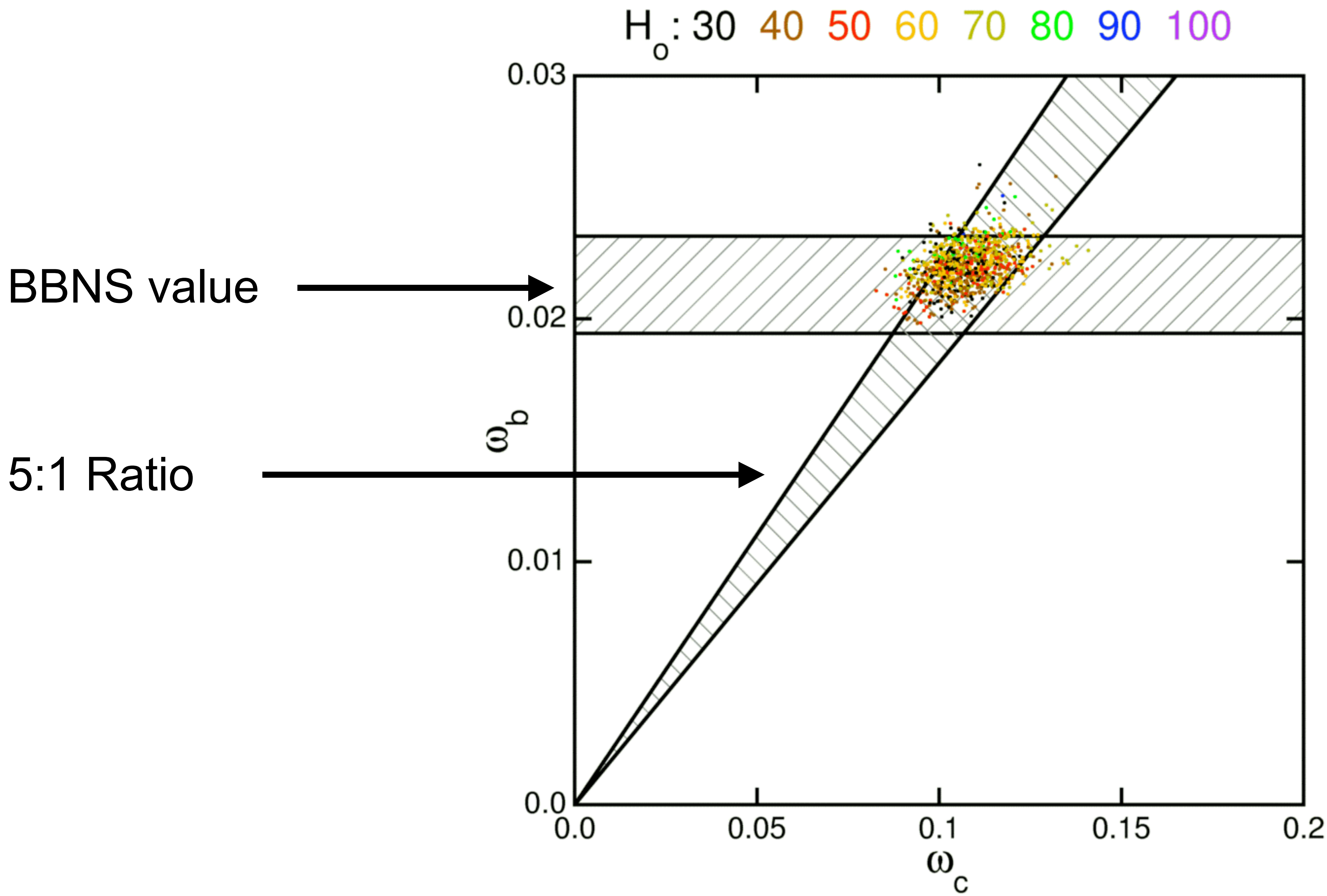
Minimum χ^2 vs Ω_{tot}: 3year



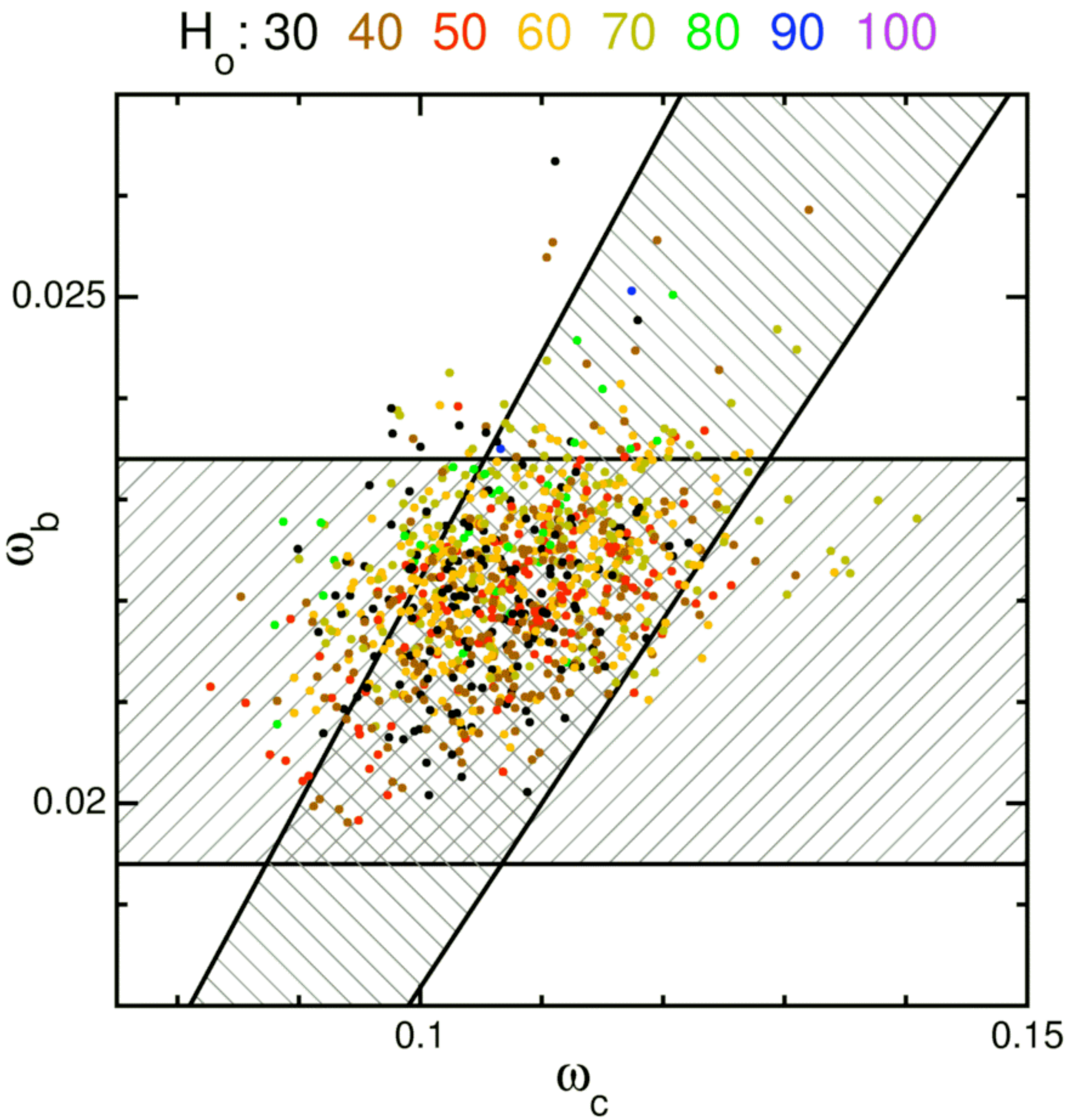
Info from peak & trough heights

- Overall Amplitude of the perturbations
  - Agrees with large scale structure if almost all the dark matter is COLD dark matter
- Primordial power spectrum power law spectral index: $n = 0.951 \pm 0.017$ without running index.
  - EPAS inflationary prediction is $n = 1$
- Baryon/photon and DM/baryon density ratios
  - ρ_b = 0.42 yoctograms/m^3 = 0.42×10^{-30} gm/cc
  - ρ_{cdm} = 1.9 yg/m^3 [$\omega \equiv \Omega h^2 = \rho/\{18.8 \text{ yg/m}^3\}$]

