# Possible Variation in the Cosmological Baryon Fraction

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# Is the cosmological fraction of matter that is in the form of baryons a universal constant?

- $\delta\rho/\rho \sim 10^{-5}$, but this is total $\rho$: baryonic + non-baryonic

- we investigate 3 effects of variation of the baryon fraction

  1. constraints from light-element abundances

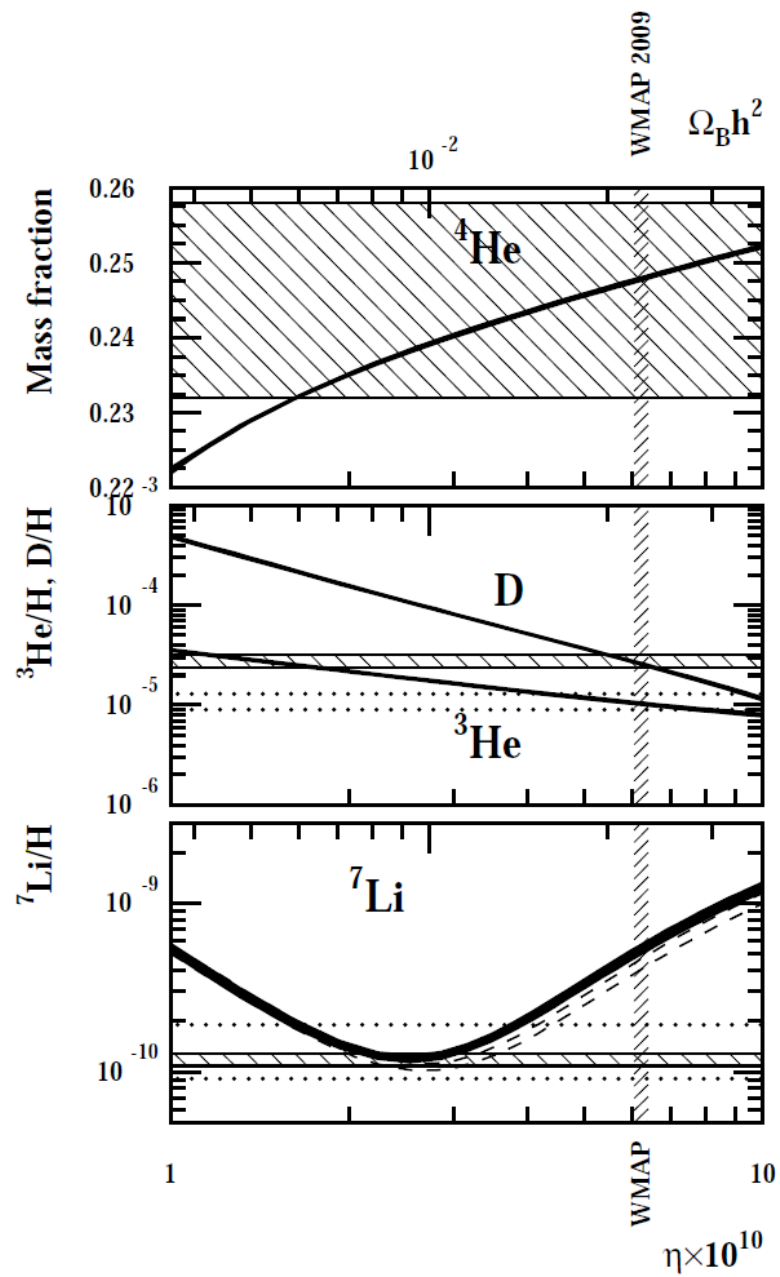
  2. constraints from galaxy cluster gas fractions

  3. CMB differential Thomson scattering + predictions for polarization

- A compensated baryon-cdm isocurvature mode would have negligible effect on CMB power

