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Strong Hydrogen Absorption at Cosmic Dawn: the Signature of a Baryonic Universe

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INTRODUCTION

Bowman et al. (2018) recently reported the detection of redshifted 21cm absorption at $z \approx 17$. The observed strength of this signal is anomalously strong for ΛCDM. Here I show that this signal is expected in a purely baryonic universe (McGaugh 1999).

THE COSMIC BARYON FRACTION

In ΛCDM, most of the mass is in the form of non-baryonic cold dark matter. This is a radical hypothesis that remains to be confirmed by a laboratory detection. Alternatively, it is conceivable that the missing mass problem indicates a breakdown of known dynamical laws: the radical hypothesis of modified gravity. Measurements sensitive to the baryon fraction ($f_b = \Omega_b/\Omega_m$) of the universe provide a distinguishing test. If non-baryonic dark matter is indeed the dominant form of mass in the universe, then the baryon fraction is $f_b = 0.16$ (Planck Collaboration et al. 2014). If CDM does not exist, then $f_b = 1$.

The detection of 21cm absorption reported by Bowman et al. (2018) provides a test for the baryon fraction. This signal arises from the decoupling of the spin temperature T_S of the 21cm line from the radiation temperature, causing the predominantly neutral IGM to be seen in absorption against the CMB (Zaldarriaga et al. 2004; Pritchard & Loeb 2012). The amount of absorption depends on the baryon density, with little sensitivity to other cosmological parameters or to the necessary astrophysical details.

This is a problem of radiative transfer in the early universe. It depends on known atomic physics, not whatever new physics causes the mass discrepancy. Writing eq. 2 of Zaldarriaga et al. (2004) in terms of the baryon fraction, the amplitude of absorption is

$$T_{21}(z) = (20\ \mathrm{mK})\, x_{\mathrm{HI}} \left[(1+z) f_b \left(\frac{\Omega_b h^2}{0.02}\right)\right]^{1/2} \left(1 - \frac{T_{\mathrm{CMB}}}{T_S}\right) \tag{1}$$

where x_{HI} is the neutral hydrogen fraction. The absolute baryon density is known from BBN (Cyburt et al. 2016), the CMB temperature declines as the universe expands, the kinetic temperature of the gas declines faster, and the spin temperature is bounded between the two ($T_K \leq T_S \leq T_{CMB}$; Cohen et al. 2017). The baryon fraction is the only variable that can increase the the absorption within these bounds.

The maximum possible signal occurs when $x_{\mathrm{HI}} = 1$ and $T_S = T_K$. At $z = 17$, $T_{\mathrm{CMB}}/T_K \approx 8.1$ (Fig. 5 of Cohen et al. 2017). Equation 1 then predicts a maximum absorption of

$$T_{21,\ \mathrm{max}} = -0.24\ \mathrm{K}\ \text{for}\ f_b = 0.16; \tag{2}$$

$$T_{21,\ \mathrm{max}} = -0.60\ \mathrm{K}\ \text{for}\ f_b = 1. \tag{3}$$

The observed value is $T_{21} \approx -0.5$ K (Bowman et al. 2018), and appears from their Fig. 2 to be closer to -0.55 K. Such a strong signal is expected in a baryonic universe, but is unobtainable[1] in ΛCDM.

Fig. 1 shows models for the 21cm absorption adopted from Cohen et al. (2017), who make a thorough exploration of astrophysical effects. These affect the redshift at which the absorption feature appears, and can modulate its amplitude somewhat. A stronger signal than the limit given in eq. 2 is profoundly unnatural in ΛCDM.

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[1] Barkana (2018) engages in special pleading to artificially decrease T_K. Allowing $T_S = T_K \to 0$ facilitates arbitrary signal strength.

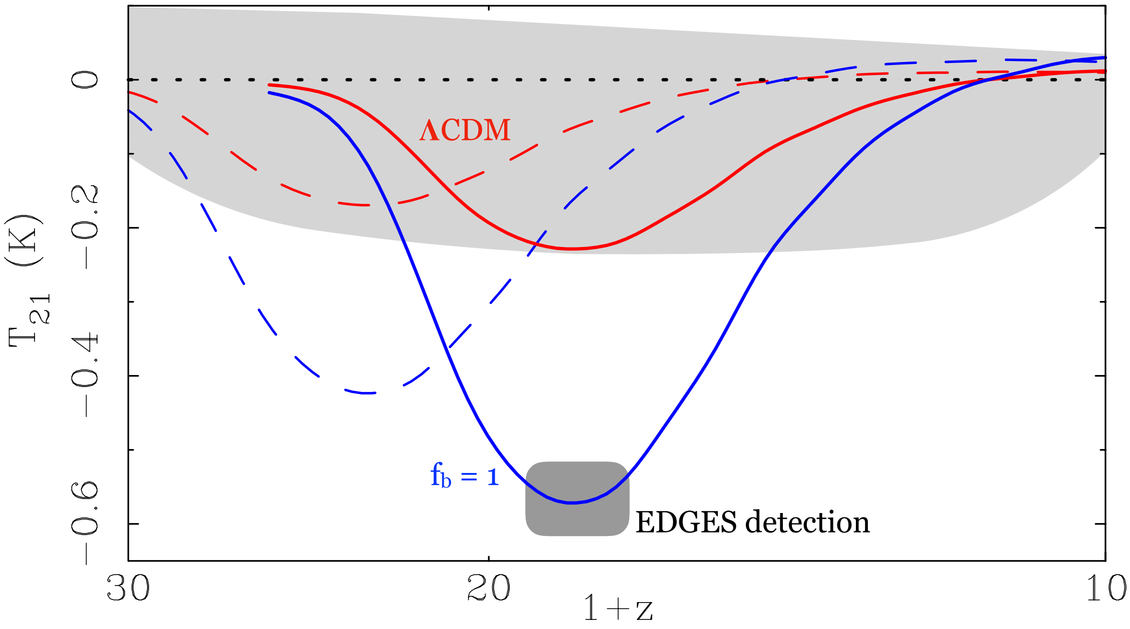

Figure 1. The predicted 21cm absorption signal as a function of redshift. Red lines are ΛCDM models from Cohen et al. (2017). The dashed red line is their standard model; the solid red line represents the maximum absorption attained at $z \approx 17$. The light gray area illustrates the range of parameter space occupied for a wide range of astrophysical parameters (see Fig. 1 of Cohen et al. 2017). Blue lines represent baryonic models, which have deeper absorption by the factor $f_b^{-1/2} = 2.5$ (eq. 1), consistent with the detection by Bowman et al. (2018, dark gray).

FURTHER PREDICTIONS

A review of dark matter and modified gravity is beyond the scope of this note (see McGaugh & de Blok 1998; Sanders & McGaugh 2002; Famaey & McGaugh 2012; McGaugh 2015). It suffices to say that there are remarkable genuine successes and apparently insurmountable hurdles for both approaches (see Merritt 2017). Here I make a few additional predictions for a baryonic universe:

1. Strong 21cm absorption will also be observed during the dark ages ($z > 30$).
2. The 21cm power spectrum will show pronounced baryonic features.
3. Large galaxies and the cosmic web emerge earlier than anticipated in ΛCDM (Sanders 1998; McGaugh 2015).

The first two predictions stem simply from a universe made of baryons. Only the third prediction is model-specific; some hints of large early structures already exist (e.g., Steinhardt et al. 2016; Franck & McGaugh 2016). This implies that structure grows nonlinearly, erasing baryonic features at late times through mode mixing (McGaugh 1999).

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