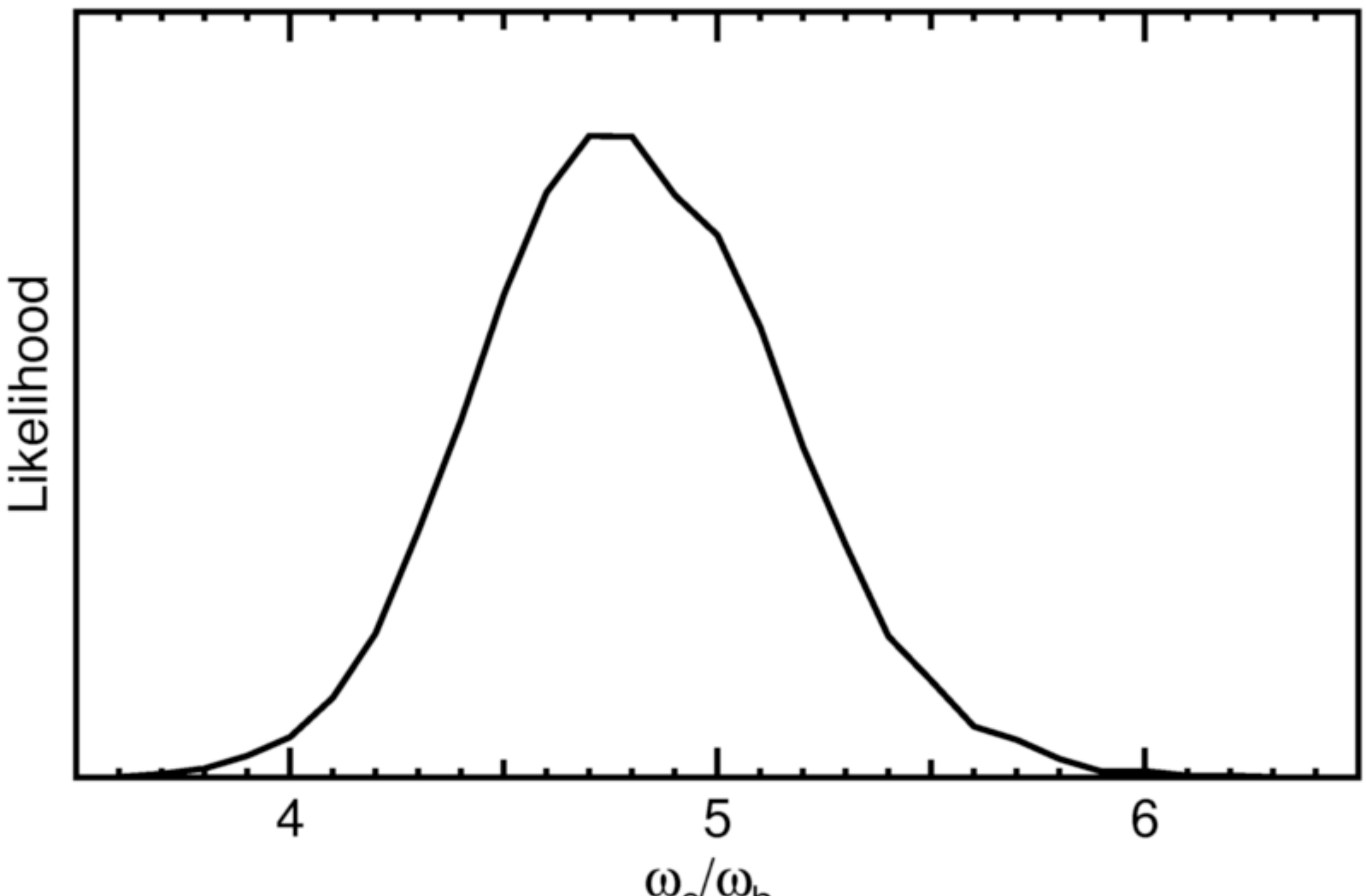
Baryon & CDM densities



Is CDM:baryons an integer?



Maybe



If $w = -1$, then flat ΛCDM is a good fit to all the data. If $\Omega = 1$, then $w = -1$ is a good fit to all the data.

$w(z)$

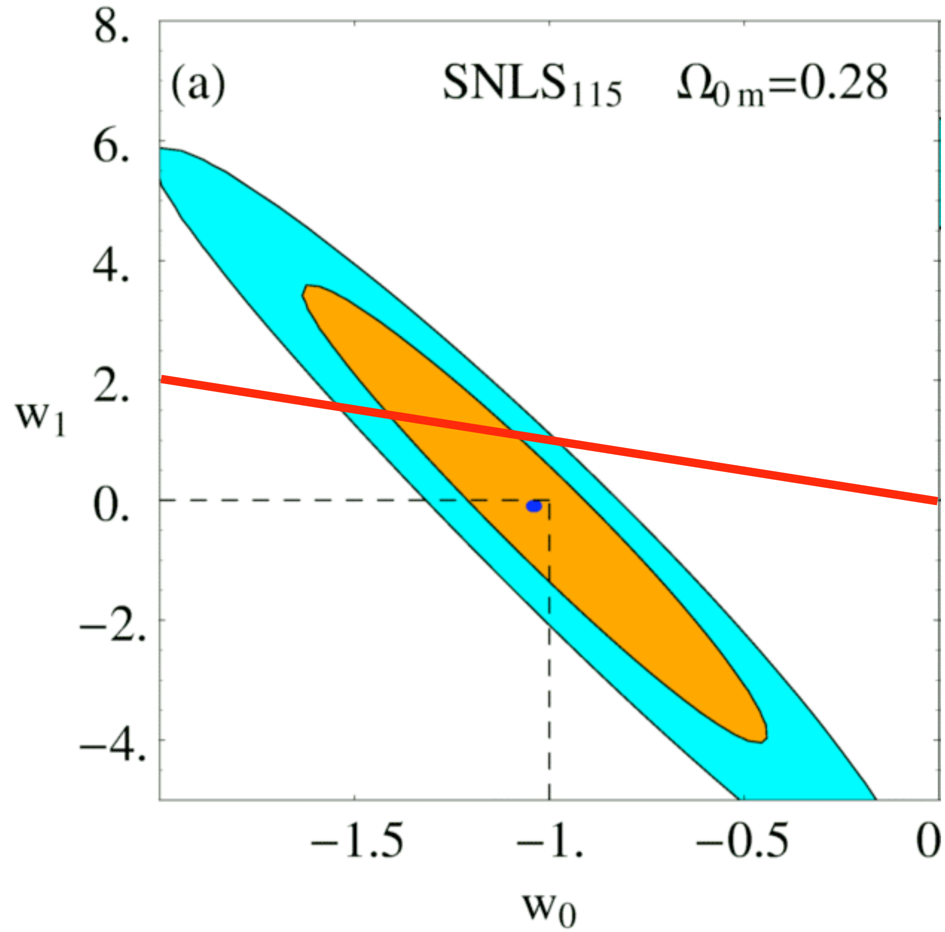
- Dark Energy Constraints in the Universe
- Equation of state: w = pressure to energy density ratio
  - w = 0 for ordinary matter ("dust"), density scales like $(1+z)^3$
  - w = 1/3 for radiation, density scales likes $(1+z)^4$
  - w = -1 for a cosmological constant, density scales like $(1+z)^0$
- Dark Energy Task Force suggested using

$$w(z) = w_0 + w_1 z/(1+z) = w_0 + w_a(1-a)$$

- CAUTION: if $w_0 + w_1 > 0$ then dark energy can dominate at high z. This is BAD

