Possible Variation in the Cosmological Baryon Fraction

A. van Engelen
McGill University

G. Holder, K. Nollett
McGill University, Argonne National Lab
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
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, $\sim 0.1$ pc (neutrino streaming scale; neutron diffusion scale; Jeans scale).

- ..or considered locally homogeneous BBN, which mixed later
Measuring abundances

$^4$He: BCD HII region, $z < 0.1$
We use Izotov et al (2007) - 93 BCDs

D: QSO absorption, $z \sim 3$
We use 7 D/H observations, $z=3.5-4.5$

$^7$Li: halo stars, $z = 0$

Nollett 2007
Light-element abundance dispersion

\[ \Omega_{m} h^2 \]

- \[ Y_p \]
  - \( z \approx 0.1 \)
- \[ D/H \]
  - \( z \approx 3 \)
- \[ \text{Li}/H \]
  - \( z = 0 \)

\[ n_s \]

- \[ ^4\text{He} \]
- \[ ^3\text{He} \]
- \[ ^7\text{Li} \]

\[ \Omega_{b} h^2 \]

Coc & Vangioni 2010
Cluster dispersion

- Allen et al. (2008) X-ray survey: 42 relaxed galaxy clusters, $z \sim 0.06-1$

- $f_{\text{gas}}$ is systematically below the WMAP mean

- star formation, feedback from BH accretion

- but little evidence for cluster-to-cluster scatter

- $f_{\text{gas}}/\bar{f}_{\text{gas}}$
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):
  
  $\delta \rho_B/\rho_B < 0.08\ (f_{\text{gas}})$
  $\delta \rho_B/\rho_B < 0.26\ (\text{D}/\text{H})$
  $\delta \rho_B/\rho_B < 0.27\ (^4\text{He})$
Cluster selection effect?

- Clusters are selected for being relaxed - undisturbed & relatively circular

- Baryons lead to suppression on small scales

- Conversely, lower baryon density $\Rightarrow$ 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 $0.072 \pm 0.022$ (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 $0.8 \pm 0.3$

- 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 $\tau_{\text{RMS}} = 0.2 \tau_{\text{mean}}$: 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 $\sim$15% baryon fluctuation
- observability in 21cm neutral hydrogen distribution:

\[
\Delta C_\ell \approx \sqrt{\frac{2}{2\ell + 1}} \Delta \ell \text{fsky} \left( C_\ell + C_{\text{noise}} \right).
\]
Summary

- large-scale variation in $\Omega_B h^2$ is constrained by non-CMB observations:
  - scatter in cluster $f_{\text{gas}}$: < 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