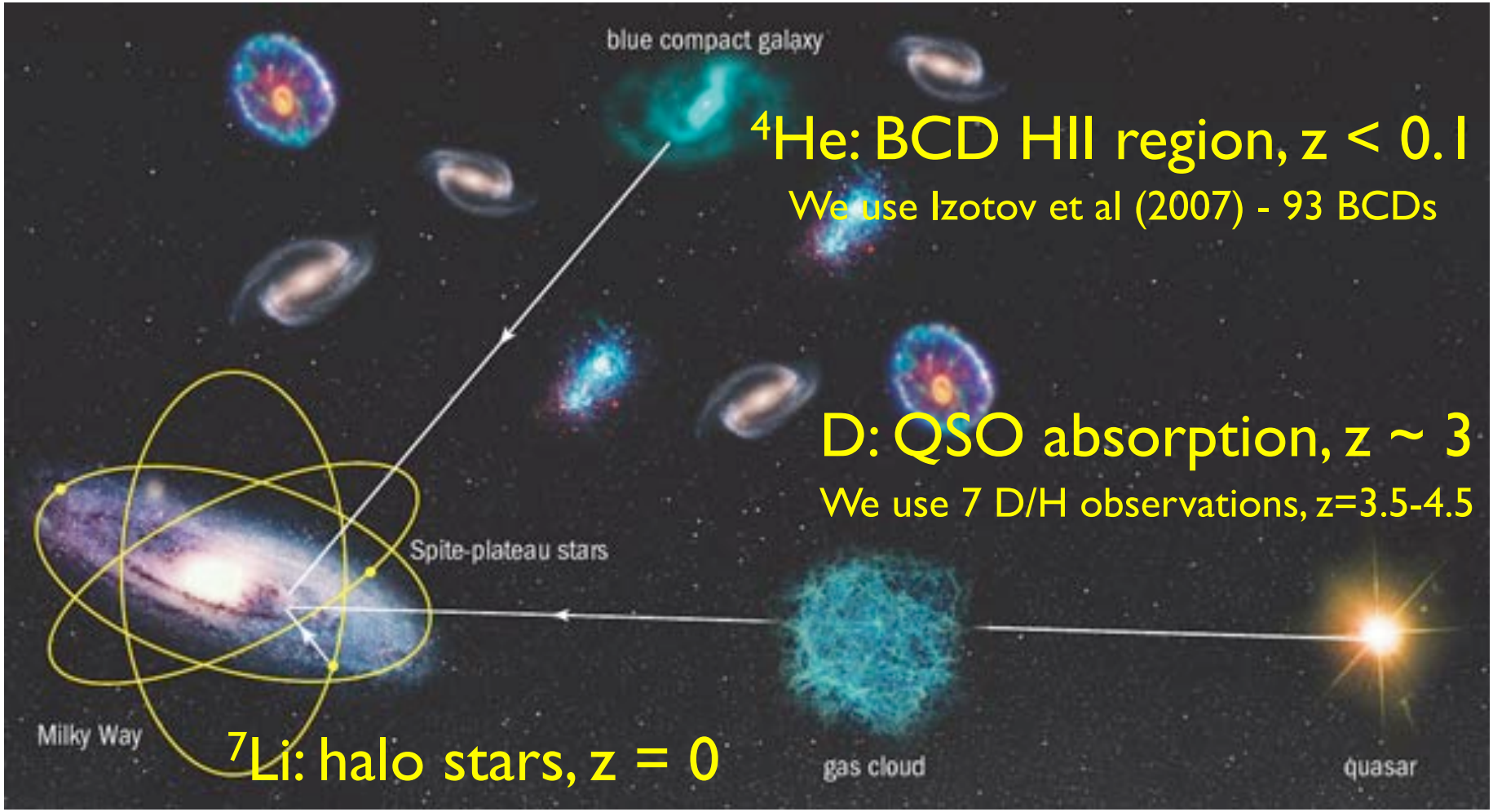
# BBN

- light-nuclide yields from BBN are functions only of $\Omega_B h^2$ under standard assumptions of BBN (uniform entropy per baryon, only SM particles, neutrino-antineutrino asymmetries not much larger than the corresponding baryon asymmetry, no late additions of entropy)
- Predicted D/H steep with baryon density; $\Omega_B h^2 = 0.0213 \pm 0.0010$ (Pettini et al 2008)
  - cf. WMAP: $0.02258 \pm 0.00057$
- studies of inhomogeneous BBN have a long history (e.g. trying to avoid DM)
  - but these generally considered baryon inhomogeneities within BBN length scales, ~0.1 pc (neutrino streaming scale; neutron diffusion scale; Jeans scale),
  - ..or considered locally homogeneous BBN, which mixed later