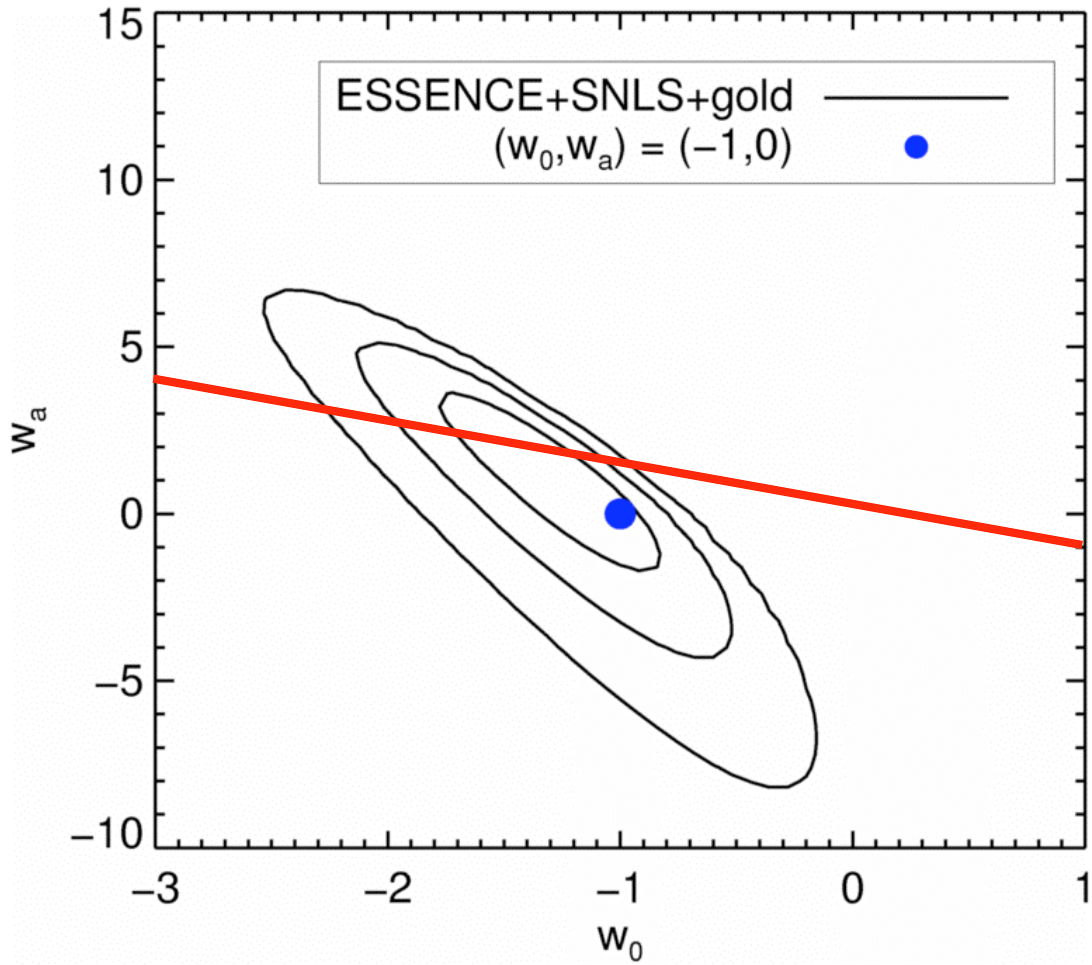
Bad 1

- Nesseris & Perivolaropoulos (astro-ph/0612653)
- Fitting to supernovae and an Ω_m prior



Bad 2

- Wood-Vasey et al. (astro-ph/0701041)
- Fitting supernovae and and an Ω_m prior

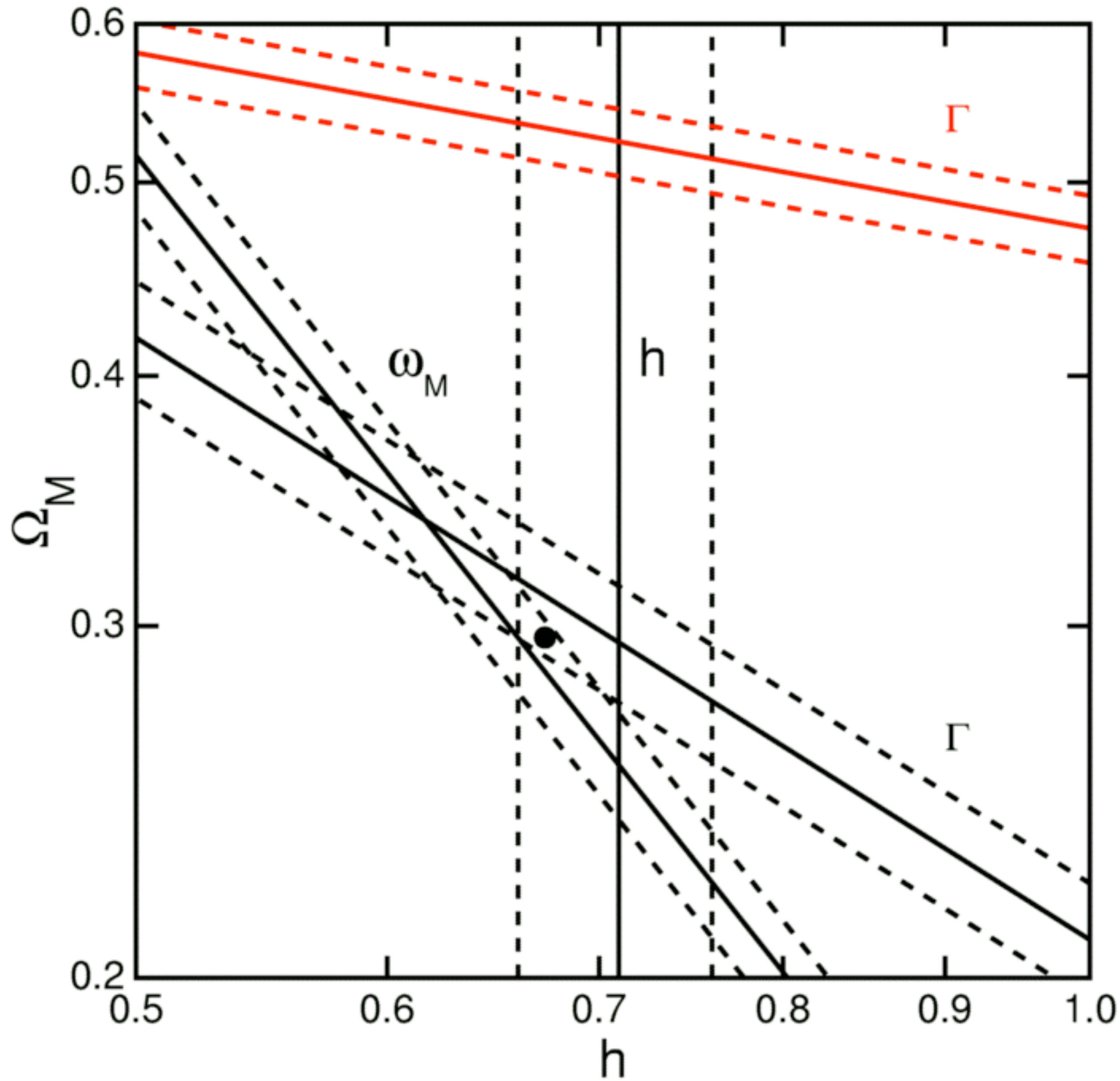


Why is this bad?

