arXiv:astro-ph/9709227v1 24 Sep 1997

Limits on the Variability of Physical Constants

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Abstract. We have compared the frequency of high-redshift Hydrogen HI 21 cm absorption with that of associated molecular absorption in two quasars to place new (1 sigma) upper limits on any variation in $y \equiv g_p\alpha^2$ (where α is the fine structure constant and g_p is the proton g-factor) of $\Delta y/y < 5 \times 10^{-6}$ at redshifts $z = 0.25$ and $z = 0.68$.

1 Introduction

Recent measurements of molecular absorption in some radio sources corresponding to known HI 21 cm absorption systems give us ideal laboratories in which we can search for any possible temporal and spatial variation in the fundamental constants of Nature (a summary is given in [6]). The rotational transition frequencies of diatomic molecules such as CO are proportional to $\hbar/(Ma^2)$ where M is the reduced mass and $a = \hbar^2/(m_e e^2)$ is the Bohr radius. The 21 cm hyperfine transition in hydrogen has a frequency $\sim \mu_p\mu_B/(\hbar a^3)$, where $\mu_p = g_p e\hbar/(4m_p c)$, g_p is the proton g-factor and $\mu_B = e\hbar/(2m_e c)$. Consequently (assuming m_p/M is constant) the ratio of the hyperfine frequency to the molecular rotational frequency $\sim g_p\alpha^2$ where $\alpha = e^2/(\hbar c)$ is the fine structure constant. Any variation in $y \equiv g_p\alpha^2$ would therefore be observed as a difference in the apparent redshifts: $\Delta z/(1+z) \approx \Delta y/y$. Two sources have common extragalactic molecular and HI absorption detections published: 0218+357 and 1413+135 (see Table 1) which we use in this paper to put constraints on any such variations.

2 New HI Analysis

One possible problem with this approach is that the HI and molecular absorptions might result from different clouds along the respective lines of sight. We investigated this by looking at a sample of Galactic mm-wave continuum sources [5] with both HCO^+ and HI [3] absorption detected. We deconvolved the complex HI absorption into single systems and then identified the closest matching HI line to each HCO^+ absorption: the distribution of velocity differences is centred close to zero (mean $\Delta v = 0.4\,\mathrm{km\,s^{-1}}$) and very narrow with a Gaussian dispersion of only $1.2\,\mathrm{km\,s^{-1}}$. This is equal to the spectral resolution of the HI data (0.6–1.3 $\mathrm{km\,s^{-1}}$) and shows the absorption is from the same clouds to within our velocity resolution.

Paper presented at the 13th IAP Colloquium: Structure and Evolution of the IGM from QSO Absorption Line Systems, held in Paris, 1997 July 1-5, eds. P. Petitjean, S. Charlot

We used the same approach to decompose the high-redshift HI absorption systems listed in Table 1, fitting a number of components to each system [4]. The fitting routine gave uncertainties less than $1\,\mathrm{km\,s^{-1}}$ for the strong lines; these were added in quadrature with the velocity scale uncertainty of $0.3\,\mathrm{km\,s^{-1}}$ to obtain the errors. As with the low-redshift Galactic absorption we picked the the HI absorption closest in velocity to each molecular absorption and list these new redshifts in Table 1.

Table 1. Comparison of Molecular and Atomic Absorption Data

Name	Molecular z	Atomic z	Atomic z (new)	$\sigma_{\Delta z/1+z}$
0218+357	0.684680±.000006[10]	0.68466[2]	0.684684±.000006	5×10^{-6}
1413+135	0.246710±.000005[9]	0.24671[1]	0.246710±.000004	5×10^{-6}

Molecular measurements are much more precise than the HI data (velocity uncertainties of $0.1\,\mathrm{km\,s^{-1}}$) but the published values were not quoted to this precision, so we estimated the molecular redshifts and uncertainties from the publications as listed in Table 1 (we excluded a third source 1504+377 because of evidence of an offset in its molecular velocity scale)[4]. In both sources the redshifts agree to within our errors so we combined the uncertainties in quadrature to give 1 sigma upper limits on the redshift differences in Table 1. The corresponding limits on any change in $y = g_p\alpha^2$ are $\Delta y/y < 5\times10^{-6}$ at $z = 0.25$ and $z = 0.68$. These are significantly lower than the previous best limit of 1×10^{-4}[7] (it was quoted as a limit on nuclueon mass, but it actually refers to $g_p\alpha^2$). As there are no theoretical grounds to expect that the changes in g_p and α^2 are inversely proportional, we obtain independent rate-of-change limits of $|\dot{g_p}/g_p| < 2\times10^{-15}\,\mathrm{y^{-1}}$ and $|\dot{\alpha}/\alpha| < 1\times10^{-15}\,\mathrm{y^{-1}}$ at $z = 0.25$ and $|\dot{g_p}/g_p| < 1\times10^{-15}\,\mathrm{y^{-1}}$ and $|\dot{\alpha}/\alpha| < 5\times10^{-16}\,\mathrm{y^{-1}}$ at $z = 0.68$ (for $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $q_0 = 0$). These are much lower than the previous 1 sigma limit of $|\dot{\alpha}/\alpha| < 8\times10^{-15}\,\mathrm{y^{-1}}$ at $z \approx 3$ [8].

Acknowledgements. We thank Chris Carilli, Harvey Liszt, and John Dickey for many helpful discussions and for allowing us to use their data.

References

[1] Carilli, C. L., Perlman, E. S., Stocke, J. T. 1992, ApJ 400, L13
[2] Carilli, C. L., Rupen, M. P., Yanny, B. 1993, ApJ 412, L59
[3] Dickey, J.E., Kulkarni, S.R., van Gorkom, J., Heiles, C.E. 1983, ApJS, 53, 591
[4] Drinkwater, M.J., Webb, J.K., Barrow, J.D., 1997, MNRAS, submitted
[5] Liszt, H., Lucas, R. 1996, AA, 314, 917
[6] Varshalovich, D.A., Potekhin, A.Y. 1995, Space Science Review, 74, 259
[7] Varshalovich, D.A., Potekhin, A.Y. 1996, Astron. Lett., 22, 1
[8] Varshalovich, D.A., Panchuk, V.E., Ivanchik, A.V. 1996, Astron. Lett., 22, 6
[9] Wiklind, T., Combes, F. 1994, A&A 286, L9
[10] Wiklind, T., Combes, F. 1995, A&A 299, 382