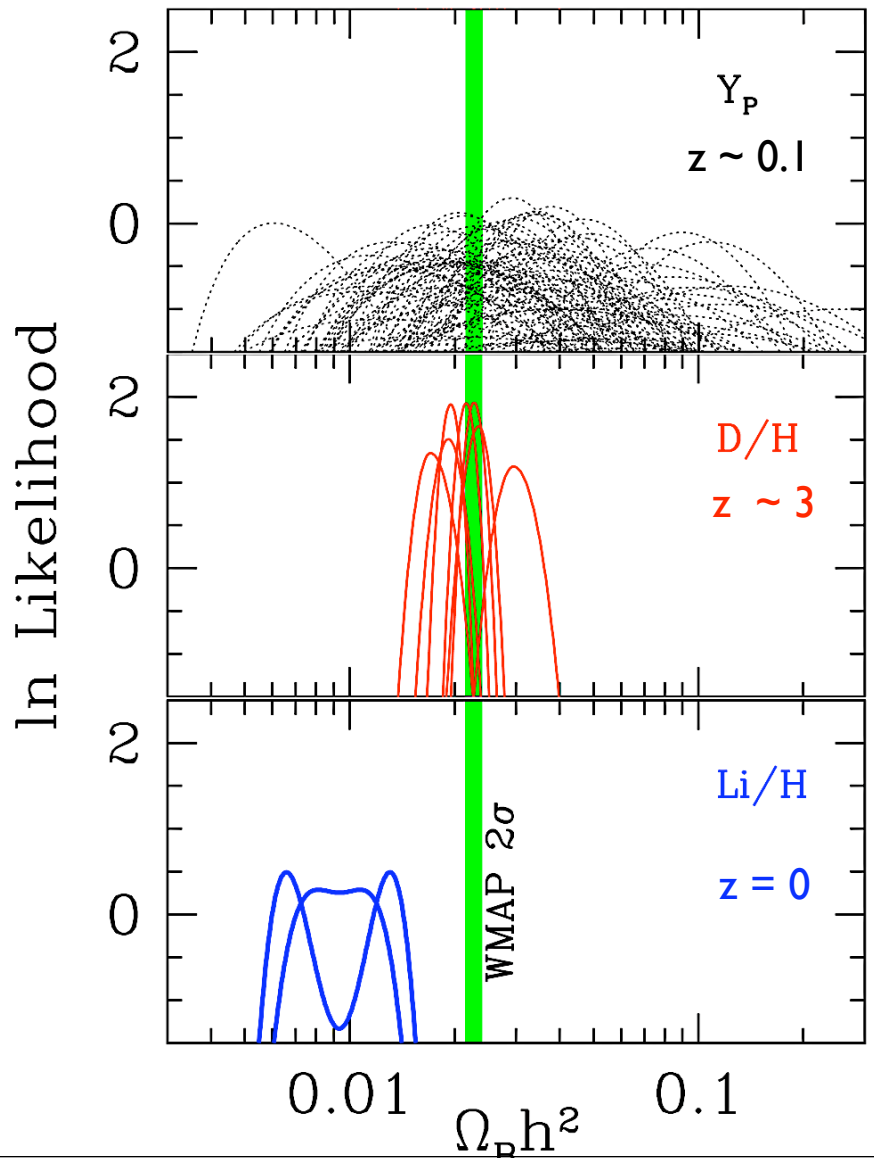

Coc & Vangioni 2010

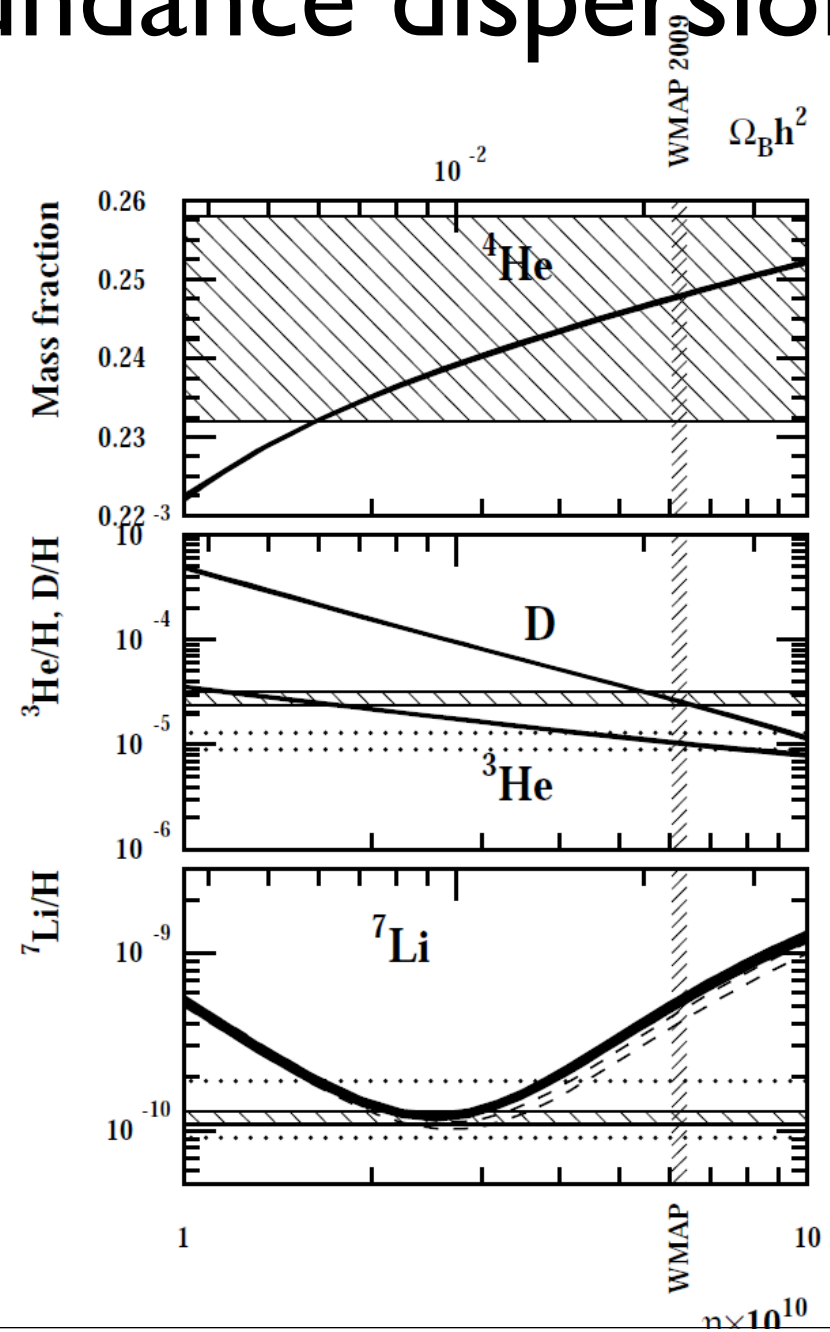
# Measuring abundances




Nollett 2007

# Light-element abundance dispersion