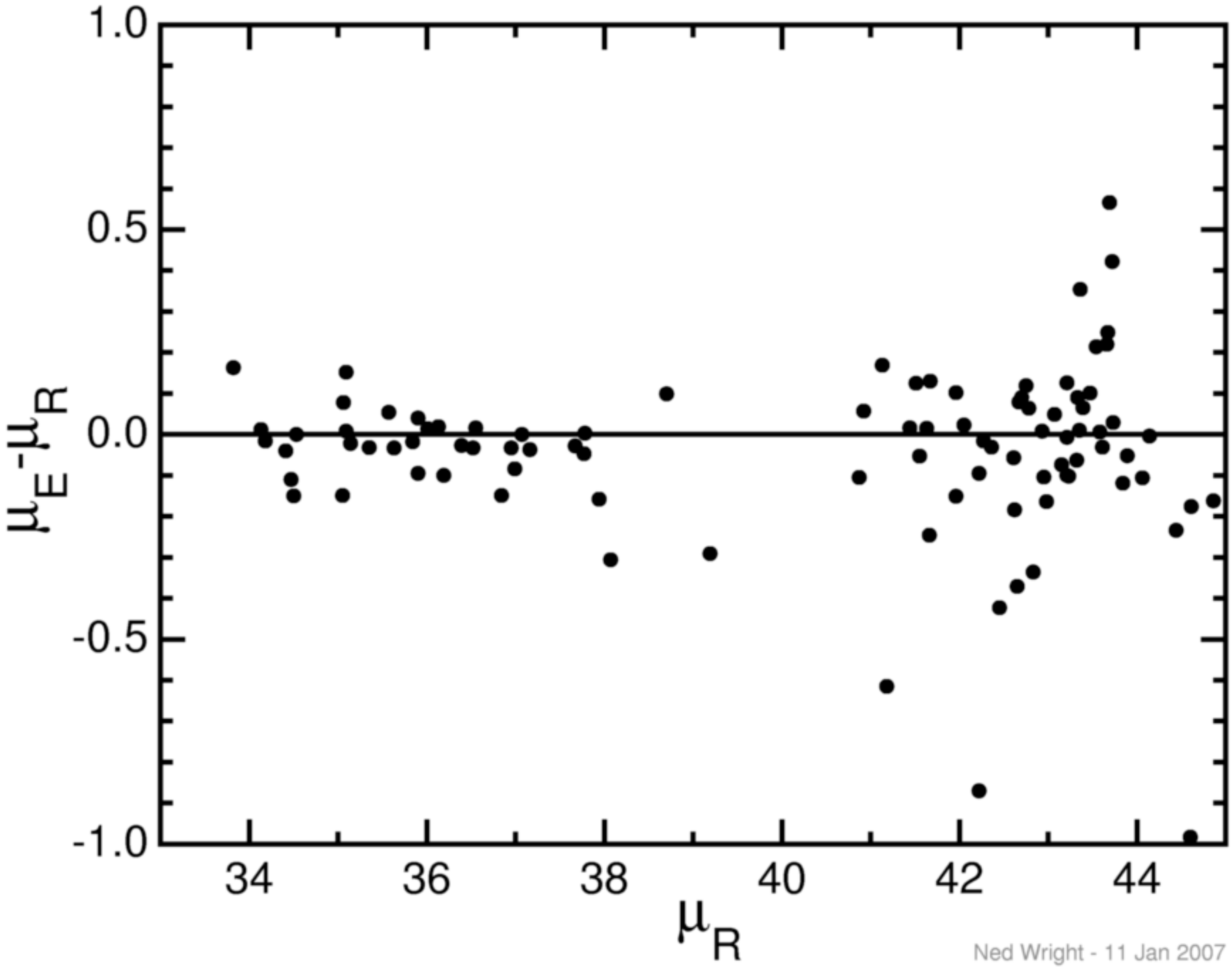
- Supernovae data don't sample the high z behavior of w.
- But the only precise methods for determining an Ω_m prior depend on high z processes:
  - The big bend in the density perturbation power spectrum P(k) gives $\Gamma = \Omega_m h$ but is determined by z_{eq} which is about 3300.
  - The CMB acoustic peak heights give $\Omega_m h^2$ but depend on sound waves at $z > 1089$.
  - The total mass to baryon mass ratio from X-ray clusters of galaxies times the baryon density from Big Bang Nucleosynthesis depends on processes at $z = 10^8$.
- CONCLUSION: Ω_m prior is bogus when fitting w(z). We need to get back to the data.

