Big Bang Nucleosynthesis and the Missing Hydrogen Mass in the Universe[1]

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Abstract. It is proposed that when the era of the big-bang nucleosynthesis ended, almost all of the 75 percent of the observed total baryonic matter remained in the form of hydrogen and continued to exist in the form of protons and electrons. They are present today as baryonic dark matter in the form of intergalactic hydrogen plasma. To test our hypothesis we have investigated the effects of Thomson scattering by free electrons on the reported dimming of Type Ia supernovae. The quantitative results of our calculation suggest that the dimming of these supernovae, which are dimmer than expected and hence more distant than predicted by Hubble expansion, is a result of Thomson scattering without cosmic acceleration.

Recent observations [1-2] of Type Ia supernovae (SNe Ia) appear to suggest that the universe is accelerating. The basic idea proposed to account for the acceleration is dark energy or quintessence [3-6]. However, as yet there is no direct confirmation of their existence or exact nature. The present work examines whether the question of acceleration can be resolved within the limits of established laws of physics. Consequently, we have investigated the effects of Thomson scattering of photons by free electrons present in the form of H-plasma while propagating from the supernova source to the point of observation. This particular scattering process has been chosen for the following reasons: the scattering cross-section is pure elastic in nonrelativistic region, the total cross-section is a universal constant and it is independent of the incident frequency [7]. Hence characteristics of the atomic spectra, which are relevant in the present work, remain unchanged. The calculation is performed within the framework of Friedmann-Robertson-Walker (FRW) cosmology [8] for the special case of a flat universe, consistent with the recent cosmic microwave background anisotropy measurements [9,10] indicating a spatially flat, critical density universe with $\Omega = 1$ and with the inflationary model [11-13] of cosmology. Hence in the present investigation we consider a universe, for large-scale structure, consisting only of matter and negligible radiation without cosmological constant in accord with all popular cosmological models prior to the late 1990s. Therefore in terms of stan-

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dard notation,

$$\Omega = \frac{\rho(z)}{\rho_c(z)} = 1 \tag{1}$$

and

$$\rho_c(z) = \frac{3H^2(z)}{8\pi G} = \frac{3H_0^2}{8\pi G}(1+z)^3 \tag{2}$$

where ρ is the total mass density including radiation, ρ_c is the critical density, G is the gravitational constant, H is the Hubble constant and in which we have incorporated the flat universe relation between $H(z)$ and the current Hubble constant H_0.

In light of the above considerations, the total matter density of universe consists of ordinary baryonic matter, baryonic dark matter and nonbaryonic dark matter; thus we have $\Omega = \Omega_{bm} + \Omega_{bdm} + \Omega_{nbdm}$ where each term is in units of ρ_c, and where the subscripts refer, respectively, to the three aforementioned components. The observed mass density $\Omega_m \approx 0.30 \pm 0.10$ as estimated from its gravitational pull on visible matter and is assumed to consist of ordinary baryonic matter and baryonic dark matter instead of exotic dark matter [14]; thus $\Omega_m = \Omega_{bm} + \Omega_{bdm}$. Big bang nucleosynthesis and synthesis of heavy elements in stars have been extensively investigated for more than half a century. The quantitative results of atomic abundances of various groups of elements [15-16] by mass-fraction of the total are hydrogen $\cong 0.75$ and rest of the elements $\cong 0.25$. From the above value of Ω_m we obtain the magnitude of Ω_{bm} which includes all the elements formed during big bang nucleosynthesis, and of Ω_{bdm} which remained as free hydrogen (in the form of mostly protons and equal number of electrons, neutrons having decayed into protons and electrons) within half an hour after the era of big bang nucleosynthesis ended. These magnitudes are $0.05 \leq \Omega_{bm} \leq 0.10$ and $0.15 \leq \Omega_{bdm} \leq 0.30$. From this analysis we conclude that when the era of the big bang nucleosynthesis ended, the universe continued expanding for several thousand years or so until the temperature dropped low enough to form neutral atoms. We believe that it is in this time interval that most of the free protons and electrons (contained in Ω_{bdm}) escaped into cosmic space and are most likely present in the form of an intergalactic hydrogen plasma [17]. They are dark because they cannot emit light.