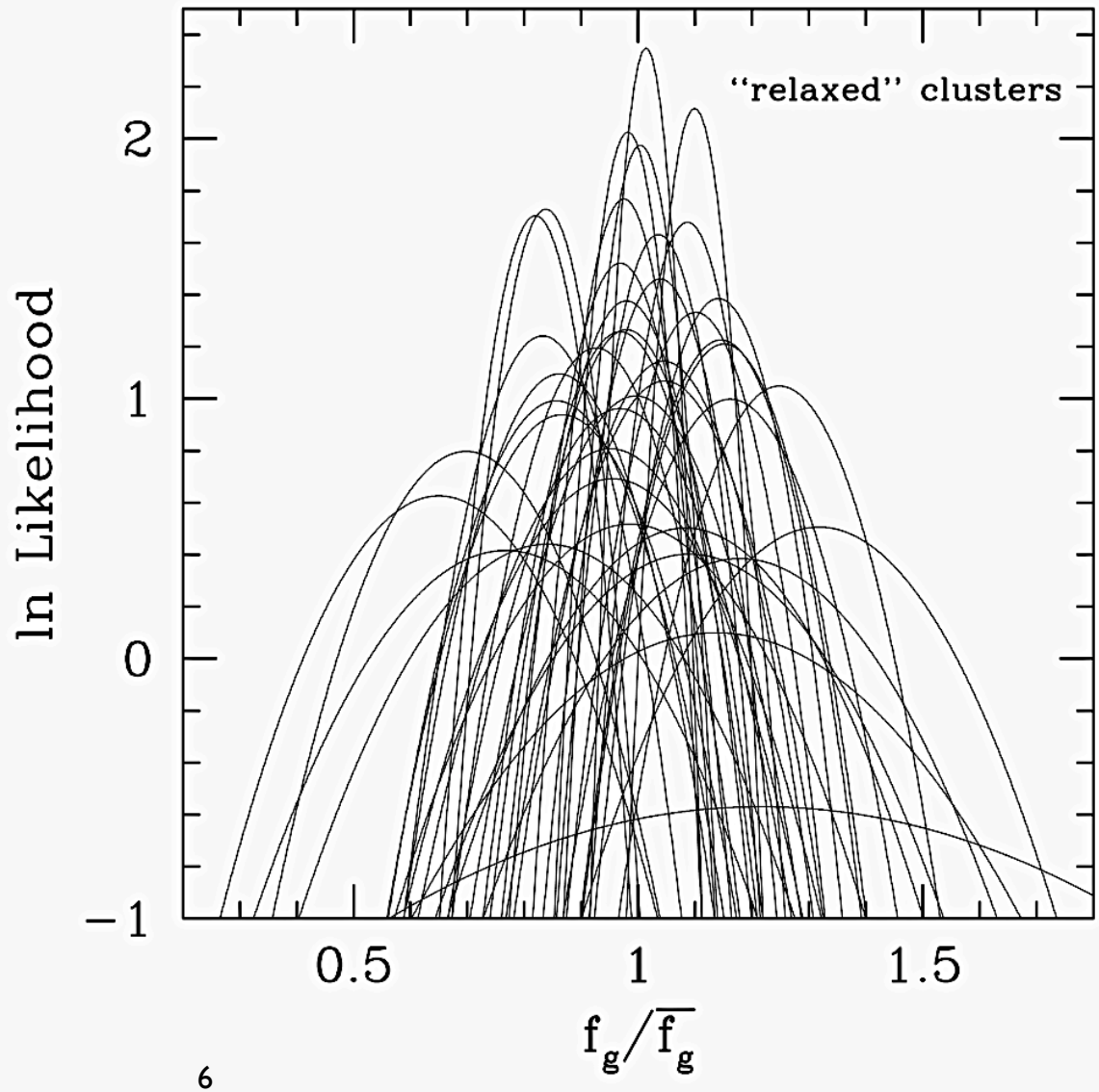



Coc & Vangioni 2010

# Cluster dispersion

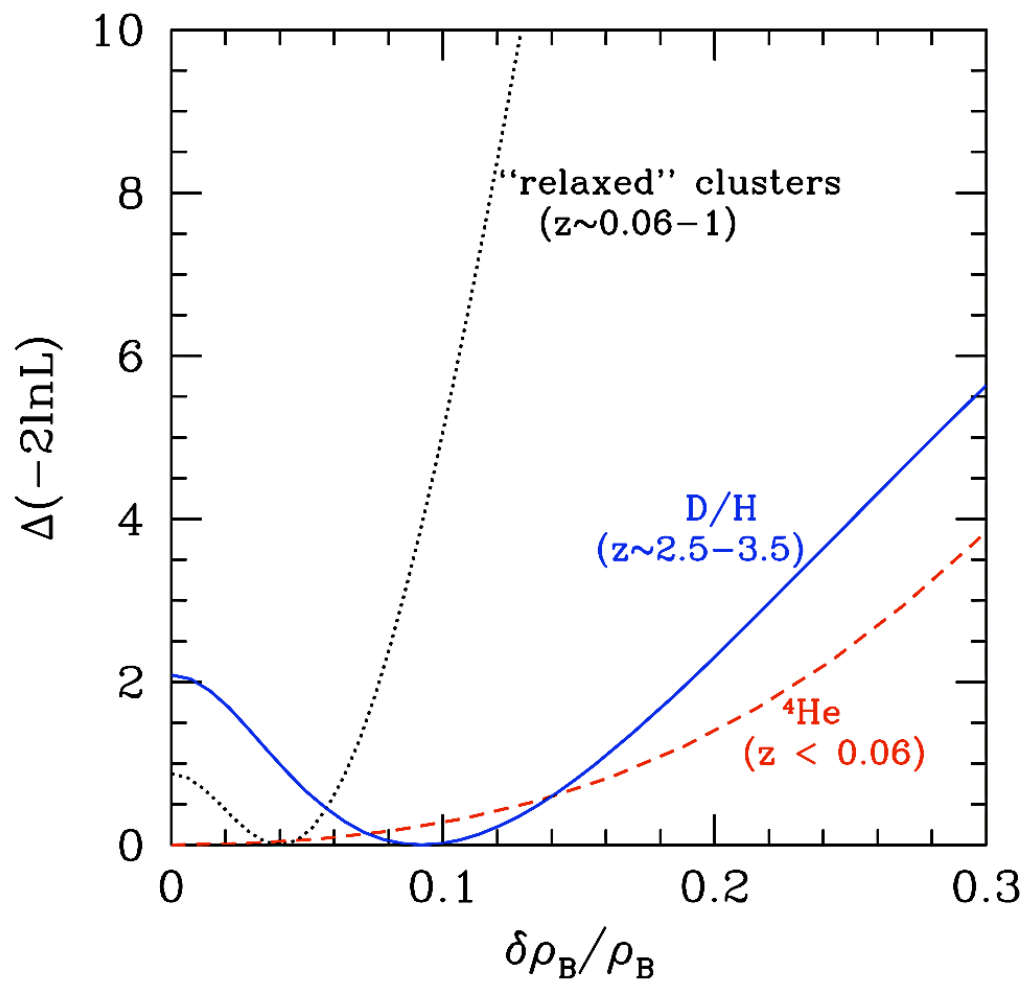
- Allen et al. (2008) X-ray survey: 42 relaxed galaxy clusters, z ~ 0.06-1
- $f_{gas}$ is systematically below the WMAP mean
  - star formation, feedback from BH accretion
- but little evidence for cluster-to-cluster scatter