$\Gamma\omega$h Concordance Goes Away

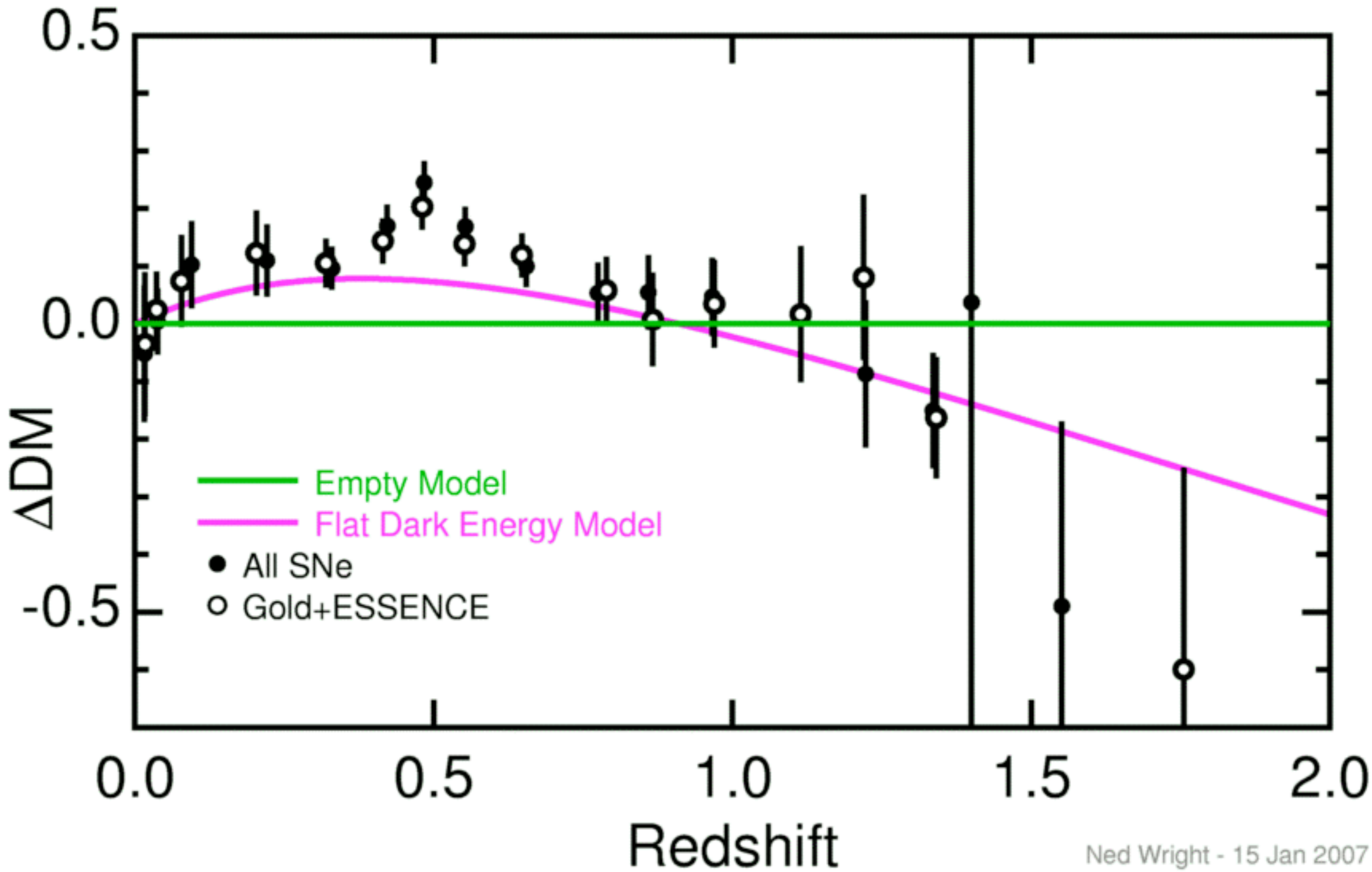
- For $\rho_{DE}/\rho_{M\gamma} = 0$ there is a triple crossing of h, $\omega = \Omega_m h^2$ & $\Gamma = \Omega_m h$
- For $\rho_{DE}/\rho_{M\gamma} = 0.4$ this goes away.