The intensity of the radiation lost to Thomson scattering depends critically on the density of free electrons in the path from the source to the observer. We take the free electron number density at redshift z as

$$n(z) = \frac{\Omega_{bdm}\rho_c(z)}{m_h} \tag{3}$$

where $\Omega_{bdm}\rho_c$ is the hydrogen mass density and m_h is the hydrogen mass. We consider radiation emitted by a Type Ia supernova at redshift z_S and received by an infinitesimal volume element of length cdt at redshift z. The fractional reduction of intensity owing to Thomson scattering by free electrons within this volume is

$$\frac{-dI}{I(z)} = \sigma_T n(z) c dt \tag{4}$$

where $I(z)$ is the incident intensity and σ_T is the total Thomson scattering cross-section by a free electron. The total attenuation by scattering is the integral of eq. (7) over

TABLE 1. Distance moduli are those reported in ref. [1]. Data at $z = 0.43$ and 0.48 are the mean values of two observations at each of these redshifts. Distances in columns 3-6 are computed from eq. (8). Column 3 lists distances computed from observed values of $m-M$ and the values in columns 4-6 result from distance moduli corrected for Thomson scattering; these three columns correspond to the extreme values of the hydrogen mass fraction Ω_{bdm} cited above and to their midpoint, $\Omega_{bdm} \simeq 0.23$. Values of the theoretical luminosity distance in the last column are computed from eq. (9). The best agreement with the theoretical values in column 7 are those listed for $\Omega_{bdm} \simeq 0.23$ in column 5.

Redshift z	Distance modulus $(m-M)$	Distance $R_{\rm obs}$ (Mpc)	With Thomson scattering correction			Theoretical distance D_L (Mpc)
			$\Omega_{bdm} = 0.15$ (Mpc)	$\Omega_{bdm} = 0.23$ (Mpc)	$\Omega_{bdm} = 0.30$ (Mpc)	
0.0043	31.72	22	22	22	22	20
0.0077	32.81	36	36	36	36	36
0.025	35.35	117	117	117	117	115
0.052	36.72	221	219	218	217	241
0.053	37.12	265	263	262	261	248
0.068	37.58	328	324	322	320	318
0.090	38.51	504	495	491	487	424
0.17	39.95	977	945	929	915	825
0.30	41.38	1888	1775	1718	1670	1474
0.38	41.63	2118	1956	1874	1807	1893
0.43	42.15	2692	2454	2336	2238	2160
0.44	41.95	2455	2234	2296	2035	2214
0.48	42.39	3006	2783	2560	2438	2430
0.50	42.40	3020	2707	2553	2428	2539
0.57	42.76	3565	3138	2931	2766	2924
0.62	42.98	3945	3428	3179	2982	3203
0.83	43.67	5420	4447	4000	3656	4400
0.97	44.39	7551	5937	5221	4681	5225

the entire path taken by the light from the supernova. We perform the integration by identifying dt with $dT_H(z)$ where $T_H(z)$ is the Hubble time $H^{-1}(z)$. Thus

$$dt = dT_H(z) = -\frac{3}{2}H_0^{-1}(1+z)^{-5/2}dz. \tag{5}$$

Combining eqs. (2)-(5) then yields

$$\frac{dI}{I} = \sigma_T \Omega_{bdm} \frac{9cH_0}{16\pi G m_h}(1+z)^{1/2}dz. \tag{6}$$

Integrating over a path from the source to the observer at $z = 0$ yields

$$I(0) = I_S \exp\left\{-\sigma_T \Omega_{bdm} \frac{3cH_0}{8\pi G m_h}[(1+z)^{3/2} - 1]\right\} \tag{7}$$

where I_S is the light intensity at the source and in which the exponential factor represents the loss of intensity by Thomson scattering.

Observations of redshift and distance modulus $m-M$ for Type Ia supernovae reported by Riess et al. [1] are listed in Table 1 in columns 1 and 2. Column 3 contains the distance computed for each distance modulus according to [18]

$$R_{\text{obs}} = 10^{(m-M-25)/5} \tag{8}$$

where R_{obs} is the distance in Mpc. Corrections for Thomson scattering are effected by multiplying the observed values of $m-M$ by the ratio $I(0)/I_S$ from eq. (7) and columns 4-6 contain the corrected distances as computed from eq. (8); these three columns correspond to the extreme values of the hydrogen mass fraction Ω_{bdm} listed above and to their midpoint, $\Omega_{bdm} \cong 0.23$. The calculations employ $H_0 = 65$ km-s^{-1}-Mpc^{-1}. The last column lists values of the theoretical luminosity distance D_L which, for a flat universe with deceleration parameter $q_0 = 1/2$, is given by [8]

$$D_L = \frac{2c}{H_0}(1+z-\sqrt{1+z}). \tag{9}$$

Conclusion. The effects of Thomson scattering on enhanced dimming of SNe Ia presented in Table 1 suggests that (i) the recently observed supernovae data can be understood without dark energy; (ii) the amounts of baryonic ordinary matter, baryonic dark matter and nonbaryonic dark matter are in the ranges of 5-10%, 15-30% and 60-80%, respectively; and (iii) the total matter density Ω consists of 5-10% baryonic ordinary matter and 90-95% total dark matter, consistent with the understanding of most cosmologists prior to late 1990s. Further details of the present investigation will be published elsewhere.

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