# Likelihoods & upper limits

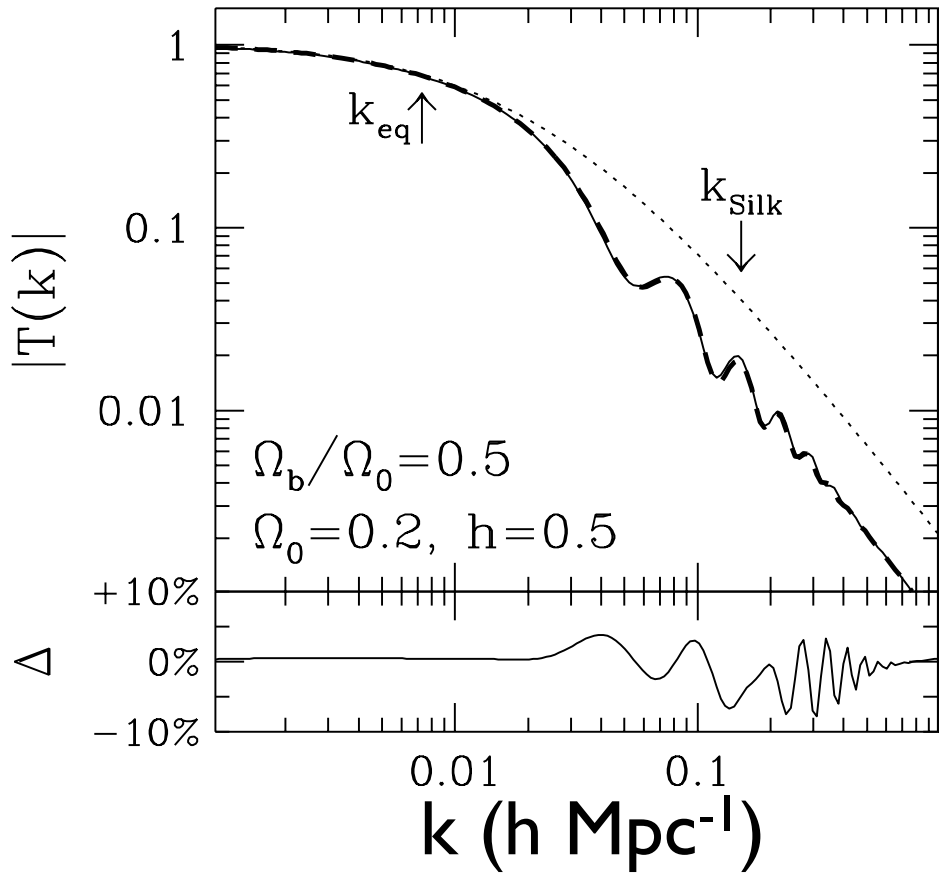
- Plot shows likelihood vs. baryon fluctuation for different datasets
  - assume overall scatter in observed quantity that adds to measurement error & map this into $\delta\rho_B/\rho_B$
  - upper limits (95% CL):

    $\delta\rho_B/\rho_B < 0.08$ ($f_{gas}$)
    $\delta\rho_B/\rho_B < 0.26$ (D/H)
    $\delta\rho_B/\rho_B < 0.27$ ($^4$He)



# Cluster selection effect?

- Clusters are selected for being relaxed - undisturbed & relatively circular
  - Baryons lead to suppression on small scales
  - Conversely, lower baryon density ⇒ higher CDM fluctuations
  - Selecting clusters for being relaxed could therefore preferentially favor regions of lower baryon fraction, since clusters form earlier there