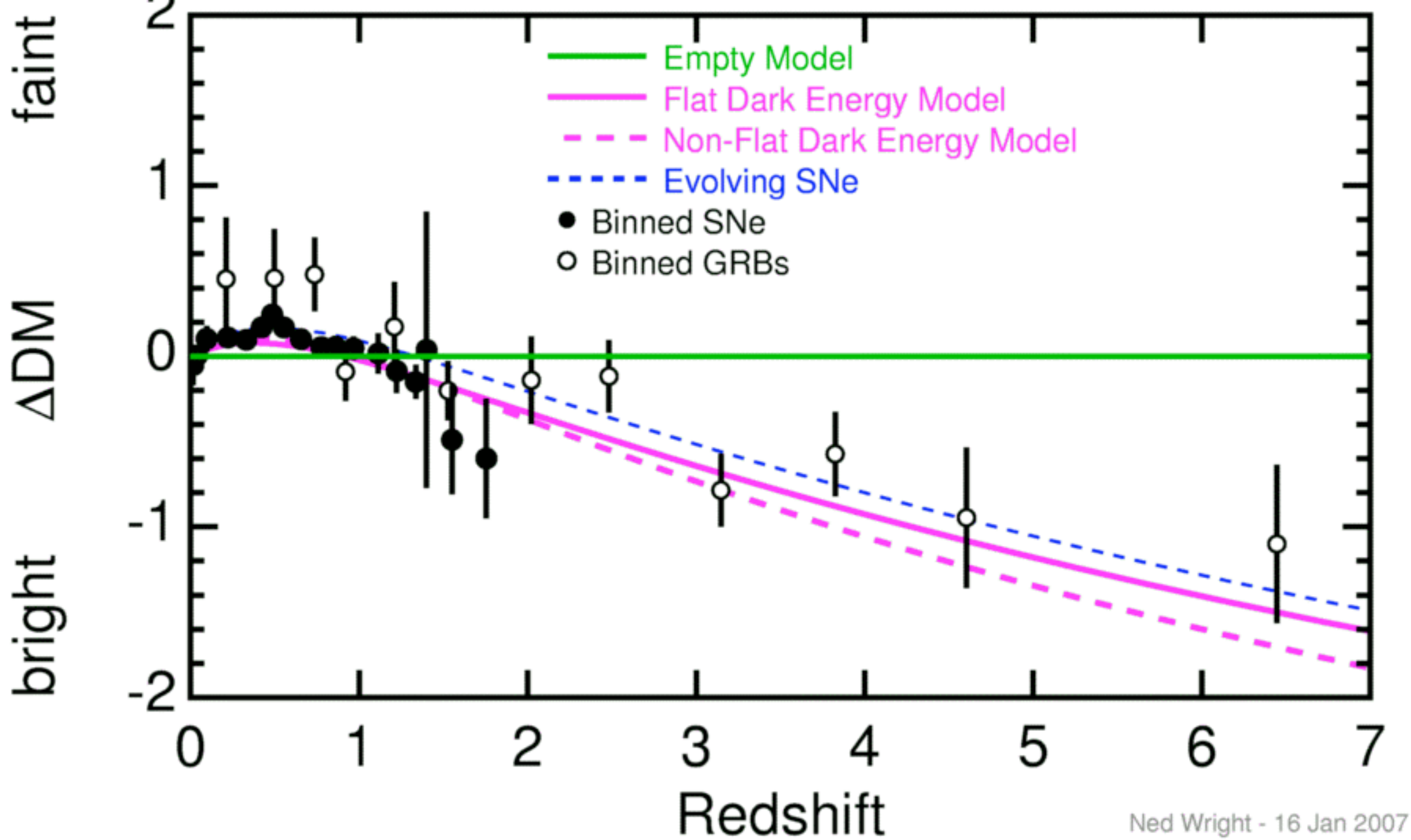
ESSENCE vs Riess: Large Scatter



Fit to 358 Supernovae: $\Omega_m = 0.37$

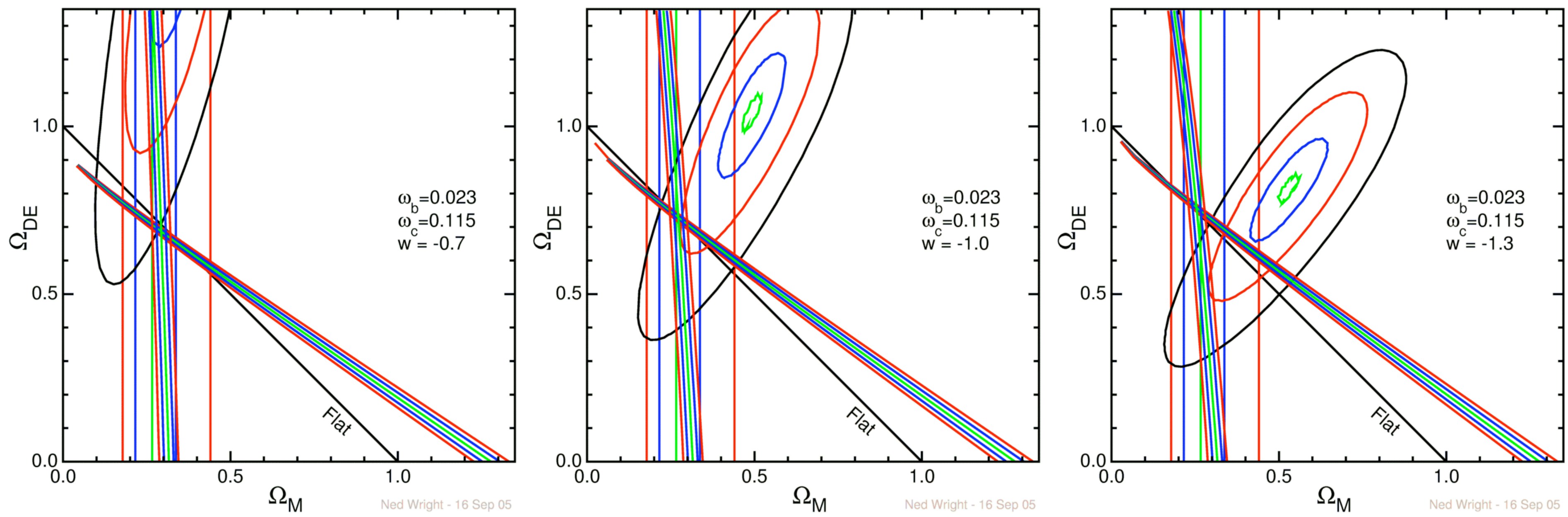


Fit to 358 SNe & GRBs:



- $\Omega_m = 0.42$, $\Omega_k = -0.12$

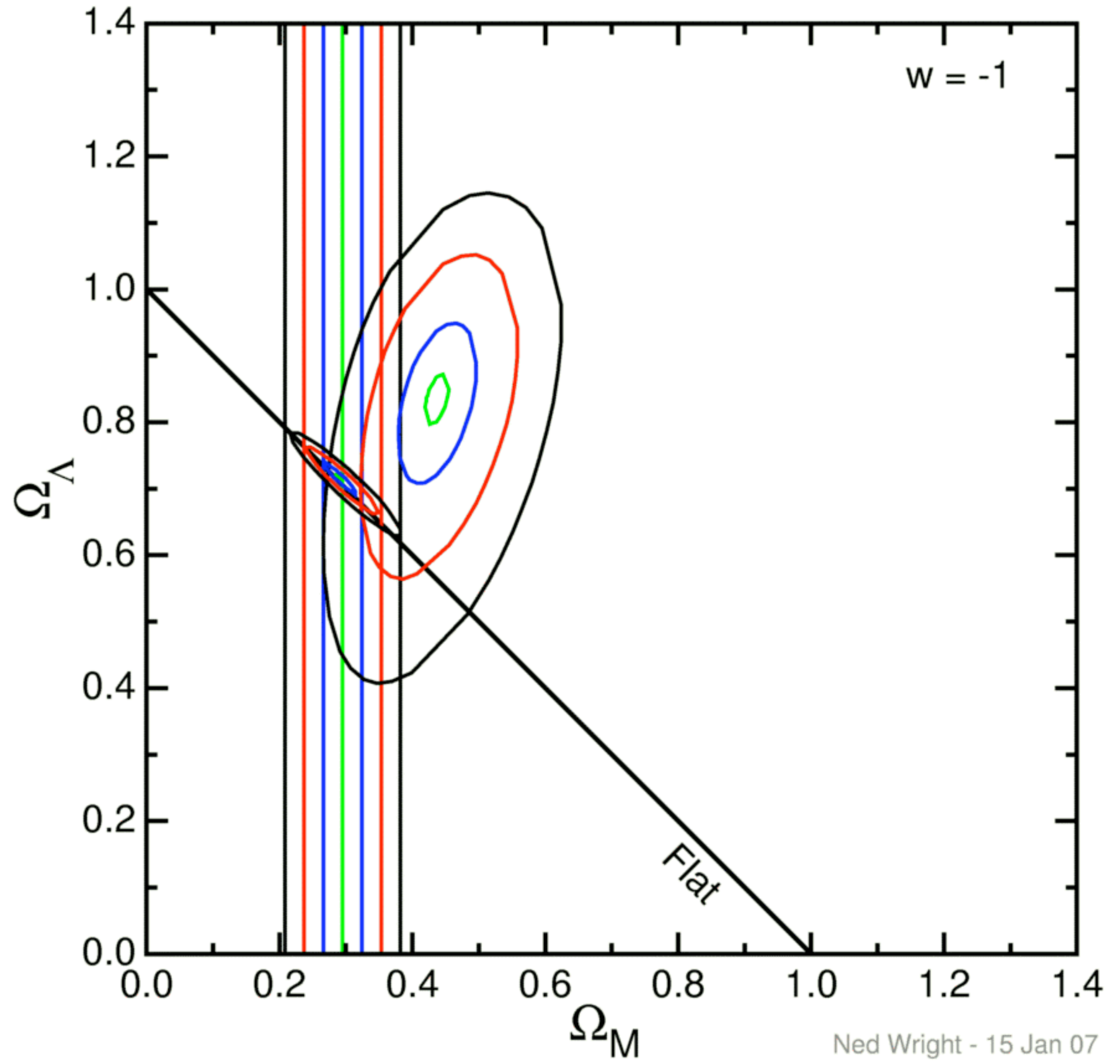
Can we say anything about w?



- Pretty good mutual agreement of 4 datasets (CMB, SNe, H_o & Baryon oscillations) for w = -1 and Ω_{tot} =1.
- This agreement is slowly lost as w moves away from -1.

Force w = -1

- CMB and BAO gives the best result
- Supernovae and GRB are not as constraining, even with 358 SNe
- The Ω_m prior does work if one assumes a constant w.