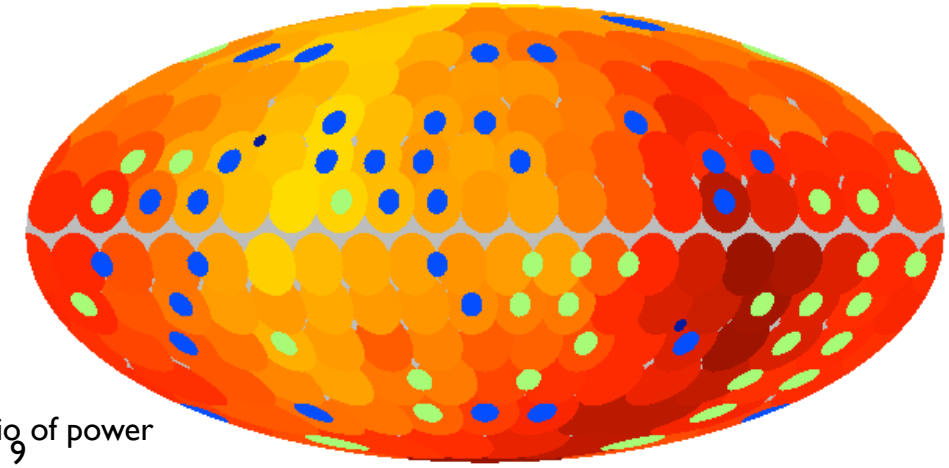

Eisenstein & Hu 1998

# CMB: Differential Thomson scattering

- Large-scale asymmetry of CMB power would arise from varying baryon fraction in the reionized region

- Observed dipole asymmetry is 0.072 ± 0.022 (68% CL) (Hoftuft et al. 2009); given best-fit $\tau = 0.088 \pm 0.015$ (Komatsu et al 2009), need baryon fluctuations on cosmological scales of 0.8 ± 0.3

  - such large fluctuations not observed in light-element abundances or clusters, but smaller ones could be consistent with both the asymmetry and the light-element constraints



Eriksen et al 2004; color indicates N/S ratio of power

# Effect on B-mode CMB polarization

B-mode power induced through two effects:

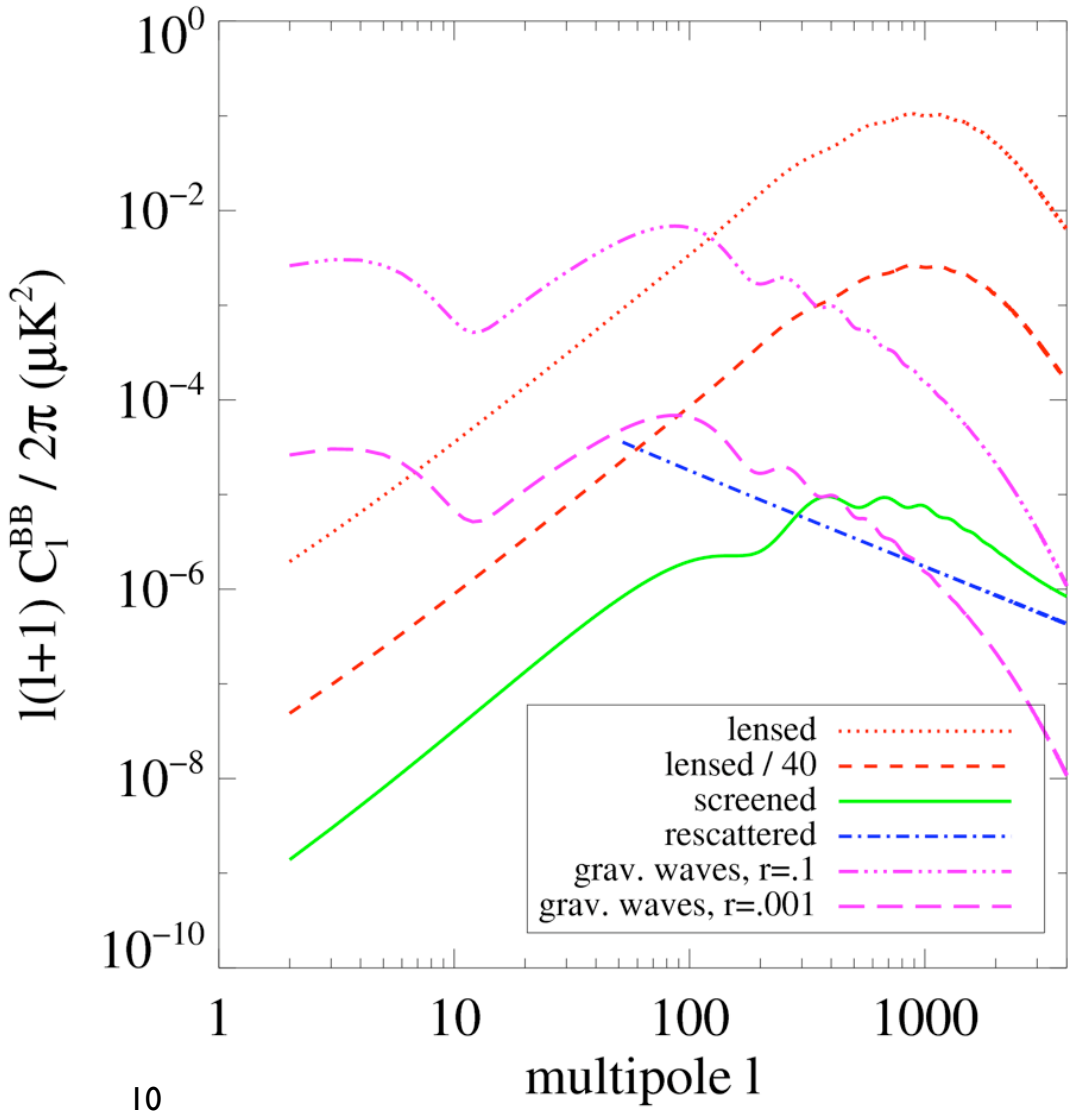
1. rescattering from incident quadrupole (Hu 2000)