CMB Peak Position Measures

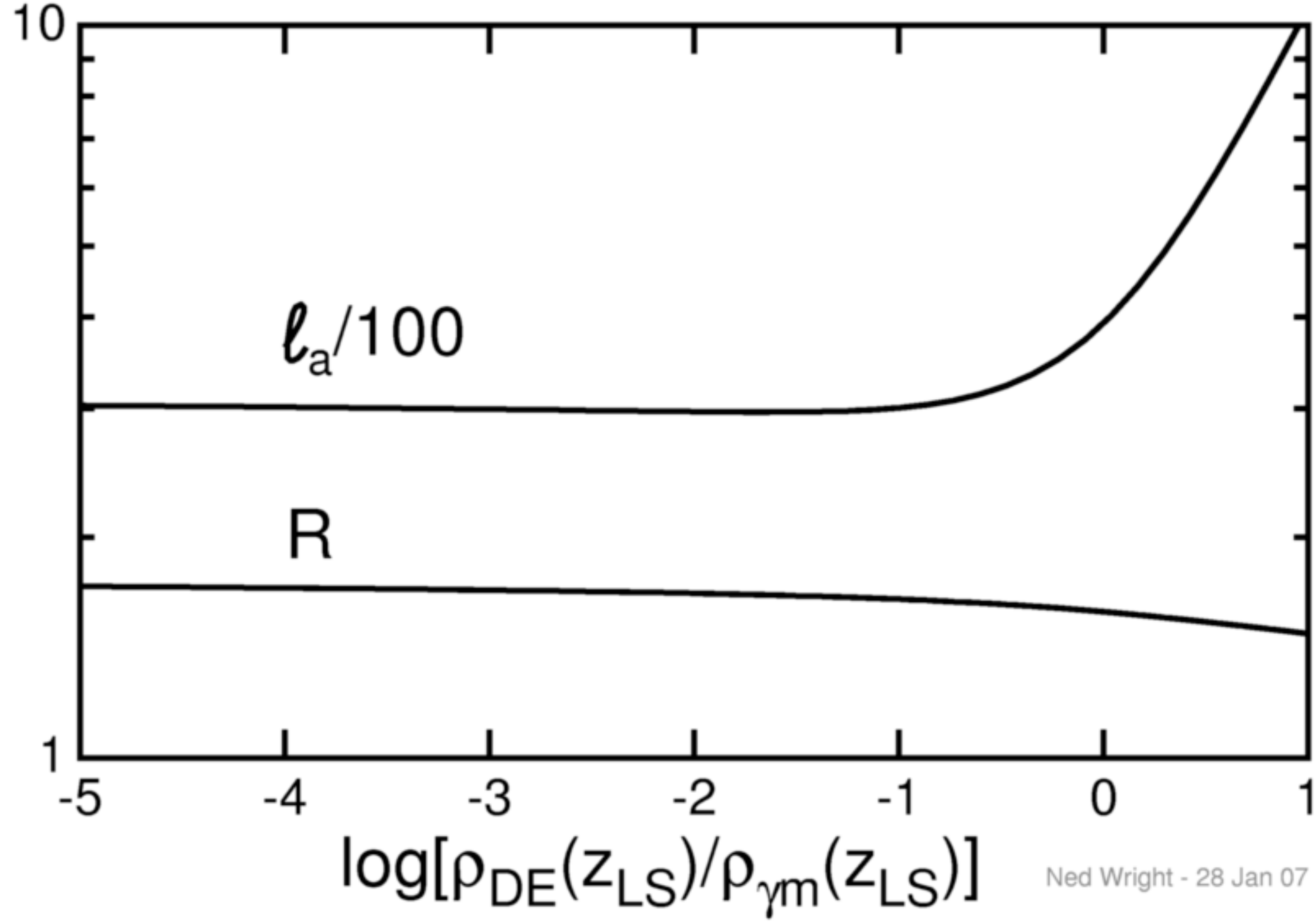
- The acoustic scale

$$\ell_a = \frac{\pi(1+z_{LS})D_A(z_{LS})}{\int_0^{1/(1+z_{LS})} c_s da/(a\dot{a})}$$

- Assuming the denominator goes likes $(\Omega_m h^2)^{-1/2}$ gives the shift parameter R:

$$R = \Omega_M^{1/2} H_\circ (1+z_{LS}) D_A(z_{LS})/c$$

Behavior when ρ_{DE} gets big



- Shift parameter varies less and in the wrong direction because it uses an approximation for the sound travel horizon

Expansion Rate Constraints

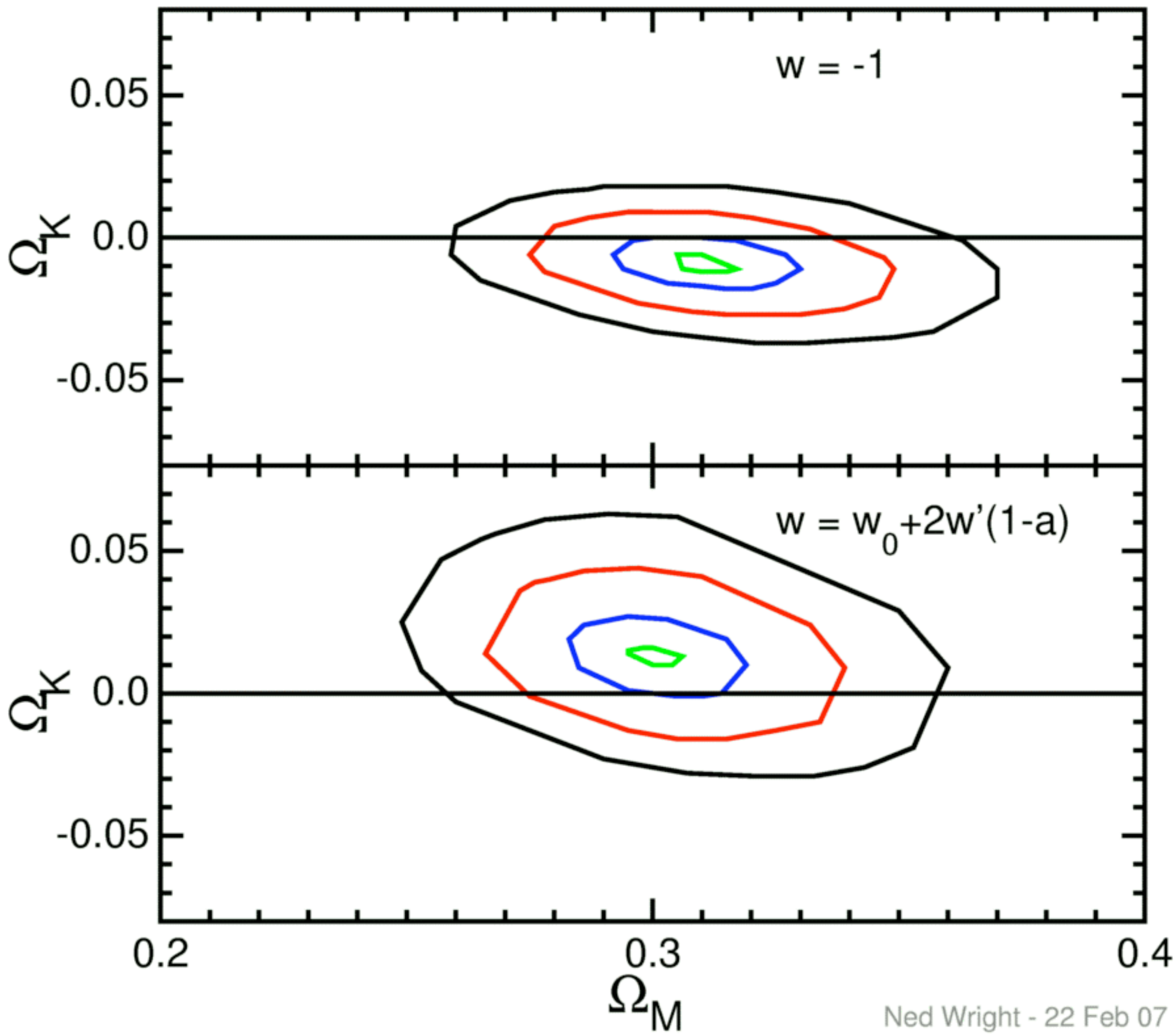
- BBNS: more dark energy means faster expansion and more ^{4}He (Steigman 2006):

$$S^{BBNS} = (1 + \rho_{DE}/\rho_{\gamma+m+k})^{1/2} = 0.942 \pm 0.030$$

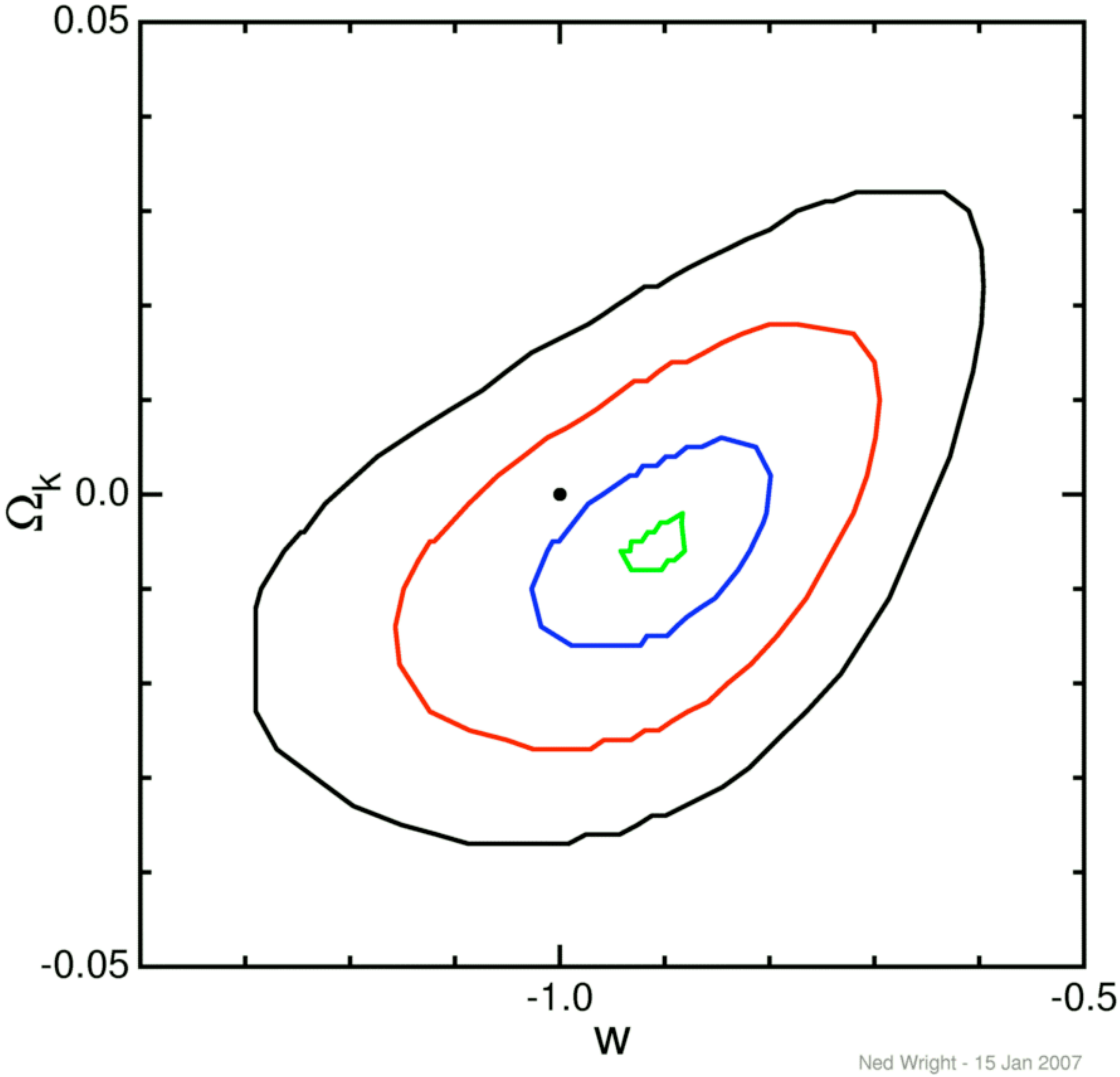
- Surface of last scattering: more dark energy means a faster transition and less Silk damping (Zahn & Zaldarriaga 2003):

$$S^{LS} = (1 + \rho_{DE}/\rho_{\gamma+m+k})^{1/2} = 1.04 \pm 0.24$$

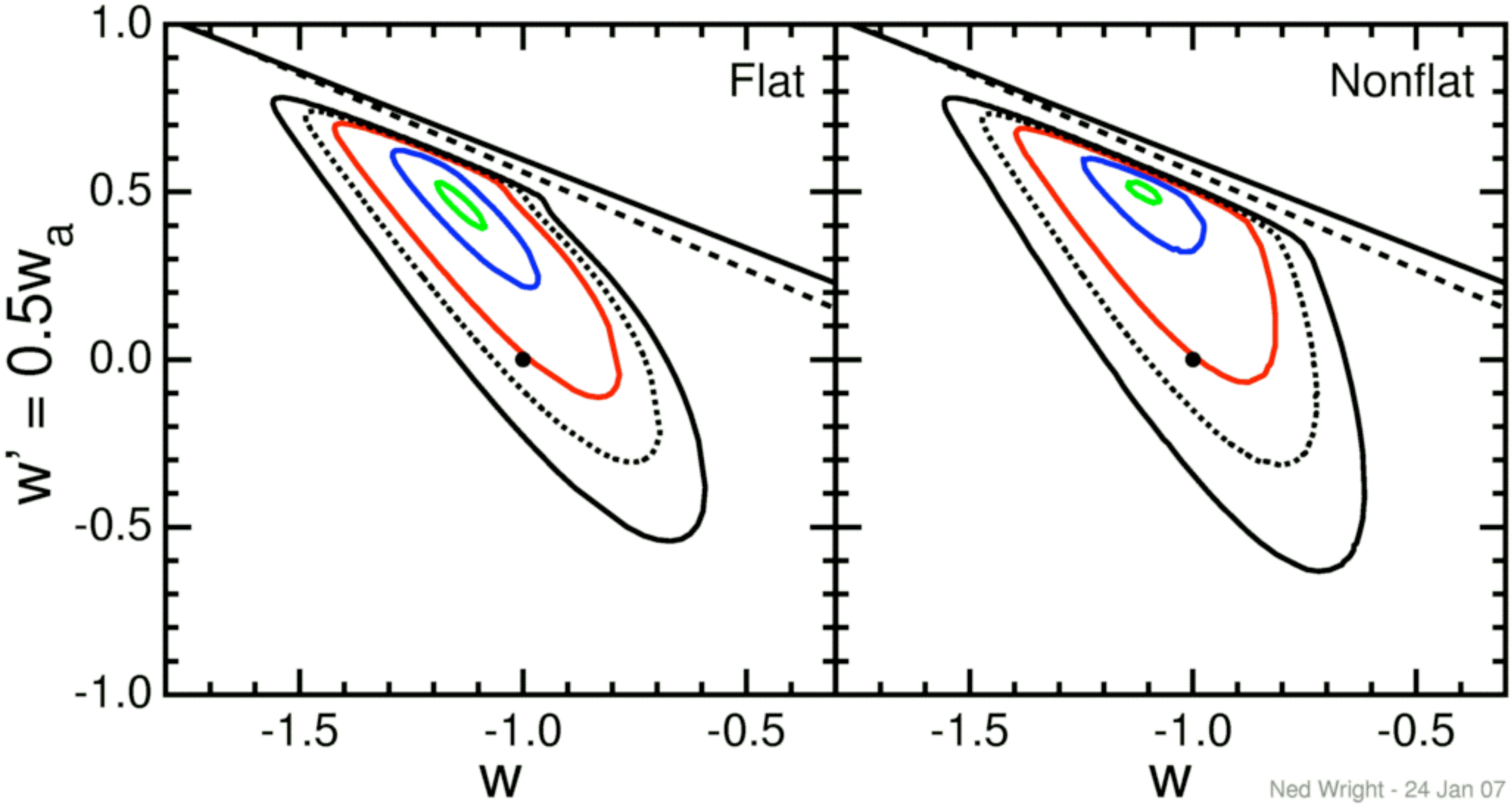
Fitting for Ω's



Fitting for constant w



Fitting for variable w



- Diagonal lines show the last scattering and BBNS constraints

Conclusion

- The current data cannot constrain even the simplest (DETF) variable w model – even the 1σ contours bump into the last scattering constraints
- Therefore the simple Ω_m prior is WRONG!
- Even with 358 SNe, the SN data is much less powerful than the BAO and CMB data. 2000 SNe from SNAP won't revolutionize the field.