- assuming power-law $\tau$ fluctuations $C_l^\tau \propto l^{-3}$ and

  $\tau_{RMS} = 0.2\ \tau_{mean}$ : possibly observable above reduced B-mode lensing floor at $l \sim 70$

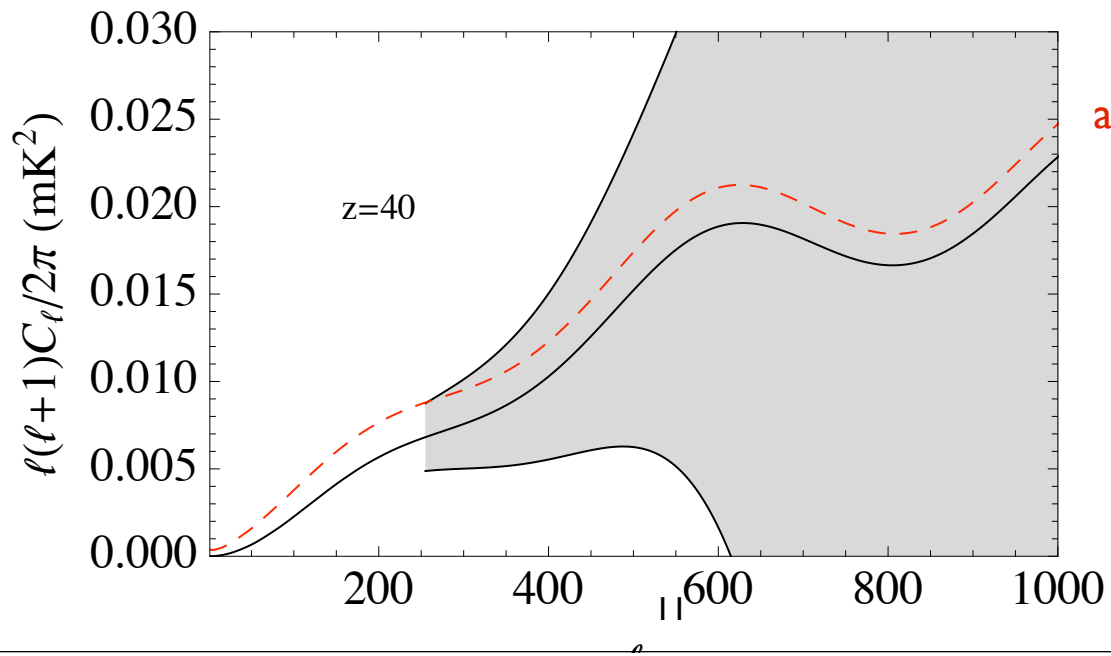
2. differential screening turns E to B (Dvorkin et al 2009)

- subdominant to lensing B-modes



# Other datasets

- CMB: can run independent cosmological parameter estimation on subsections of the sky; or construct quadratic estimator
- baryonic effects on the matter transfer function:
  - limit on $\nabla \ln \sigma_8$ of 3% (99% confidence) across cosmological volume from QSO number counts (Hirata 2009) ; translates into ~15% baryon fluctuation
- observability in 21cm neutral hydrogen distribution:




adiabatic + CIC
adiabatic only

Gordon & Pritchard 2009

# Summary

- large-scale variation in $\Omega_B h^2$ is constrained by non-CMB observations:
  - scatter in cluster $f_{gas}$: < 8% (95% CL)
  - scatter in light-element abundances: < 26% (95% CL)
- Can alleviate tension with observed $^7$Li abundance, and explain CMB power asymmetry, but only at higher amplitude than that allowed by BBN & clusters
- Can show up in search for gravitational waves in CMB